2019 INTERNATIONAL CONFERENCE ON UNMANNED AIRCRAFT SYSTEMS

ICUAS' 19

June 11-14, 2019

Atlanta Marriott Buckhead Hotel & Conference Center
3405 Lenox Road NE, Atlanta, Georgia 30326

FINAL PROGRAM

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Welcome Message from the ICUAS Association

Dear participants and attendees:

On behalf of the ICUAS Association Inc., and in my capacity as President, it is a great pleasure and honor to welcome you to ICUAS’19. The ICUAS Association is a non-profit organization. Its vision is threefold: i) Establish the annually organized and fully sponsored ICUAS as the flagship technical conference in unmanned aerial vehicles, both nationally and internationally, eventually expanding conference objectives to include all types of unmanned systems; ii) Through the Association's activities and initiatives, contribute to pushing forward the frontiers of unmanned systems leading to the next generation of fully autonomous and fully functional prototypes, and, iii) Contribute to educating students, researchers, scientists, engineers and practitioners, as well as the general public, about unmanned systems.

The mission of the Association is to advance knowledge, education, basic and applied research and development in unmanned systems by: Organizing annual conferences, workshops, tutorials and other technical meetings in unmanned systems in general, and in Unmanned Aircraft Systems in particular; Offering short courses and other technical courses in unmanned systems to scientists, engineers, researchers and practitioners who are interested in learning and/or improving their knowledge in this area; Publishing annually the ICUAS proceedings; Publishing on an 'as needed basis' highly technical research monographs and textbooks in topics of interest in unmanned systems.

Our goals are to: Benefit researchers, scientists, engineers and practitioners; Advance the state-of-the-art in unmanned systems; Contribute to developing the next generation of unmanned systems; Contribute to the advancement of higher education; Educate the public about how unmanned systems may be used in a wide spectrum of civilian and public domain applications like search and rescue, emergency response, early fire detection and forest protection, environmental monitoring, to name but a few applications.

We are looking forward to your involvement, contributions and feedback. We welcome your participation and we are open to your ideas and suggestions to register the ICUAS Association as the primary organization that: Benefits students, researchers, scientists, engineers, practitioners and end-users; Advances the state-of-the-art in UAS; Contributes to the advancement of higher education.

My best wishes for a successful and productive conference, and I look forward to seeing you in Atlanta.

Kimon P. Valavanis

Welcome Message from the General Chairs

Dear participants and attendees:

On behalf of the 2019 ICUAS Organizing Committee, it is a privilege and a pleasure to welcome you to this year’s conference, on June 11-14, 2019. The three-day Conference is preceded by a one-day Workshops / Tutorials program, on Tuesday, June 11. We are certain you will be very pleased with the conference venue, and you will enjoy all the attractions Atlanta offers.

Conference participants represent academia, industry, government agencies, lawyers, policy makers, manufacturers, students and end-users, all having deep interest in the state-of-the-art and future directions in unmanned aircraft systems. We received 237 contributed/invited session papers. This is the second highest number since launching ICUAS. Following a very thorough and in-depth peer review process in which each paper had at least four reviews (three external reviewers plus a member of the organizing committee), and in some cases as many as eight, roughly 77% of contributed, invited session and poster papers were accepted. All papers were also checked following the *iThenticate* Document Viewer Guide receiving a ‘similarity score’ and a ‘max percentage match’ before final decision was made. We have assembled a full three-day top-quality Technical Program. We also have three Plenary Lectures in which the keynote speakers address pressing and important issues related to unmanned aviation in civil and restricted airspace.

The Organizing Committee members have devoted an enormous amount of time and effort to make sure that the conference is exciting, informative and educational. We are privileged and honored to have worked with all the members and we are truly indebted to everyone for their dedication and professionalism. We also extend a wholehearted “thank you” to all reviewers, Associate Editors and members of the Technical Program Committees; their help was integral to assembling a top-quality Technical Program. The peer review process was coordinated by the Program Chairs and Co-Chairs. Dr. Pradeep Misra was the essential “glue” that kept everything together, since all papers were submitted through https://controls.papercept.net. We wouldn’t have been able to complete the paper review process without his help.

We thank you for your participation and contributions. We hope you enjoy the conference, as well as Atlanta and the other surrounding areas.

Didier Theilliol and *Yang-Quan Chen*

Welcome Message from the Program Chairs

Dear participants and attendees:

Welcome to ICUAS’19. This year we received 237 contributed, invited session full-length papers and poster papers. This number is the second highest compared to any previous ICUAS. The paper review process has been extremely thorough and rigorous. All papers were also checked for originality using the *iThenticate* Document Viewer Guide. Our initial goal was for each paper to have at least three reviews. We exceeded this goal; each paper had on average more than 3 reviews and some papers had as many as 8 reviews! However, considering that the Program Chairs and other members of the Organizing Committee coordinated all paper reviews and read all papers, each paper received an average of more than 4 reviews.

Authors of submitted papers used among the following key words to classify their paper: Airspace Control, Airspace Management, Airworthiness, Air Vehicle Operations, Autonomy, Biologically Inspired UAS, Certification, Control Architectures, Energy Efficient UAS, Environmental Issues, Fail-Safe Systems, Frequency Management, Integration, Interoperability, Levels of Safety, Manned/Unmanned Aviation, Micro- and Mini- UAS, Navigation, Networked Swarms, Payloads, Path Planning, Regulations, Reliability of UAS, Risk Analysis, See-and-avoid Systems, Security, Sensor Fusion, Simulation, Smart Sensors, Standardization, Swarms, Technology Challenges, Training, UAS Applications, UAS Communications, UAS Testbeds.

The review process resulted in accepting 188 contributed, invited and poster session papers. The technical program spans three days, during which all accepted, and poster papers will be presented. Submitted/accepted papers are from the following countries (listed in ascending order of submissions): USA, Mexico, Brazil, India, Canada, France, Spain, China, Italy, Norway, Singapore, South Korea, Denmark, Germany, Portugal, Hungary, Japan, Australia, United Kingdom, Argentina, Croatia, Cyprus, New Zealand, Pakistan, Paraguay, Poland, Qatar, South Africa, Switzerland, Taiwan, United Arab Emirates.

We would like to thank all the authors for their contributions. Our rigorous review process would not have been possible if we did not have such a strong community of expert reviewers in unmanned aircraft systems. We thank all reviewers for their professional service.

Pradeep Misra helped us in working and using effectively the on-line paper submission and review system. He has been very responsive and helpful in issues related to the system. Our questions were mostly due to our novice and inexperience with the on-line system. We acknowledge that this on-line system is very sophisticated and yet very practical to use for both small and large-scale conferences. It is very hard to imagine how things would have been done without this excellent on-line system!

We hope you enjoy not only the technical aspects of the conference but also beautiful Atlanta. Fly high and safe, to the next ICUAS!

James Morrison and *Antonios Tsourdos*

ICUAS'19 Tutorials and Workshops

ICUAS'19 offers three pre-conference Workshops/Tutorials addressing current and future topics in unmanned aircraft systems from experts in academia, national laboratories, and industry. Interested participants may find details on the Conference web, www.uasconferences.com, and they may use the on-line system for registration.

All Tutorials / Workshops will take place on Tuesday, June 11, 2019. See the attached map for the location of the rooms. Tutorial/Workshop duration is either ***Full-Day*** (9:00 AM – 5:30 PM) or ***Half-Day*** (09:00 AM – 01:00 PM).

Location	Time	Title
T1 ***Heritage A***	Full-Day 9:00 AM–5:30 PM	**NEW DEVELOPMENTS ON SENSE-AND-AVOID (S&A), FAULT-TOLERANT CONTROL (FTC) AND FAULT-TOLERANT COOPERATIVE CONTROL (FTCC) TECHNIQUES FOR UNMANNED SYSTEMS AND THEIR APPLICATIONS** *Organizers: Drs. Youmin Zhang and Didier Theilliol*
T2 ***Heritage B***	Half-Day 9:00 AM-1:00 PM	**TOWARDS NETWORKED AIRBORNE COMPUTING: APPLICATIONS, CHALLENGES, AND ENABLING TECHNOLOGIES** *Organizers: Drs. Yan Wan, Kejie Lu, Shengli Fu, Junfei Xie*
T3 ***Heritage C***	Half-Day 9:00 AM-1:00 PM	**UAV HEALTH MANAGEMENT ISSUES: CAN SMALL UAVS SURVIVE EXTREME DISTURBANCE ENVIRONMENTS?** *Organizers: Drs. George J. Vachtsevanos and Kimon P. Valavanis*

ICUAS'19 Plenary Lectures

ICUAS'19 includes three Keynote / Plenary Lectures given by leading authorities in their respective fields. We are honored to include their talks as part of this year's Conference program. All Plenary/Keynote lectures will be in the General Session Room, ***Heritage B***. There will be two Plenary/Keynote lectures on Wednesday, June 12, and one on Thursday, June 13. The schedule for the lectures is shown next.

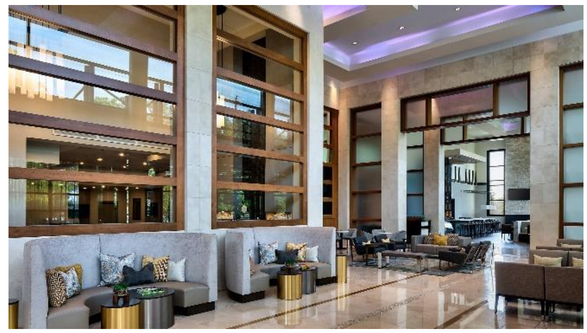
WEDNESDAY – JUNE 12 – HERITAGE B	
8:45 – 9:45 AM	**LAW, LAWFARE AND TECH: AN ARGUMENT FOR COLLABORATION** *CHARLES J. DUNLAP (MAJ. GEN. USAF, RET.), Professor of the Practice of Law, Executive Director of the LENS Center on Law, Ethics & National Security, Duke Law School*
1:45 – 2:45 PM	**THE 2018 FAA REAUTHORIZATION ACT – WHERE TO FROM HERE?** *JAMES O. POSS (MAJ. GEN. USAF, RET.), Chief Executive Officer, ISR Ideas*

THURSDAY - JUNE 13 – HERITAGE B	
8:45 – 9:45 AM	**THE INVASIONS OF DRONES - PUBLIC PERCEPTION AND SAFETY** *Dr. Brandon Stark, Center of Excellence for Unmanned Aircraft System Safety University of California - Merced*

ICUAS’19 Information

The Venue

The Conference venue is the Atlanta Marriott Buckhead Hotel & Conference Center, located in the heart of Atlanta. There is a plethora of Local Attractions close to the venue, including: Lenox Square Mall; Phipps Plaza Mall; World of Coca Cola; Callanwolde Fine Arts Center; The King Center; Stone Mountain Park; Georgia Aquarium; College Football Hall of Fame; Underground Atlanta; North Georgia Premium Outlet Mall; Buckhead Shops and Restaurants; CNN Center; Georgia Governor's Mansion; High Museum of Art; Martin Luther King Jr Center; Six Flags Over Georgia; World Congress Center, and, Atlanta Zoo.



Travel Directions

The hotel does not provide shuttle services.

Hartsfield-Jackson Atlanta International Airport (ATL)

Hotel direction: 17 miles N

Estimated taxi fare: 40 USD (one way). Subway service, fee: 2.5 USD (one way)

Driving directions: Take I-85 North to Exit #87 (Georgia 400), to Exit #2 (Lenox Road); Turn right and follow Lenox Road Signs, cross Peachtree Road. The Hotel is 1.5 blocks on the left.

Dekalb-Peachtree Airport (PDK)

Hotel direction: 5 miles E

Estimated taxi fare: 18 USD (one way). Subway service, fee: 2.5 USD (one way)

Driving directions: Going South on Clairmont Road NE toward 9th Street, turn right at Dresden Drive NE, turn left at Peachtree Road NE, turn left at Lenox Road NE. The hotel is on the left side.

Conference Registration

All Conference attendees must register by using the on-line registration when they upload the final version of their papers. It is not required to upload a paper to register for the conference. Late and on-site registration is also available for non-authors who want to attend the conference. To register, follow the steps:

- ✓ Go to https://controls.papercept.net
- ✓ Scroll down the list until you find ICUAS 2019 - Choose ICUAS 2019 (from the list of conferences)
- ✓ Click on Register for ICUAS’19
- ✓ Login with your PIN and Password. *First time users must create a ‘profile’, get a PIN and Password.*
- ✓ After you Log in, choose **Registree**
- ✓ Follow the self-explained screens to register.

All registered participants must **check in at the Registration Desk** to pick up their registration packages. Personal badges will be provided to all registered participants. ***Attendees must wear their badges at all times when attending any ICUAS’19 event*** (technical sessions, exhibits, and social functions). This is very important for security reasons.

Registration will be in the ***Heritage Prefunction*** area. Registration hours will be open as follows:

TUESDAY, JUNE 11-	*Workshop/Tutorial Registration ONLY*	8:00 AM – 11:00 AM
	Conference Registration	1:00 PM – 5:00 PM
WEDNESDAY, JUNE 12:		8:00 AM – 5:00 PM
THURSDAY, JUNE 13:		8:00 AM – 3:00 PM
FRIDAY, JUNE 14:		8:30 AM – 11:00 AM

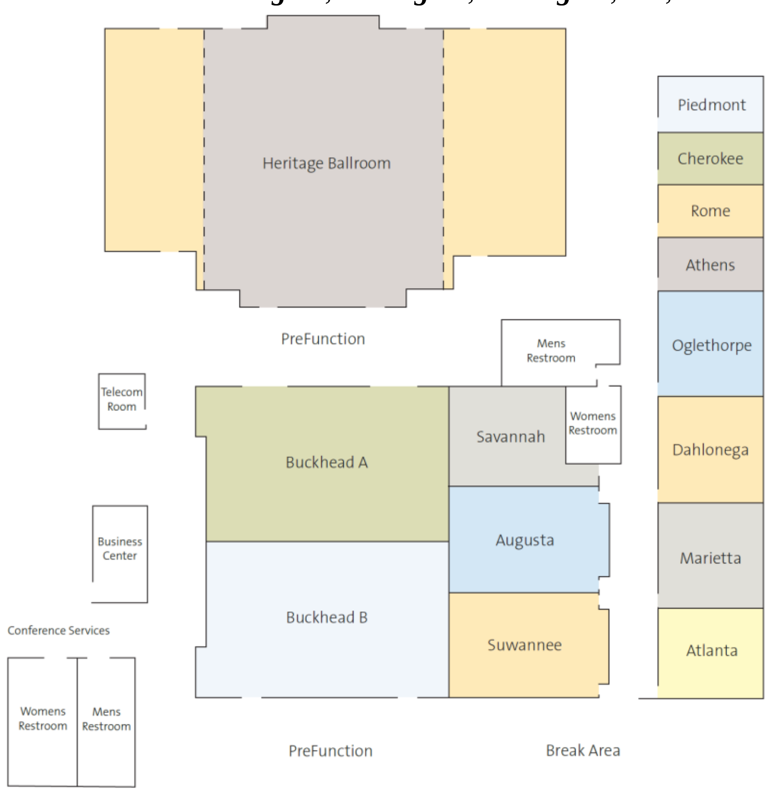
On-site conference registration policy and fees: Attendees will be able to register for the Conference under the following registration categories/rates:

ATTENDEES	ON-SITE REGISTRATION
Academic, Industry, Government	$600
Legal and Policy Track (only)	$300
Student	$350
Workshop / Tutorials	$150 / $180
Extra Banquet Ticket	$100
Extra Proceedings	$40

Meeting Area and Exhibits

The meeting area is in the same floor, see attached floorplan. All activities, Registration, Workshops / Tutorials, Technical Sessions, Exhibits and Coffee Breaks will take place in one level, for the duration of the Conference.

- ✓ Workshops/Tutorials will be in: ***Heritage A***, ***Heritage B*** and ***Heritage C***.
- ✓ The Legal and Policy Track (Wednesday, June 13) will be in ***Oglethorpe***.
- ✓ Technical Sessions will be in: ***Heritage A***, ***Heritage B***, ***Heritage C***, and, ***Savannah***.



Internet Access

All *registered attendees* will have complementary internet access in the meeting space area. Log in and Password information will be provided at the conference registration desk.

Continental Breakfast and Coffee Breaks

Continental Breakfast will be served in the morning, Wednesday to Friday, for all ***registered attendees***, 7:45-8:30 AM. There will be two coffee breaks per day, one in the morning and one in the afternoon. Continental Breakfast and coffee breaks will be served in the ***Heritage Prefunction*** area.

Events and Receptions

The ICUAS'19 social agenda include:

Welcome Reception, 7:00 PM:	***Winning Edge*** (Lobby Level)	Tuesday, June 11
Gala Dinner: 7:30 PM	***Buckhead Ballroom***	Thursday, June 13

Conference Technical Sessions - Wednesday, June 12 – Friday, June 14

In addition to the Plenary/Keynote lectures, there will be four parallel technical sessions each day. All Technical Sessions will be in ***Heritage A***, ***Heritage B***, ***Heritage C***, and, ***Savannah***.

Exhibits

Exhibits will be in the ***Heritage Prefunction*** area to guarantee maximum traffic and exposure.

Poster Papers

Poster papers will be presented on Wednesday, June 12, in the ***Heritage Prefunction*** area.

ICUAS'19 Legal and Policy Track Information

Location: Oglethorpe Wednesday, June 12

10:00 – 11:00 AM	**LAWYERING FOR DRONE CLIENTS IN THE U.S.: BASICS OF FEDERAL DRONE REGULATION, UTM, AND CORPORATE BEST PRACTICES** ***M. A. SWANSON***, *Partner*, Wilkinson, Barker, Knauer, LLP., Washington, D.C. ***D. E. GRIFFITH***, Esq., *Attorney*, Jones Day, Washington, D.C. ***M. BLANKS***, *Director, Virginia Tech Mid-Atlantic Aviation Partnership*, Virginia Tech
11:00 AM–12:15 PM	**ROUND TABLE PANEL DISCUSSION: THE LEGAL, POLICY AND ETHICAL IMPLICATIONS OF AI** ***Moderator***: ***R. G. GROSS*** (Brig. Gen. USA, Ret.), *Former Legal Counsel, Chair Joint Chiefs of Staff,* Self-Employed Senior Counsel/Strategic Advisor, Knoxville ***Panelists*** ***L. R. BLANK***, *Clinical Professor of Law/Dir. Center for International and Comparative Law and International Humanitarian Law Clinic*, Emory Univ. School of Law, Atlanta ***F. COPPERSMITH***, *CEO/Founder*, Smarter Reality, Austin ***J. Z. MALEKOS SMITH***, J.D., *Reuben Everett Cyber Scholar*, Duke Law, Center of Law & Technology/Center for Law, Ethics & National Security, Durham ***S. V. DAVIS***, Lt Col, USAF, *Chief, Air & Space Law Division, Operations & International Law Directorate*, Headquarters Air Force, Office of The Judge Advocate General
12:15 – 12:45 PM	**LUNCH**
12:45 – 1:45 PM	**SPECIAL CLE PROFESSIONAL WELLNESS SESSION** ***SUPER LAWYERS: ETHICAL IMPLICATIONS OF STRESS, BURNOUT AND WELL-BEING*** **C. W. PATTON,** J.D., M.ED. ED.D., *National Legal Education Speaker, Professor, Executive Well-Being Advisor*, ChildAdvocateLaw.com, KY & ID **J. W. PATTON,** LL.M., M.DIV**.,** *Chief Legal Officer & Vice President for Advancement*, The Broadhurst Group, KY & ID
3:00 – 4:15 PM	**ROUND TABLE PANEL DISCUSSION: AN UPDATE ON INTERNATIONAL RPAS REGULATION** ***Moderator***: **J. MARTIN**, Esq., *Associate General Counsel, Electric Power Research Institute (EPRI)* ***Panelists*** **A. KONERT**, PhD, *Dean, Faculty of Law and Administration and Law Professor, Director of Institute of Air & Space Law*, Lazarski Univ., Warsaw, Poland **P. KASPRZYK**, PhD, *Attorney at Law & Research Fellow, Institute of Air and Space Law*, Lazarski Univ. Warsaw, Poland **E. BASSI**, PhD, *Nexa Center for Internet & Society, Dept. of Control & Computer Engineering*, Politecnico di Torino, Italy
4:15 – 5:30 PM	**LEGAL JEOPARDY GAMESHOW LIGHTNING ROUND: CONTEMPORARY GLOBAL LEGAL & POLICY ISSUES IN DRONE OPERATIONS"** ***Moderator*****: D. M. K. ZOLDI** (Col USAF, Ret.), *Associate General Counsel, U.S. Air Force Academy Business Matters, Office of Air Force General Counsel, CO & DC* **Panelists** **S. J. NILSSON**, PhD, J.D., M.A.S., *Assistant Professor of Aviation and UAS Law* Embry Riddle Aeronautical University, Prescott **C. CHAN,** Esq., *Partner*, Eversheds Sutherland (U.S.) LLP, Atlanta **F. QUAGLIOTTI**, *Professor Ing., Department of Mechanical & Aerospace Engineering*, Politecnico di Torino, Italy **F. X. NOLAN IV**, Esq., *Counsel*, Eversheds Sutherland (U.S.) LLP, New York
SOCIAL HOUR 5:45PM – 7PM, *CLE participants only*	

ICUAS'19 TECHNICAL PROGRAM AT A GLANCE

Wednesday, June 12

Heritage B	Heritage A	Heritage C	Savannah
10:00-12:00 WeA1 Path Planning I	10:00-12:00 WeA2 Swarms I	10:00-12:00 WeA3 Risk and Reliability	10:00-12:00 WeA4 Control Architectures I
15:00-17:00 WeB1 Path Planning II	15:00-17:00 WeB2 Swarms II	15:00-17:00 WeB3 UAS Applications I	15:00-17:00 WeB4 Control Architectures II
17:00-19:00 WeC1 Fault Diagnosis, Accommodation & Fault-Tolerant Control	17:00-19:00 WeC2 Regulations	17:00-19:00 WeC3 UAS Applications II	17:00-19:00 WeC4 Control Architectures III

Poster Papers WeP5: Heritage Prefunction – Exhibit and Presentation Timeframe: 13:00 – 18:00 PM

Thursday, June 13

10:00-12:00 ThA1 Path Planning III	10:00-12:00 ThA2 Micro and Mini UAS	10:00-12:00 ThA3 UAS Applications III	10:00-12:00 ThA4 Energy Efficient UAS
13:30-15:30 ThB1 Path Planning IV	13:30-15:30 ThB2 Sensor Fusion I	13:30-15:30 ThB3 UAS Applications IV	13:30-15:30 ThB4 Airspace Management
16:00-18:00 ThC1 See-and-Avoid Systems	16:00-18:00 ThC2 Sensor Fusion II	16:00-18:00 ThC3 UAS Applications V	16:00-18:00 ThC4 Airspace Control

18:00-19:00 PM: Heritage B - Round Table: - UAV Contributions and Challenges to Society
Chair: G. J. Vachtsevanos, Georgia Institute of Tech.

Friday, June 14

9:00-11:00 FrA1 UAS Design	9:00-11:00 FrA2 Autonomy I	9:00-11:00 FrA3 UAS Navigation I	9:00-11:00 FrA4 Environmental Issues
11:30-13:30 FrB1 Risk Analysis and Risk-Based Methods for UAS	11:30-13:30 FrB2 Autonomy II	11:30-13:30 FrB3 UAS Navigation II	11:30-13:30 FrB4 UAS Testbeds

ICUAS'19 Content List

Technical Program for Wednesday June 12, 2019

Chair: Ciarletta, Laurent — Université De Lorraine, Loria

Co-Chair: Jensen, Kjeld — University of Southern Denmark

10:00-10:20 WeA3.1

Improving Redundancy and Safety of UTM by Leveraging Multiple UASs, pp. 100-110.

Schwalb, Edward — MSC Software

Schwalb, Joseph

10:20-10:40 WeA3.2

Monitor-Centric Mission Definition with Sophrosyne, pp. 111-119.

Viard, Louis — Université De Lorraine

Ciarletta, Laurent — Université De Lorraine, LORIA

Moreau, Pierre-Etienne — Université De Lorraine, LORIA

10:40-11:00 WeA3.3

*Game Theoretic Strategies for an Unmanned Aerial Vehicle Network Host under DDoS Attack**.

Mairaj, Aakif — University of Toledo

Majumder, Subhrajit — University of Toledo

Javaid, Ahmad Y — The University of Toledo

11:00-11:20 WeA3.4

A Methodology for Evaluating Commercial Off the Shelf Parachutes Designed for sUAS Failsafe Systems, pp. 120-128.

Tofterup, Vincent Klyverts — University of Southern Denmark

Jensen, Kjeld — University of Southern Denmark

11:20-11:40 WeA3.5

Embedding Consequence Awareness in Unmanned Aerial Systems with Generative Adversarial Networks, pp. 129-134.

Zhang, Guoxiang — University of California, Merced

Alcala, Jose — MESA Lab, University of California, Merced

Ng, Jeffrey — University of California, Merced

Chen, Mighty — MESA Lab, University of California, Merced

Wu, Xiangyu — UC Berkeley

Mueller, Mark Wilfried — UC Berkeley

Chen, YangQuan — University of California, Merced

WeA4 Savannah

Control Architectures I (Regular Session)

Chair: Sarcinelli-Filho, Mário — Federal University of Espirito Santo

Co-Chair: Kuchwa-Dube, Chioniso — University of the Witwatersrand

10:00-10:20 WeA4.1

Quadrotor-Based Aerial Manipulator Altitude and Attitude Tracking Using Adaptive Super-Twisting Sliding Mode Control, pp. 135-142.

Kuchwa-Dube, Chioniso — University of the Witwatersrand

Pedro, Jimoh Olarewaju — University of the Witwatersrand

10:20-10:40 WeA4.2

Robust Control Architecture for Wind Rejection in Quadrotors, pp. 143-152.

Verberne, Johannes — Embry-Riddle Aeronautical University

Moncayo, Hever — Embry-Riddle Aeronautical University

10:40-11:00 WeA4.3

Input Shaped Trajectory Generation and Controller Design for a Quadrotor-Slung Load System, pp. 153-161.

Fielding, Sean — McGill University

Nahon, Meyer — McGill University

11:00-11:20 WeA4.4

Adaptive Control for a Tilted-Motors Hexacopter UAS Flying on a Perturbed Environment, pp. 162-168.

Arizaga-Leon, Jorge Manuel — Tecnologico De Monterrey

Castaneda, Herman — Tecnologico De Monterrey

Castillo, Pedro — Unviersité De Technologie De Compiègne

11:20-11:40 WeA4.5

Architecture-Independent Quaternion-Based Attitude Planning and Control Allocation for Multirotors, pp. 169-177.

Borges Farçoni, Leonardo — University of São Paulo

Terra, Marco Henrique — University of Sao Paulo at Sao Carlos

Inoue, Roberto Santos — Federal University of São Carlos

11:40-12:00 WeA4.6

Trajectory-Tracking of a Heterogeneous Formation Using Null Space-Based Control, pp. 178-186.

Ernandes, Valentim — Universidade Federal De Vicosa

Sarcinelli-Filho, Mário — Federal University of Espirito Santo

Brandao, Alexandre Santos — Federal University of Vicosa

WeB1 Heritage B

Path Planning II (Regular Session)

Chair: Rothmund, Sverre Velten — Norwegian University of Science and Technology

Co-Chair: Morrison, James R. — KAIST

15:00-15:20 WeB1.1

A 3D Mobility Model for Autonomous Swarms of Collaborative UAVs, pp. 187-195.

Falomir, Ema — University of Bordeaux, THALES DMS France

Chaumette, Serge — LaBRI, Univ. Bordeaux / NFC-Interactive

Guerrini, Gilles — Thales DMS France

15:20-15:40	WeB1.2

Robust Multi-UAV Route Planning Considering UAV Failure, pp. 196-203.

Patel, Ruchir	University of Maryland, College Park
Rudnick-Cohen, Eliot	University of Maryland, College Park
Azarm, Shapour	University of Maryland, College Park
Herrmann, Jeffrey	University of Maryland

15:40-16:00	WeB1.3

Routing Problems for Reconnaissance Patrolling Missions, pp. 204-211.

Rajan, Sudarshan	Texas A&M University
Sundar, Kaarthik	Texas A&M University
Gautam, Natarajan	Texas A&M University

16:00-16:20	WeB1.4

Risk-Based Obstacle Avoidance in Unknown Environments Using Scenario-Based Predictive Control for an Inspection Drone Equipped with Range Finding Sensors, pp. 212-221.

Rothmund, Sverre Velten	Norwegian University of Science and Technology
Johansen, Tor Arne	Norwegian Univ. of Sci. & Tech

16:20-16:40	WeB1.5

Flight Patterns for Clouds Exploration with a Fleet of UAVs, pp. 222-228.

Verdu, Titouan	ENAC, Université De Toulouse
Hattenberger, Gautier	ENAC
Lacroix, Simon	LAAS/CNRS

16:40-17:00	WeB1.6

On Systems of UAVs for Persistent Security Presence: A Generic Network Representation, MDP Formulation and Heuristics for Task Allocation, pp. 229-236.

Kim, Minjun	KAIST
Morrison, James R.	KAIST

WeB2	Heritage A
Swarms II (Regular Session)	

Chair: Castaneda, Herman	Tecnologico De Monterrey
Co-Chair: Castillo, Pedro	Unviersité De Technologie De Compiègne

15:00-15:20	WeB2.1

A Computational Tool to Assess Communications' Range and Capacity Limits of Ad-Hoc Networks of UAVs Operating in Maritime Scenarios, pp. 237-243.

Oliveira, Tiago	Portuguese Air Force
Agamyrzyansc, Anna	Portuguese Air Force
Correia, Luis	IST/INESC-ID, University of Lisbon

15:20-15:40	WeB2.2

Probabilistic Search and Track with Multiple Mobile Agents, pp. 244-253.

Papaioannou, Savvas	KIOS CoE, University of Cyprus
Kolios, Panayiotis	University of Cyprus
Theocharides, Theocharis	University of Cyprus
Panayiotou, Christos	University of Cyprus
Polycarpou, Marios M.	University of Cyprus

15:40-16:00	WeB2.3

Backstepping-Based Controller for Flight Formation, pp. 254-260.

Flores Palmeros, Pedro	Cinvestav IPN
Castillo, Pedro	Unviersité De Technologie De Compiègne
Castanos, Fernando	Cinvestav Del IPN

16:00-16:20	WeB2.4

Containment Control Based on Adaptive Sliding Mode for a MAV Swarm System under Perturbation, pp. 261-266.

Katt, Carlos	Tecnologico De Monterrey
Castaneda, Herman	Tecnologico De Monterrey

16:20-16:40	WeB2.5

Time-Delay Control of a Multi-Rotor VTOL Multi-Agent System towards Transport Operations, pp. 267-274.

Alvarez Muñoz, Jonatan Uziel	Université De Grenoble, GIPSA-Lab
Castillo Zamora, Jose de Jesus	IPSA & Laboratoire Des Signaux Et Systèmes
Escareno Castro, Juan Antonio	XLIM Research Institute - University of Limoges
Boussaada, Islam	IPSA & Laboratoire Des Signaux Et Systèmes
Méndez-Barrios, César Fernando	Universidad Autónoma De San Luis Potosí
LABBANI, Ouiddad	XLIM Research Institute - ENSIL-ENSCI - University of Limoges

16:40-17:00	WeB2.6

Formation Control and Navigation of a Quadrotor Swarm, pp. 275-282.

Fernando, Malintha	Indiana University
Liu, Lantao	Indiana University

WeB3	Heritage C
UAS Applications I (Regular Session)	

Chair: Vitzilaios, Nikolaos	University of South Carolina

15:00-15:20	WeB3.1

Discrete-Time Control of LineDrone: An Assisted Tracking and Landing UAV for Live Power Line Inspection and Maintenance, pp. 283-289.

Hamelin, Philippe	Hydro-Québec
Mirallès, François	Hydro-Québec
Lambert, Ghislain	Hydro-Québec
Lavoie, Samuel	Hydro-Québec
Pouliot, Nicolas	Hydro-Québec
Montfrond, Matthieu	Hydro-Québec
Montambault, Serge	Hydro-Québec

15:20-15:40	WeB3.2

Autonomous Aerial Robotic Exploration of Subterranean

Environments Relying on Morphology-Aware Path Planning, pp. 290-296.

Papachristos, Christos	University of Nevada Reno
Khattak, Shehryar	University of Nevada, Reno
Mascarich, Frank	University of Nevada, Reno
Dang, Tung	University of Nevada, Reno
Alexis, Kostas	University of Nevada, Reno

15:40-16:00 WeB3.3

Building Mosaics Using Images Autonomously Acquired by a UAV, pp. 297-304.

Amorim, Lúcio André	Corpo De Bombeiros Militar Do Espírito Santo
Vassallo, Raquel	Federal University of Espirito Santo
Sarcinelli-Filho, Mário	Federal University of Espirito Santo

16:00-16:20 WeB3.4

Planning System for Integrated Autonomous Infrastructure Inspection Using UAVs, pp. 305-312.

Ramon Soria, Pablo	University of Seville
Perez Jimenez, Manuel	Universidad De Sevilla
Arrue, B.C.	Escuela Superior De Ingenieros, Universidad De Sevilla
Ollero, Anibal	Universidad De Sevilla

16:20-16:40 WeB3.5

Dynamic Structural Health Monitoring Using a DIC-Enabled Drone, pp. 313-319.

Kalaitzakis, Michail	University of South Carolina
Kattil, Sreehari Rajan	University of South Carolina
Vitzilaios, Nikolaos	University of South Carolina
Rizos, Dimitris	University of South Carolina
Sutton, Michael	University of South Carolina

16:40-17:00 WeB3.6

UAV Aided Dynamic Routing of Resources in a Flood Scenario, pp. 320-327.

KASHYAP, ABHISHEK	Indian Institute of Science, Bangalore
Ghose, Debasish	Indian Institute of Science
Prathyush, Purushothama Menon	University of Exeter
Sujit, P. B	IIITD
Das, Kaushik	TATA Consultancy Service

WeB4 Savannah

Control Architectures II (Regular Session)

Chair: Sharma, Rajnikant — University of Cincinnati

15:00-15:20 WeB4.1

Design and Implementation of an Artificial Neural Network Wavelet for Load Transportation with Two Unmanned Aircraft Systems, pp. 328-335.

Juarez Vargas, Cesar Eduardo	Autonomous University of Hidalgo State
Suárez Cansino, Jóel	Autonomous University, Hidalgo
Espinoza Quesada, Eduardo Steed	Center for Research and Advanced Studies of the National Polytec
GARCIA CARRILLO, Luis Rodolfo	Texas A&M University - Corpus Christi
Ramos-Velasco, Luis Enrique	Universidad Politécnica Metropolitana De Hidalgo, México
Lozano, Rogelio	University of Technology of Compiègne

15:20-15:40 WeB4.2

Robustness Studies on Quadrotor Control, pp. 336-344.

Brossard, Jérémy	ÉTS
Bensoussan, David	ETS University of Quebec
Landry, René Jr.	Superior Technology School
Hammami, Maher	Faculté Des Sciences De Sfax - Tunisie

15:40-16:00 WeB4.3

Flight Control Methods for Multirotor UAS, pp. 345-353.

Ackerman, Kasey	NASA Langley Research Center
Gregory, Irene	NASA Langley Research Center
Hovakimyan, Naira	UIUC

16:00-16:20 WeB4.4

A Survey of Artificial Neural Networks with Model-Based Control Techniques for Flight Control of Unmanned Aerial Vehicles, pp. 354-363.

Gu, Weibin	University of Denver
Valavanis, Kimon	University of Denver
Rutherford, Matthew	University of Denver
Rizzo, Alessandro	Politecnico Di Torino

16:20-16:40 WeB4.5

Centroid Vectoring Control Using Aerial Manipulator: Experimental Results, pp. 364-369.

Ivanovic, Antun	University of Zagreb
Car, Marko	University of Zagreb
Orsag, Matko	University of Zagreb
Bogdan, Stjepan	University of Zagreb

16:40-17:00 WeB4.6

Robust and Synchronous Nonlinear Controller for Autonomous Formation Flight of Fixed Wing UASs, pp. 370-379.

Cordeiro, Thiago	University of Brasilia
Ferreira, Henrique Cezar	University of Brasilia
Ishihara, João Yoshiyuki	University of Brasília

WeC1 Heritage B

Fault Diagnosis, Accommodation and Fault-Tolerant Control (Regular Session)

Chair: Hasan, Agus — University of Southern Denmark

17:00-17:20 WeC1.1

Interactive Multiple Neural Adaptive Observer Based Sensor and Actuator Fault Detection and Isolation for Quadcopter, pp. 380-388.

Lee, Woo-Cheol	Korea Advanced Institute of Science and Technology
Choi, Han-Lim	Korea Advanced Institute of Science and Technology

17:20-17:40 WeC1.2

Observer-Based Super Twisting Controller Robust to Wind Perturbation for Multirotor UAV, pp. 389-397.

Hamadi, Hussein	Université De Technologie De Compiègne
Lussier, Benjamin	University of Technology of Compiègne
Fantoni, Isabelle	CNRS
Francis, Clovis	Lebanese University
Shraim, Hassan	Consulting Company

17:40-18:00 WeC1.3

Model-Based Fail-Safe Module for Autonomous Multirotor UAVs with Parachute Systems, pp. 398-404.

Hasan, Agus	University of Southern Denmark
Tofterup, Vincent Klyverts	University of Southern Denmark
Jensen, Kjeld	University of Southern Denmark

18:20-18:40 WeC1.5

Actuator Fault Diagnosis and Fault Tolerant Control Using Intelligent-Output-Estimator Applied on Quadrotor UAV, pp. 405-412.

Al Younes, Younes	Higher Colleges of Technology
Noura, Hassan	Islamic University of Lebanon
Rabhi, Abdelhamid	MIS
El Hajjaji, Ahmed	Univ. De Picardie-Jules Verne

18:40-19:00 WeC1.6

Fault-Tolerant Adaptive Neural Control of Multi-UAVs against Actuator Faults, pp. 413-418.

Yu, Ziquan	Northwestern Polytechnical University
Zhang, Youmin	Concordia University
Qu, Yaohong	Northwestern Polytechnical University
Su, Chun-Yi	Concordia Univ
Zhang, Yintao	Concordia University
Xing, Zhewen	Northwestern Polytechnical University

WeC2 Heritage A

Regulations (Regular Session)

Chair: Bassi, Eleonora — Politecnico Di Torino

17:00-17:20 WeC2.1

Drones Are Flying Outside of Segregated Airspace in Poland – New Rules for BVLOS UAVs Operations, pp. 419-424.

Konert, Anna	Lazarski University in Warsaw
Kasprzyk, Piotr	Lazarski University in Warsaw

17:20-17:40 WeC2.2

A Survey of Unmanned Aircraft System Technologies to Enable Safe Operations in Urban Areas, pp. 425-434.

Bloise, Nicoletta	Politecnico Di Torino
Primatesta, Stefano	Politecnico Di Torino
Antonini, Roberto	Company
Fici, Gian Piero	TIM
Gaspardone, Marco	TIM
Guglieri, Giorgio	Politecnico Di Torino
Rizzo, Alessandro	Politecnico Di Torino

17:40-18:00 WeC2.3

European Drones Regulation: Today's Legal Challenges, pp. 435-442.

Bassi, Eleonora	Politecnico Di Torino

18:00-18:20 WeC2.4

Risk Assessment Based on SORA Methodology for a UAS Media Production Application, pp. 443-451.

Capitán, Carlos	University of Seville
Capitan, Jesus	University of Seville
Castaño, Ángel Rodríguez	University of Seville
Ollero, Anibal	Universidad De Sevilla

18:20-18:40 WeC2.5

Towards a Tool for Assessing UAS Compliance with the JARUS SORA Guidelines, pp. 452-458.

Terkildsen, Kristian Husum	University of Southern Denmark
Jensen, Kjeld	University of Southern Denmark

WeC3 Heritage C

UAS Applications II (Regular Session)

Chair: Lozano, Rogelio — University of Technology of Compiègne

17:00-17:20 WeC3.1

Comparative Study for Coordinating Multiple Unmanned HAPS for Communications Area Coverage, pp. 459-466.

Anicho, Ogbonnaya	Liverpool Hope University
Charlesworth, Philip	Liverpool Hope University
Baicher, Gurvinder	Liverpool Hope University
Nagar, Atulya	Liverpool Hope University
Buckley, Neil	Liverpool Hope University

17:20-17:40 WeC3.2

Water Take-Off and Landing - Hybrid Copter Approach for Maritime CONOPs, pp. 467-473.

Galante, João	Universidade Do Porto - Faculdade Engenharia
Manuel, Ribeiro	Universidade Do Porto - Faculdade Engenharia
de Nobrega, Roberto	Universidade Do Porto - Faculdade Engenharia
Neiva, Jorge	Universidade Do Porto - Faculdade Engenharia
Ferreira, António Sérgio	University of Porto
Sousa, Joao	Universidade Do Porto - Faculdade Engenharia

17:40-18:00 WeC3.3

Three Dimensional UAV Path Following Using SDRE Guidance, pp. 474-482.

Singh, Mandeep	IIIT Delhi
Manoharan, Amith	IIIT Delhi
Ratnoo, Ashwini	Indian Institute of Science
PB, Sujit	Indraprastha Institute of Information Technology Delhi

18:00-18:20 WeC3.4

Satellite and UAV Data for Precision Agriculture Applications, pp. 483-489.

Mancini, Adriano	Universita' Politecnica Delle Marche
Frontoni, Emanuele	Università Politecnica Delle Marche
Zingaretti, Primo	Università Politecnica Delle Marche

18:20-18:40 WeC3.5

Attitude and Altitude Control for a Fixed Wing UAV Applied to Photogrammetry, pp. 490-494.

Hernandez, Jorge Luis	CINVESTAV IPN
Gonzalez-Hernandez, Ivan	Cinvestav - IPN
Lozano, Rogelio	University of Technology of Compiègne

WeC4 Savannah

Control Architectures III (Regular Session)

Chair: Azimov, Dilmurat	University of Hawaii at Manoa
Co-Chair: Zhang, Fu	University of Hong Kong

17:00-17:20 WeC4.1

Nonlinear Model Predictive Attitude Control for Fixed-Wing Unmanned Aerial Vehicle Based on a Wind Frame Formulation, pp. 495-504.

Reinhardt, Dirk	Norwegian University of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology

17:20-17:40 WeC4.2

Integrated Optimal Control and Explicit Guidance for Quadcopters, pp. 505-514.

Kawamura, Evan	University of Hawaii: Manoa
Azimov, Dilmurat	University of Hawaii at Manoa

17:40-18:00 WeC4.3

Deep Reinforcement Learning Attitude Control of Fixed-Wing UAVs Using Proximal Policy Optimization, pp. 515-525.

Bøhn, Eivind	SINTEF, Norwegian University of Science and Technology
Coates, Erlend M.	Norwegian University of Science and Technology
Moe, Signe	Norwegian University of Science and Technology, SINTEF
Johansen, Tor Arne	Norwegian University of Science and Technology

18:00-18:20 WeC4.4

Enabling Bidirectional Thrust for Aggressive and Inverted Quadrotor Flight, pp. 526-533.

Jothiraj, Walter	McGill University
Miles, Corey	McGill University
Bulka, Eitan	McGill University
Sharf, Inna	McGill University
Nahon, Meyer	McGill University

18:40-19:00 WeC4.6

Full Attitude Control of an Efficient Quadrotor Tail-Sitter VTOL UAV with Flexible Modes, pp. 534-542.

Xu, Wei	University of Hong Kong
Gu, Haowei	Hong Kong University of Science and Technology
Qin, Youming	University of Hong Kong
Lin, Jiarong	The University of Hong Kong
Zhang, Fu	University of Hong Kong

WeP5 Heritage Foyer

Poster Papers (Poster Session)

Chair: Morrison, James R.	KAIST

13:00-18:00 WeP5.1

Robust Flight Control of a Tri-Rotor UAV Based on Modified Super-Twisting Algorithm, pp. 543-548.

Paiva, Enrique	Universidad Nacional De Asunción, Facultad De Ingeniería
Rodas, Jorge	Universidad Nacional De Asunción, Facultad De Ingeniería
Kali, Yassine	École Mohammadia d'Ingénieurs, University of Mohammed V
Gregor Recalde, Raul Igmar	Universidad Nacional De Asunción, Facultad De Ingeniería
Saad, Maarouf	Ecole De Technologie Superieure

13:00-18:00 WeP5.2

On Coordination in Multiple Aerial Engagement, pp. 549-554.

Strickland, Laura	Georgia Institute of Technology, Georgia Tech Research Institute
Squires, Eric	Georgia Tech Research Institute
Day, Michael	Georgia Tech Research Institute
Pippin, Charles	Georgia Tech Research Institute

13:00-18:00 WeP5.3

Planning for Decentralized Formation Flight of UAV Fleets in Uncertain Environments with Dec-POMDP, pp. 555-560.

de Oliveira Floriano, Bruno Rodolfo	Universidade De Brasilia
Borges, Geovany Araújo	University of Brasília
Ferreira, Henrique Cezar	University of Brasilia

13:00-18:00 WeP5.5

Smart City Investments: A Rapid Decision Framework for Public Private Partnerships, pp. 561-566.

Rayi, Paul Sujith	Syracuse University

Bothra, Rishie Lavendra	Syracuse University
Wallace, Stephen	Syracuse University
Venkatesh, Murali	Syracuse University School of Information Studies

13:00-18:00 WeP5.6

Sense-And-Avoid System Development on an FPGA, pp. 567-571.

Kóta, Fülöp	Faculty of Information Technology and Bionics, Pázmány Péter Cat
Zsedrovits, Tamás	Pázmány Péter Catholic University
Nagy, Zoltán	Faculty of Information Technology and Bionics, Pázmány Péter Cat

ThA1	Heritage B
Path Planning III (Regular Session)	
Chair: Darbha, Swaroop	Texas A & M University
Co-Chair: Choi, Youngjun	Georgia Institute of Technology

10:00-10:20 ThA1.1

Cooperative Search Area Optimization Using Multiple Unmanned Aerial Vehicles in a GPS-Denied Environment, pp. 572-579.

Misra, Sohum	University of Cincinnati
Biswas, Srijanee	University of Cincinnati
Minai, Ali	University of Cincinnati
Sharma, Rajnikant	University of Cincinnati

10:20-10:40 ThA1.2

Randomized Continuous Monitoring of a Target by Agents with Turn Radius Constraints, pp. 580-587.

Stephens, Shawn	Air Force Institute of Technology, WPAFB, OH
Manyam, Satyanarayana Gupta	Infoscitex Corporation
Casbeer, David	Air Force Research Laboratories
Cichella, Venanzio	UIUC
Kunz, Donald	Air Force Institute of Technology

10:40-11:00 ThA1.3

A Multi-UAS Trajectory Optimization Methodology for Complex Enclosed Environments, pp. 588-596.

Barlow, Sarah	Georgia Institute of Technology
Choi, Youngjun	Georgia Institute of Technology
Briceno, Simon	Georgia Tech
Mavris, Dimitri	Georgia Institute of Technology

11:00-11:20 ThA1.4

Efficient Computation of Optimal UAV Routes for Persistent Monitoring of Targets, pp. 597-606.

Hari, Sai Krishna Kanth	Texas A & M University, College Station
Rathinam, Sivakumar	Texas A & M University
Darbha, Swaroop	Texas A & M Univ
Kalyanam, Krishna	PARC
Manyam, Satyanarayana Gupta	Infoscitex Corporation
Casbeer, David	Air Force Research Laboratories

11:20-11:40 ThA1.5

Bounding Algorithms for Persistent Monitoring of Targets Using Unmanned Vehicles, pp. 607-613.

Hari, Sai Krishna Kanth	Texas A & M University, College Station
Rathinam, Sivakumar	Texas A & M University
Darbha, Swaroop	Texas A & M Univ
Kalyanam, Krishna	PARC
Manyam, Satyanarayana Gupta	Infoscitex Corporation
Casbeer, David	Air Force Research Laboratories

11:40-12:00 ThA1.6

System Design and Resource Analysis for Persistent Robotic Presence with Multiple Refueling Stations, pp. 614-621.

Park, Hyorin	KAIST, Department of Industrial and Systems Engineering
Morrison, James R.	KAIST

ThA2	Heritage C
UAS Applications III (Regular Session)	
Chair: Johansen, Tor Arne	Norwegian Univ. of Sci. & Tech

10:00-10:20 ThA2.1

Feasibility Study for a MEDEVAC Electric UAS Capability, pp. 622-627.

Pickell, William	United States Military Academy
Kopeikin, Andrew	US Military Academy
Bristow, Elizabeth	United States Military Academy
Bluman, James	United States Military Academy

10:20-10:40 ThA2.2

Multi-UAV Based Autonomous Wilderness Search and Rescue Using Target Iso-Probability Curves, pp. 628-635.

Kashino, Zendai	University of Toronto
Nejat, Goldie	University of Toronto
Benhabib, Beno	University of Toronto

10:40-11:00 ThA2.3

Cooperative Load Transportation Using Three Quadrotors, pp. 636-642.

Pizetta, Igor	Federal University of Espirito Santo
Brandao, Alexandre Santos	Federal University of Vicosa
Sarcinelli-Filho, Mário	Federal University of Espirito Santo

11:00-11:20 ThA2.4

Colored-Noise Tracking of Floating Objects Using UAVs with Thermal Cameras, pp. 643-652.

Helgesen, Haakon Hagen	Norwegian University of Science and Technology
Stendahl Leira, Frederik	Norwegian University of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology

11:20-11:40 ThA2.5

A Solution for Searching and Monitoring Forest Fires Based on Multiple UAVs, pp. 653-658.

Zhang, Yintao	Concordia University

Zhang, Youmin	Concordia University
Yu, Ziquan	Northwestern Polytechnical University

11:40-12:00 ThA2.6

Anomaly Detection and Cognizant Path Planning for Surveillance Operations Using Aerial Robots, pp. 659-665.

Dang, Tung	University of Nevada, Reno
Khattak, Shehryar	University of Nevada, Reno
Papachristos, Christos	University of Nevada Reno
Alexis, Kostas	University of Nevada, Reno

ThA3 Heritage A

Micro and Mini UAS (Regular Session)

Chair: Chao, Haiyang	University of Kansas
Co-Chair: Kanistras Kostas	U of Alabama, Huntsville

10:00-10:20 ThA3.1

A Novel Quadcopter with a Tilting Frame Using Parallel Link Mechanism, pp. 666-675.

Sakaguchi, Akinori	Osaka University
Takimoto, Takashi	National Institute of Technology, Kitakyushu College
Ushio, Toshimitsu	Osaka University

10:20-10:40 ThA3.2

Direct Position Control of an Octarotor Unmanned Vehicle under Wind Gust Disturbance, pp. 676-683.

Baldini, Alessandro	Università Politecnica Delle Marche
Felicetti, Riccardo	Università Politecnica Delle Marche
Freddi, Alessandro	Università Politecnica Delle Marche
Longhi, Sauro	Università Politecnica Delle Marche
Monteriù, Andrea	Università Politecnica Delle Marche

10:40-11:00 ThA3.3

Smooth Saturation Function-Based Position and Attitude Tracking of a Quad-Rotorcraft Avoiding Singularity, pp. 684-695.

Dasgupta, Ranjan	Tata Consultancy Services Ltd

11:00-11:20 ThA3.4

Error-State LQR Control of a Multirotor UAV, pp. 696-703.

Farrell, Michael David	Brigham Young University
Jackson, James	Brigham Young University
Nielsen, Jerel	Utah State University
Bidstrup, Craig	Brigham Young University
McLain, Timothy W.	Brigham Young University

11:20-11:40 ThA3.5

A Fuzzy Gain Scheduling Control Algorithm for Formation Flight of Multi-UAVs, pp. 704-712.

Rojo Rodriguez, Erik Gilberto	Universidad Autonoma De Nuevo Leon
Ollervides Vazquez, Edmundo Javier	CIIIA-FIME-UANL; TecNM-Instituto Tecnologico De La Laguna
Zambrano-Robledo, Patricia	CIIIA-FIME-UANL
Garcia Salazar, Octavio	CIIIA-FIME-UANL

11:40-12:00 ThA3.6

Model Based Roll Controller Tuning and Frequency Domain Analysis for a Flying-Wing UAS, pp. 713-720.

Flanagan, Harold	University of Kansas
Chao, Haiyang	University of Kansas
Hagerott, Steven G.	Textron Aviation

ThA4 Savannah

Energy Efficient UAS (Regular Session)

Chair: Ollero, Anibal	Universidad De Sevilla
Co-Chair: Bezzo, Nicola	University of Virginia

10:00-10:20 ThA4.1

A Simple Model for Gliding and Low-Amplitude Flapping Flight of a Bio-Inspired UAV, pp. 721-729.

Martín-Alcántara, Antonio	University of Seville
Grau, Pedro	Robotics, Vision and Control Group, University of Seville
Fernandez-Feria, Ramón	Fluid Mechanics, Andalucía Tech., University of Málaga
Ollero, Anibal	Universidad De Sevilla

10:20-10:40 ThA4.2

Multiphysical Modeling of Energy Dynamics for Multirotor Unmanned Aerial Vehicles, pp. 730-739.

Michel, Nicolas	UC Davis
Sinha, Anish Kumar	University of California Davis
Kong, Zhaodan Kong	University of California, Davis
Lin, Xinfan	University of California, Davis

10:40-11:00 ThA4.3

Propulsion System Modeling for Small Fixed-Wing UAVs, pp. 740-749.

Coates, Erlend M.	Norwegian University of Science and Technology
Wenz, Andreas Wolfgang	Norwegian University of Science and Technology
Gryte, Kristoffer	Norwegian University of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology

11:00-11:20 ThA4.4

Grid-Based Coverage Path Planning with Minimum Energy Over Irregular-Shaped Areas with UAVs, pp. 750-759.

Cabreira, Tauã	Universidade Federal De Pelotas
Di Franco, Carmelo	University of Virginia
Ferreira Jr., Paulo R.	Universidade Federal De Pelotas
Buttazzo, Giorgio	Scuola Superiore Sant 'Anna

11:20-11:40 ThA4.5

Exploiting Ground and Ceiling Effects on Autonomous UAV Motion Planning, pp. 760-769.

Gao, Shijie	University of Virginia
Di Franco, Carmelo	University of Virginia

Carter, Darius	University of Virginia
Quinn, Daniel	University of Virginia
Bezzo, Nicola	University of Virginia

11:40-12:00 ThA4.6

Mission Planning Strategy for Multirotor UAV Based on Flight Endurance Estimation, pp. 770-778.

Schacht Rodríguez, Ricardo	Centro Nacional De Investigacion Y Desarrollo Tecnologico
Ponsart, Jean-Christophe	Université De Lorraine
Garcia Beltran, Carlos Daniel	Centro Nacional De Investigación Y Desarrollo Tecnológico
Astorga-Zaragoza, Carlos	TecnolÓgico Nacional De MÉxico - Cenidet
Theilliol, Didier	University of Lorraine

ThB1 Heritage B

Path Planning IV (Regular Session)

Chair: Morrison, James R.	KAIST
Co-Chair: Ahmadian, Navid	University of Houston

13:30-13:50 ThB1.1

A Study on 3D Optimal Path Planning for Quadcopter UAV Based on D Lite*, pp. 779-785.

Kim, Hyowon	Pusan National University
Jeong, Jinseok	Pusan National University
Kim, Namyool	Pusan National University
Kang, Beomsoo	Pusan National University

13:50-14:10 ThB1.2

Collision-Free Multi-UAV Flight Scheduling for Power Network Damage Assessment, pp. 786-790.

Ahmadian, Navid	University of Houston
Lim, Gino	University of Houston
Torabbeigi, Maryam	University of Houston
Kim, Seon Jin	Republic of Korea Army

14:10-14:30 ThB1.3

Multi-UAS Path-Planning for a Large-Scale Disjoint Disaster Management, pp. 791-799.

Choi, Younghoon	Georgia Institute of Technology
Choi, Youngjun	Georgia Institute of Technology
Briceno, Simon	Georgia Tech
Mavris, Dimitri	Georgia Institute of Technology

14:30-14:50 ThB1.4

A UAV Resolution and Waveband Aware Path Planning for Onion Irrigation Treatments Inference, pp. 800-804.

Niu, Haoyu	UC, Merced
Zhao, Tiebiao	MESA LAB at UC Merced
Wang, Dong	USDA ARS Parlier
Chen, YangQuan	University of California, Merced

14:50-15:10 ThB1.5

Data Quality Aware Flight Mission Design for Fugitive Methane Sniffing Using Fixed Wing SUAS, pp. 805-810.

Hollenbeck, Derek	MESA Lab at UC Merced
Dahra, Moataz	MESA Lab at UC Merced
Christensen, Lance	JPL
Chen, YangQuan	University of California, Merced

15:10-15:30 ThB1.6

A Unified Framework for Reliable Multi-Drone Tasking in Emergency Response Missions, pp. 811-819.

Terzi, Maria	KIOS Research and Innovation Center of Excellence, University of Cyprus
Kolios, Panayiotis	University of Cyprus
Panayiotou, Christos	University of Cyprus
Theocharides, Theocharis	University of Cyprus

ThB2 Heritage C

UAS Applications IV (Regular Session)

Chair: Quagliotti, Fulvia	Politecnico Di Torino

13:30-13:50 ThB2.1

Patrolling a Terrain with Cooperative UAVs Using Random Walks, pp. 820-829.

Caraballo de la Cruz, Luis Evaristo	University of Seville
Díaz-Báñez, José-Miguel	University of Seville
Fabila-Monroy, Ruy	CINVESTAV
Hidalgo-Toscano, Carlos	CINVESTAV

13:50-14:10 ThB2.2

Rapid and Automated Urban Modeling Techniques for UAS Applications, pp. 830-839.

Choi, Youngjun	Georgia Institute of Technology
Pate, David	Research Engineer
Briceno, Simon	Georgia Tech
Mavris, Dimitri	Georgia Institute of Technology

14:10-14:30 ThB2.3

Communication Technology for Unmanned Aerial Vehicles: A Qualitative Assessment and Application to Precision Agriculture, pp. 840-847.

Neji, Najett	Université Paris Saclay
Mostfa, Tumader	Université Paris Saclay

14:30-14:50 ThB2.4

UAVs at Your Service: Towards IoT Integration with HAMSTER, pp. 848-857.

Rodrigues, Mariana	Universidade De São Paulo
Branco, Kalinka Regina Lucas Jaquie Castelo	University of São Paulo

14:50-15:10 ThB2.5

Urban Monitoring of Smart Communities Using UAS, pp. 858-865.

Pannozzi, Pierluigi	Polytechnic University of Turin
Valavanis, Kimon	University of Denver

Rutherford, Matthew	University of Denver
Guglieri, Giorgio	Politecnico Di Torino
Scanavino, Matteo	Politecnico Di Torino
Quagliotti, Fulvia	Politecnico Di Torino

ThB3 Heritage A

Sensor Fusion I (Regular Session)

Chair: Pereira, Guilherme — West Virginia University

13:30-13:50 ThB3.1

Increasing Perception Space of a Ground Standing Robot Via Data Transmission from an Aerial Robot, pp. 866-874.

Sohn, Kiwon	University of Hartford
Murshid, Mohammad	University of Hartford

13:50-14:10 ThB3.2

Perceptual Ability Advancement of a Humanoid with Limited Sensors Via Data Transmission from an Aerial Robot, pp. 875-881.

Sohn, Kiwon	University of Hartford
Murshid, Mohammad	University of Hartford

14:10-14:30 ThB3.3

State Estimation for Aerial Vehicles in Forest Environments, pp. 882-890.

Chiella, Antonio Carlos Bana Chiella	Federal University of Minas Gerais
Teixeira, Bruno Otávio S.	Federal University of Minas Gerais
Pereira, Guilherme	West Virginia University

14:30-14:50 ThB3.4

Deep Learning Based Semantic Situation Awareness System for Multirotor Aerial Robots Using LIDAR, pp. 891-900.

Sanchez-Lopez, Jose Luis	SnT, University of Luxembourg
Sampedro, Carlos	University
Cazzato, Dario	Interdisciplinary Centre for Security, Reliability and Trust
Voos, Holger	University of Luxembourg

14:50-15:10 ThB3.5

Networked Radar Systems for Cooperative Tracking of UAVs, pp. 901-907.

Anderson, Brady	Brigham Young University
Ellingson, Jaron	Brigham Young University
Eyler, Michael	Brigham Young University
Buck, David	Brigham Young University
Peterson, Cameron	Brigham Young University
McLain, Timothy W.	Brigham Young University
Warnick, Karl	Brigham Young University

15:10-15:30 ThB3.6

Depth Map Estimation Methodology for Detecting Free-Obstacle Navigation Areas, pp. 908-914.

Trejo, Sergio Marcelino	Centro De Investigaciones En Optica
Martínez, Karla	Centro De Investigaciones En Óptica
Flores, Gerardo	Center for Research in Optics

ThB4 Savannah

Airspace Management (Regular Session)

Chair: Ko, Woo-Hyun — Texas A&M University

13:30-13:50 ThB4.1

Optimum Design for Drone Highway Network, pp. 915-921.

Hamanaka, Masatoshi	RIKEN

13:50-14:10 ThB4.2

Distributed Bidding-Based Detect-And-Avoid for Multiple Unmanned Aerial Vehicles in National Airspace, pp. 922-928.

Scott, Drew	University of Cincinnati
Radmanesh, Mohammadreza	University of Cincinnati
Sarim, Mohammad	University of Cincinnati
Deshpande, Aditya	University of Cincinnati
Kumar, Manish	University of Cincinnati
Pragada, Ravikumar	InterDigital Communications

14:10-14:30 ThB4.3

A Lane-Based Approach for Large-Scale Strategic Conflict Management for UAS Service Suppliers, pp. 929-937.

Sacharny, David	University of Utah
Henderson, Thomas	University of Utah

14:30-14:50 ThB4.4

Probability-Based Collision Detection and Resolution of Planned Trajectories for Unmanned Aircraft System Traffic Management, pp. 938-943.

Ko, Woo-Hyun	Texas A&M University
Kumar, P. R.	TAMU

14:50-15:10 ThB4.5

Evolutionary Optimization-Based Mission Planning for UAS Traffic Management (UTM), pp. 944-950.

Tan, Qingyu	Air Traffic Management Research Institute
Wang, Zenkun	Nanyang Technological University
Yew Soon, Ong	Nanyang Technological University
Low, Kin Huat	Nanyang Technological University

15:10-15:30 ThB4.6

Enable UAVs Safely Flight in Low-Altitude: A Preliminary Research of the Public Air Route Network of UAVs, pp. 951-956.

Liao, Xiaohan	Institute of Geographic Science and Natural Resources Research,
Xu, Chenchen	Institute of Geographic Sciences and Natural Resources Research,
Yue, Huanyin	Institute of Geographic Science and Natural Resources Research,

ThC1 Heritage B

See-And-Avoid Systems (Regular Session)

Chair: Briese, Christoph — Deutsches Zentrum Für Luft Und Raumfahrt E.V

16:00-16:20 — ThC1.1

Below Horizon Aircraft Detection Using Deep Learning for Vision-Based Sense and Avoid, pp. 957-962.

James, Jasmin — Queensland University of Technology
Ford, Jason — Queensland University of Technology
Molloy, Timothy L. — Queensland University of Technology

16:20-16:40 — ThC1.2

High-Speed Obstacle-Avoidance with Agile Fixed-Wing Aircraft, pp. 963-972.

Bulka, Eitan — McGill University
Nahon, Meyer — McGill University

16:40-17:00 — ThC1.3

Deep Learning with Semi-Synthetic Training Images for Detection of Non-Cooperative UAVs, pp. 973-980.

Briese, Christoph — Deutsches Zentrum Für Luft Und Raumfahrt E.V
Günther, Lukas — Deutsches Zentrum Für Luft Und Raumfahrt E.V

17:00-17:20 — ThC1.4

Flight Test Validation of Collision Avoidance System for a Multicopter Using Stereoscopic Vision, pp. 981-987.

Ma, Demetria — California State Polytechnic University, Pomona
Tran, Alex — University
Keti, Nick — California Polytechnic University, Pomona
Yanagi, Ryan — Cal Poly Pomona
Knight, Peter — Cal Poly Pomona
Joglekar, Kedar — Cal Poly Pomona
Tudor, Nicholas — California State Polytechnic University, Pomona
Cresta, Burt — California Polytechnic State University Pomona
Bhandari, Subodh — California State Polytechnic University

17:20-17:40 — ThC1.5

Three-Dimensional (3D) Dynamic Obstacle Perception in a Detect-And-Avoid Framework for Unmanned Aerial Vehicles, pp. 988-996.

Lim, Catrina — Nanyang Technological University
Li, Boyang — Nanyang Technological University
Ng, Ee Meng — Nanyang Technological University
LIU, XIN — Nanyang Technological University
Low, Kin Huat — Nanyang Technological University

ThC2 — Heritage C

UAS Applications V (Regular Session)

Chair: Peterson, Cameron — Brigham Young University
Co-Chair: Brandao, Alexandre Santos — Federal University of Vicosa

16:00-16:20 — ThC2.1

The Urban Last Mile Problem: Autonomous Drone Delivery to Your Balcony, pp. 997-1004.

Brunner, Gino — ETH Zurich
Szebedy, Bence — ETH Zurich
Tanner, Simon — ETH Zurich
Wattenhofer, Roger — ETH Zurich

16:20-16:40 — ThC2.2

Real-Time Single Object Detection on the UAV, pp. 1005-1014.

Wu, Hsiang-Huang — Prairie View A&M University

16:40-17:00 — ThC2.3

Gesture Commands for Controlling High-Level UAV Behavior, pp. 1015-1022.

Akagi, John — Brigham Young University
Moon, Brady — Brigham Young University
Chen, Xingguang — Sun Yat-Sen University
Peterson, Cameron — Brigham Young University

17:00-17:20 — ThC2.4

UAS-Based Crack Detection Using Stereo Cameras: A Comparative Study, pp. 1023-1027.

Benkhoui, Yasmina — Worcester Polytechnic Institute
Reinhold, Ludwig — Worcester Polytechnic Institute
El Korchi, Tahar — Worcester Polytechnic Institute

17:20-17:40 — ThC2.5

Rod-Shaped Payload Transportation Using Multiple Quadrotors, pp. 1028-1032.

Villa, Daniel Khede Dourado — Federal University of Espírito Santo
Brandao, Alexandre Santos — Federal University of Vicosa
Sarcinelli-Filho, Mário — Federal University of Espirito Santo

ThC3 — Heritage A

Sensor Fusion II (Regular Session)

Chair: Sun, Liang — New Mexico State University

16:00-16:20 — ThC3.1

Observability Analysis and Bayesian Filtering for Self-Localization of a Tethered Multicopter in GPS-Denied Environments, pp. 1033-1039.

Al-Radaideh, Amer — New Mexico State University
Sun, Liang — New Mexico State University

16:20-16:40 — ThC3.2

An Estimation-Domain Approach to MEMS Multi-IMU Fusion for SUAS, pp. 1040-1045.

Givens, Matthew — Utah State University
Coopmans, Calvin — Utah State University
Christensen, Randall — Utah State University

16:40-17:00	ThC3.3
A Survey of Inertial Sensor Fusion: Applications in sUAS Navigation and Data Collection, pp. 1046-1052.	
Givens, Matthew	Utah State University
Coopmans, Calvin	Utah State University

17:00-17:20	ThC3.4
Robust Thermal-Inertial Localization for Aerial Robots: A Case for Direct Methods, pp. 1053-1060.	
Khattak, Shehryar	University of Nevada, Reno
Mascarich, Frank	University of Nevada, Reno
Dang, Tung	University of Nevada, Reno
Papachristos, Christos	University of Nevada Reno
Alexis, Kostas	University of Nevada, Reno

17:20-17:40	ThC3.5
A Software in the Loop (SIL) Kalman and Complementary Filter Implementation on X-Plane for UAVs, pp. 1061-1068.	
Michailidis, Michail	University of Denver
Agha, Mohammed	University of Denver
Rutherford, Matthew	University of Denver
Valavanis, Kimon	University of Denver

ThC4	Savannah
Airspace Control (Regular Session)	
Chair: Uchiyama, Kenji	Nihon University

16:00-16:20	ThC4.1
Linear Quadratic Formulation of the Target Defense Differential Game, pp. 1069-1075.	
Pachter, Meir	AFIT/ENG
Casbeer, David	Air Force Research Laboratories
Garcia, Eloy	AFRL

16:20-16:40	ThC4.2
Robust Trajectory Tracking for UAS: Dynamics Sliding Mode Approach, pp. 1076-1083.	
Reynoso, Martin	UPP
Ramos-Velasco, Luis Enrique	Universidad Politécnica Metropolitana De Hidalgo, México
Garcia-Rodriguez, Rodolfo	Metropolitan Polytechnic University of Hidalgo

16:40-17:00	ThC4.3
Controller Design Using Backstepping Algorithm for Fixed-Wing UAV with Thrust Vectoring System, pp. 1084-1088.	
Hirano, Shogo	Nihon University
Uchiyama, Kenji	Nihon University
Masuda, Kai	Nihon University

17:00-17:20	ThC4.4
*Enhanced Hover-Mode Control of a Quad-Rotor Aircraft System Based on Nested Saturation Scheme**.	
Gonzalez-Hernandez, Ivan	Cinvestav – IPN
Hernandez, Jorge Luis	CINVESTAV IPN
Vazquez-Nicolas, Jesus Manuel	Cinvestav – IPN
Lozano, Rogelio	University of Technology of Compiègne

17:20-17:40	ThC4.5
Least Square Policy Iteration for IBVS Based Dynamic Target Tracking, pp. 1089-1098.	
Srivastava, Raunak	Indian Institute of Technology Bombay
Lima, Rolif	TCS Innovation Labs
Das, Kaushik	TATA Consultancy Service
Maity, Arnab	Indian Institute of Technology Bombay

Technical Program for Friday June 14, 2019

FrA1 Heritage B
UAV Design (Regular Session)

Chair: Cawthorne, Dylan — University of Southern Denmark
Co-Chair: Kim, Yongjae — Agency for Defense Development

09:00-09:20 FrA1.1

Design and Shape Optimization of Unmanned, Semi-Rigid Airship for Rapid Descent Using Hybrid Genetic Algorithm, pp. 1099-1107.

Singh, Vinay — University of Ottawa
Lanteigne, Eric — University of Ottawa

09:20-09:40 FrA1.2

Preliminary Design, Modeling and Control of a Fully Actuated Quadrotor UAV, pp. 1108-1116.

Nigro, Michelangelo — Università Degli Studi Della Basilicata
Pierri, Francesco — Universita` Degli Studi Della Basilicata
Caccavale, Fabrizio — Universita Degli Studi Della Basilicata

09:40-10:00 FrA1.3

Value Sensitive Design of a Humanitarian Cargo Drone, pp. 1117-1125.

Cawthorne, Dylan — University of Southern Denmark
Cenci, Alessandra — University of Southern Denmark, Department of Philosophy, Instit

10:00-10:20 FrA1.4

Design of a Class I Unmanned Aircraft for Maritime Surveillance, pp. 1126-1135.

Franco, Vasco — Academia Da Força Aérea Portuguesa
Correia, João — Academia Da Força Aérea Portuguesa
Caetano, Joao Vieira — Portuguese Air Force Research Center
Félix, Luís — Academia Da Força Aérea Portuguesa

10:20-10:40 FrA1.5

Design Methodology of a Small Unmanned Airship with Optimized Fins, pp. 1136-1142.

Suvarna, Sohan — IITB-Monash Research Academy
Chung, Hoam — Monash University
Pant, Rajkumar — Indian Institute of Technology-Bombay

10:40-11:00 FrA1.6

Optimal Guidance for Range Maximization of Guided Projectile: The Effects of Autopilot Delay and Fin Deployment Timing on the Flight Range, pp. 1143-1152.

Kim, Yongjae — Agency for Defense Development
Kim, Gyeong Hun — Agency for Defense Development
Choi, Jae-Hyun — Agency for Defense Development

FrA2 Heritage A
Autonomy I (Regular Session)

Chair: Bezzo, Nicola — University of Virginia

09:00-09:20 FrA2.1

Singular Trajectories in the Two Pursuer One Evader Differential Game, pp. 1153-1160.

Pachter, Meir — AFIT/ENG
Von Moll, Alexander — Air Force Research Laboratory
Garcia, Eloy — AFRL
Casbeer, David — Air Force Research Laboratories
Milutinovic, Dejan — University of California at Santa Cruz

09:20-09:40 FrA2.2

*A K Nearest Neighborhood Based Wind Estimation for Rotary-Wing VTOL UAVs**.

Wang, Liyang — Rutgers, The State University of New Jersey
Misra, Gaurav — Rutgers, The State University of New Jersey
Bai, Xiaoli — Rutgers, The State University of New Jersey

09:40-10:00 FrA2.3

Deep RC: Enabling Remote Control through Deep Learning, pp. 1161-1167.

Ellingson, Jaron — Brigham Young University
Ellingson, Gary — Brigham Young University
McLain, Timothy W. — Brigham Young University

10:00-10:20 FrA2.4

Parameter-Free Regression-Based Autonomous Control of Off-The-Shelf Quadrotor UAVs, pp. 1168-1177.

Peddi, Rahul — University of Virginia
Bezzo, Nicola — University of Virginia

10:20-10:40 FrA2.5

Towards Breaching a Still Water Surface with a Miniature Unmanned Aerial-Underwater Vehicle, pp. 1178-1185.

Zha, Jiaming — UC Berkeley
Thacher, Eric William — UC Berkeley
Kroeger, Joseph — University of California, Berkeley
Makiharju, Simo — UC Berkeley
Mueller, Mark Wilfried — UC Berkeley

10:40-11:00 FrA2.6

A Vision-Based Unmanned Aircraft System for Autonomous Grasp & Transport, pp. 1186-1193.

Liu, Xu — Shenyang Institute of Automation, Chinese Academy of Sciences
He, Yuqing — Shenyang Institute of Automation, CAS, P. R. China
Chen, Bo — Shenyang Institute of Automation Chinese Academy

of Sciences
Hou, Yongqiang — Northeastern University
Bi, Kaiyuan — Shenyang Jianzhu University
Li, Decai — Institute of Automation Chinese, Chinese Academy of Sciences

FrA3 — Heritage C
UAS Navigation I (Regular Session)
Chair: Campoy, Pascual — Universidad Politecnica Madrid
Co-Chair: Huang, Sunan — National University of Singapore

09:00-09:20 — FrA3.1
Visual Controllers for Relative Positioning in Indoor Settings, pp. 1194-1200.
Mejias Alvarez, Luis — Queensland University of Technology
Campoy, Pascual — Universidad Politecnica Madrid

09:20-09:40 — FrA3.2
Towards Automated Under-Canopy Exploration of Plantation Forests, pp. 1201-1208.
Lin, Tzu-Jui — University of Auckland
Stol, Karl — University of Auckland

09:40-10:00 — FrA3.3
Laser-Based Collision Avoidance and Reactive Navigation Using RRT and Signed Distance Field for Multirotor UAVs*, pp. 1209-1217.
Lu, Liang — Technical University of Madrid(UPM-CSIC)
Sampedro, Carlos — University
Rodriguez-Vazquez, Javier — Universidad Politecnica De Madrid
Campoy, Pascual — Universidad Politecnica Madrid

10:00-10:20 — FrA3.4
Computationally Efficient Visibility Graph−-Based Generation of 3D Shortest Collision-Free Path among Polyhedral Obstacles for Unmanned Aerial Vehicles, pp. 1218-1223.
Huang, Sunan — National University of Singapore
Teo, Rodney — Temasek Laboratories, National University of Singapore

10:20-10:40 — FrA3.5
A Cloud-Based Framework for Intelligent Navigation and Coordination for UASs in Urban Areas, pp. 1224-1233.
Primatesta, Stefano — Politecnico Di Torino
Bloise, Nicoletta — Politecnico Di Torino
Antonini, Roberto — Company
Fici, Gian Piero — TIM
Gaspardone, Marco — TIM
Guglieri, Giorgio — Politecnico Di Torino
Rizzo, Alessandro — Politecnico Di Torino

10:40-11:00 — FrA3.6
A Carrot in Probabilistic Grid Approach for Quadrotor Line Following on Vertical Surfaces, pp. 1234-1241.
Liu, Jyi-Shane — National Chengchi University
LEE, Gong-Yi — National Chengchi University

FrA4 — Savannah
Environmental Issues (Regular Session)
Co-Chair: Chen, YangQuan — University of California, Merced

09:00-09:20 — FrA4.1
Visual Servoing for Multirotor Precision Landing in Daylight and After-Dark Conditions, pp. 1242-1248.
Wynn, Jesse S. — Lawrence Livermore National Laboratory
McLain, Timothy W. — Brigham Young University

09:20-09:40 — FrA4.2
Pitch and Roll Effects of On-Board Wind Measurements Using SUAS, pp. 1249-1254.
Hollenbeck, Derek — MESA Lab at UC Merced
Oyama, Madoka — MESA Lab at UC Merced
Garcia, Andrew — MESA Lab at UC Merced
Chen, YangQuan — University of California, Merced

09:40-10:00 — FrA4.3
Hybrid AutoGyro: Airborne Wind Energy Conversion Using Autorotation, pp. 1255-1260.
Flores, Jonathan — Umi Lafmia Cinvestav
Salazar, Sergio — Umi Lafmia Cinvestav
Lozano, Rogelio — University of Technology of Compiègne

10:00-10:20 — FrA4.4
Modeling of Aerodynamic Disturbances for Proximity Flight of Multirotors, pp. 1261-1269.
Jain, Karan — University of California, Berkeley
Fortmuller, Trey — University of California, Berkeley
Byun, Jaeseung — UC Berkeley
Makiharju, Simo — UC Berkeley
Mueller, Mark Wilfried — UC Berkeley

10:20-10:40 — FrA4.5
Wildfire Monitoring with Uneven Importance Using Multiple Unmanned Aircraft Systems, pp. 1270-1279.
Hu, Xiaolin — Georgia State University
Bent, John — Georgia State University
Sun, Jiawei — Georgia State University

10:40-11:00 — FrA4.6
Asymptotic Stability Controller Design of Three Fixed-Wing UAVs Formation with Windy Field, pp. 1280-1285.
Pu, Zhang — Northwestern Polytechnical University
Huifeng, Xue — School of Automation, Northwestern Polytechnical

	University
Shan, Gao	School of Automation, Northwestern Polytechnical University

FrB1 Heritage B

Risk Analysis and Risk-Based Methods for UAS (Invited Session)

Chair: Bertrand, Sylvain	ONERA
Co-Chair: la Cour-Harbo, Anders	Aalborg University
Organizer: Bertrand, Sylvain	ONERA
Organizer: la Cour-Harbo, Anders	Aalborg University

11:30-11:50 FrB1.1

Feasibility Analysis of UAV Operations for Monitoring of Infrastructure Networks: A Risk-Based Approach (I), pp. 1286-1295.

Bertrand, Sylvain	ONERA
Raballand, Nicolas	ONERA
Lala, Stephanie	ONERA
Flavien, Viguier	SNCF Réseau

11:50-12:10 FrB1.2

Modeling Unmanned Aerial System (UAS) Risks Via Monte-Carlo Simulation (I), pp. 1296-1305.

Rudnick-Cohen, Eliot	University of Maryland, College Park
Herrmann, Jeffrey	University of Maryland
Azarm, Shapour	University of Maryland, College Park

12:10-12:30 FrB1.3

Planning Unmanned Aerial System (UAS) Takeoff Trajectories to Minimize Third-Party Risk (I), pp. 1306-1315.

Rudnick-Cohen, Eliot	University of Maryland, College Park
Azarm, Shapour	University of Maryland, College Park
Herrmann, Jeffrey	University of Maryland

12:30-12:50 FrB1.4

Compromising Flight Paths of Autopiloted Drones, pp. 1316-1325.

Chen, Wenxin	University of Hawaii
Dong, Yingfei	University of Hawaii
Duan, Zhenhai	Florida State University

12:50-13:10 FrB1.5

Safe Decision Making for Risk Mitigation of UAS (I), pp. 1326-1335.

Castano, Lina	University of Maryland, College Park
Xu, Huan	University of Maryland

FrB2 Heritage A

Autonomy II (Regular Session)

Chair: Rodriguez Cortes, Hugo	CINVESTAV-IPN

11:30-11:50 FrB2.1

Radius of Turn and Flight Path Angle Estimation from Unmanned Aircraft Flight Trajectories, pp. 1336-1343.

Benders, Sebastian	DLR Braunschweig
Koch, Simon	Bundeswehr University Munich

11:50-12:10 FrB2.2

A Convolutional Neural Network Vision System Approach to Indoor Autonomous Quadrotor Navigation, pp. 1344-1352.

Garcia, Adriano	Binghamton University
Mittal, Sandeep	Binghamton University
Kiewra, Edward	SUNY Binghamton
Ghose, Kanad	SUNY-Binghamton, Dept. of Computer Science

12:10-12:30 FrB2.3

Flying through Gates Using a Behavioral Cloning Approach, pp. 1353-1358.

Rodriguez Hernandez, Erick	Instituto Politecnico Nacional
Vasquez-Gomez, Juan Irving	Consejo Nacional De Ciencia Y Tecnología
Herrera Lozada, Juan Carlos	Instituto Politécnico Nacional

12:30-12:50 FrB2.4

Monocular SLAM Position Scale Estimation for Quadrotor Autonomous Navigation, pp. 1359-1364.

Rodriguez Cortes, Hugo	CINVESTAV-IPN
Gómez-Casasola, Alejandro	CINVESTAV
Luis Daniel, Nieto-Hernandez	CINVESTAV-IPN

12:50-13:10 FrB2.5

Gaussian Mixture Model (GMM) Based Dynamic Object Detection and Tracking, pp. 1365-1371.

Hariharan Anand, Vishnu	TATA COnsultancy Services
Pushp, Durgakant	TATA COnsultancy Services
Raj, Rishin	TCS Research and Innovation Labs
Das, Kaushik	TATA Consultancy Service

13:10-13:30 FrB2.6

Towards a Weather Analysis Software Framework to Improve UAS Operational Safety, pp. 1372-1380.

Lundby, Tobias	University of Southern Denmark
Christiansen, Martin Peter	University of Southern Denmark
Jensen, Kjeld	University of Southern Denmark

FrB3 Heritage C

UAS Navigation II (Regular Session)

Chair: Fossen, Thor I.	Norwegain Univ. of Sci and Technology

11:30-11:50 FrB3.1

Approximating UAV and Vision Feature Point Correlations *in a Simplified SLAM Problem*, pp. 1381-1388.

Lewis, Jeffrey	Georgia Institute of Technology
Johnson, Eric	Pennsylvania State University

11:50-12:10 FrB3.2

Null Space Based Formation Control for a UAV Landing on a UGV, pp. 1389-1397.

Mafra Moreira, Mauro Sergio	Federal University of Espírito Santo
Brandao, Alexandre Santos	Federal University of Vicosa
Sarcinelli-Filho, Mário	Federal University of Espirito Santo

12:10-12:30 FrB3.3

Field Test Results of GNSS-Denied Inertial Navigation Aided by Phased-Array Radio Systems for UAVs, pp. 1398-1406.

Gryte, Kristoffer	Norwegian University of Science and Technology
Bryne, Torleiv Håland	Norwegian Univ. of Science and Technology
Albrektsen, Sigurd M	SINTEF Digital
Johansen, Tor Arne	Norwegian University of Science and Technology

12:30-12:50 FrB3.4

UAV Based Survivor Search During Floods, pp. 1407-1415.

Ravichandran, Rahul	Indian Institute of Science, Bangalore
Ghose, Debasish	Indian Institute of Science
Das, Kaushik	TATA Consultancy Service

12:50-13:10 FrB3.5

Robust Navigation System for UAVs in GNSS and Magnetometer-Denied Environments, pp. 1416-1424.

Mathisen, Paal Holthe	Norwegian University of Science and Technology
Fossen, Thor I.	Norwegian University of Science and Technology

13:10-13:30 FrB3.6

Pose Estimation of UAVs Based on INS Aided by Two Independent Low-Cost GNSS Receivers, pp. 1425-1435.

Sollie, Martin Lysvand	The Norwegian University of Science and Technology
Bryne, Torleiv Håland	Norwegian Univ. of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology

FrB4 Savannah

UAS Testbeds (Regular Session)

Chair: Theilliol, Didier	University of Lorraine
Co-Chair: Ahmad, Shakeeb	University of New Mexico

11:30-11:50 FrB4.1

A New Facility for UAV Testing in Climate-Controlled Environments, pp. 1436-1444.

Scanavino, Matteo	Politecnico Di Torino
Vilardi, Andrea	Eurac Research
Guglieri, Giorgio	Politecnico Di Torino

11:50-12:10 FrB4.2

Pitching Moment Analysis and Adjustment for Tilt-Wing UAV in VTOL Mode, pp. 1445-1450.

Sanchez-Rivera, Luz	Umi Lafmia Cinvestav
Lozano, Rogelio	University of Technology of Compiègne
Arias Montano, Alfredo	IPN ESIME Ticoman

12:10-12:30 FrB4.3

Control of a PVTOL with Tilting Rotors, pp. 1451-1457.

Offermann, Alexis	Heudiasyc Lab. 7253, Université De Technologie De Compiègne
Castillo, Pedro	Unviersité De Technologie De Compiègne
De Miras, Jérôme	Université De Technologie De Compiègne

12:30-12:50 FrB4.4

A Full Distributed Multipurpose Autonomous Flight System Using 3D Position Tracking and ROS, pp. 1458-1466.

Gargioni, Gustavo	Virginia Polytechnic Institute and State University
Peterson, Marco	Virginia Polytechnic Institute and State University
Persons, Jeffrey	Virginia Polytechnic Institute and State University
Schroeder, Kevin	Virginia Polytechnic Institute and State University
Black, Jonathan	Virginia Polytechnic Institute and State University

12:50-13:10 FrB4.5

Real-Time Quadrotor Navigation through Planning in Depth Space in Unstructured Environments, pp. 1467-1476.

Ahmad, Shakeeb	University of New Mexico
Fierro, Rafael	University of New Mexico

13:10-13:30 FrB4.6

ROS-MAGNA, a ROS-Based Framework for the Definition and Management of Multi-UAS Cooperative Missions, pp. 1477-1486.

Millán Romera, José Andrés	University of Seville
Perez-Leon, Hector	University of Seville
Castillejo-Calle, Alejandro	University of Seville
Maza, Ivan	Universidad De Sevilla
Ollero, Anibal	Universidad De Sevilla

ICUAS'19 Book of Abstracts

Technical Program for Wednesday June 12, 2019

WeA1	Heritage B
Path Planning I (Regular Session)	
Chair: Sharma, Rajnikant	University of Cincinnati
Co-Chair: Rathinam, Sivakumar	Texas A & M University

10:00-10:20 WeA1.1

Onboard Generation of Optimal Flight Trajectory for Delivery of Fragile Packages, pp. 1-8

Yuan, Weihong — Concordia University
Rodrigues, Luis — Concordia University

Real-time onboard flight trajectory generation is of great importance for all kinds of flying vehicles. This paper proposes a method to generate the trajectory, which minimizes the damage due to flight motion to a fragile package. The proposed methodology has several potential applications including drone organ delivery. A similar procedure can also be used in applications where the objective is to maximize passenger comfort during flight. An analytical solution of the optimal trajectory generation problem is derived under arbitrary two-point boundary value constraints. An approach to solve for the optimal flight time is also proposed, which can be easily implemented on common embedded processors. The algorithm is extended to guarantee that a peak velocity constraint is verified. The effects of a parameter called the cost index on the optimal solution are also discussed. Examples show how the procedure can be used in a specific application.

10:20-10:40 WeA1.2

Smooth Path Planning for Fixed-Wing Aircraft in 3D Environment Using a Layered Essential Visibility Graph, pp. 9-18

D'Amato, Egidio — University of Campania
Notaro, Immacolata — University of Campania "L. Vanvitelli"
Blasi, Luciano — Università Degli Studi Della Campania "L.Vanvitelli"
Mattei, Massimiliano — Seconda Università Di Napoli

This paper deals with the problem of flight path planning for unmanned fixed-wing air vehicles (UAVs) in complex 3D environments. Flight paths must be compliant with both mission constraints defined in terms of no-fly zones, obstacles and destination points and aircraft performance constraints such as maximum flight path angle and minimum turn radius. Trajectory generation is addressed as a minimum cost path search using a novel layered Essential Visibility Graph whose arcs and corresponding weights are obtained via an efficient branching algorithm to reduce computational time. The resulting path is a piecewise trajectory composed by only circular arcs and straight segments, according to Dubins paradigm. To prove the effectiveness of the proposed method, operational scenarios derived from real terrain morphology have been used.

10:40-11:00 WeA1.3

Hu-Moment-Based Autonomous Landing of a UAV on a Hemispherical Dome, pp. 19-25

K, Ravi Chandra — Indian Institute of Technology - Madras
Ghosh, Satadal — Indian Institute of Technology - Madras

In this paper, a vision-based autonomous landing system for a fixed wing unmanned aerial vehicle (UAV) is proposed for landing on a three-dimensional structure, which acts as an arrested landing mechanism and provides a strong visual cue for the camera to be detected easily. In particular, a red-colored hemispherical inflated air-bag (dome) has been considered as the visual cue in this paper. Moment-based shape descriptor called Hu-moments are leveraged for accurate detection of the dome. Characterization of these moments with horizontal and vertical distance of the UAV from the dome that is used to reliably detect the dome even at large distances is performed using software experiments. The proposed algorithm needs only a monocular camera and a processing unit on-board and hence is cost-effective and also applicable in GPS-denied environments. The proposed algorithm is simulated in a combined environment of V-Realm builder and MATLAB. Simulation results are presented to validate the presented algorithm for autonomous landing. This algorithm is also easily extendable to different colors and shapes of 3D structures.

11:00-11:20 WeA1.4

Nonlinear Model Predictive Control to Aid Cooperative Localization, pp. 26-32

Manoharan, Amith — IIIT Delhi
Sharma, Rajnikant — University of Cincinnati
Sujit, P. B — IIITD

This paper proposes a nonlinear model predictive control (NMPC) scheme to tackle the problem of localization and path planning of a group of unmanned aerial vehicles (UAVs) in global positioning system (GPS) denied environments. It is assumed that the UAVs can cooperate by sharing information among themselves. It is also assumed that the area under consideration contains some landmarks with known locations. The NMPC computes the optimal control inputs for the vehicles such that the vehicles cooperate to transit from a source location to a destination while choosing a path that will cover enough landmarks for localization. An Extended Kalman Filter (EKF) is used to estimate the vehicle positions using only relative bearing measurements. The efficacy of the proposed method was evaluated through numerical simulations, and the results are discussed.

11:20-11:40 WeA1.5

Landmark Placement for Cooperative Localization and Routing of Unmanned Vehicles, pp. 33-42

Wang, Bingyu — Texas A&M University
Rathinam, Sivakumar — Texas a & M University
Sharma, Rajnikant — University of Cincinnati

Most of the routing algorithms for unmanned vehicles rely on Global Positioning System (GPS) information for localization. However, disruption of GPS signals, by intention or otherwise, can render these algorithms ineffective. Known landmark information can aid localization in GPS-denied environments and cooperative localization can add more benefits to multiple vehicles. As resource constraints usually exist in practical applications, this article provides a way to optimally place additional landmarks to aid cooperative localization. Specifically, given a fleet of vehicles, a set of targets and a set of pre-planned paths for each of the vehicles, we aim to optimally place landmarks such that each of the vehicles can estimate its position and orientation by obtaining relative measurement information from at least two landmarks, and the landmark placement cost is minimized. Based on the relative position measurement graph, an integer linear program and its relaxations are presented. The performance of the proposed methodology is evaluated and compared through extensive simulation results.

11:40-12:00 WeA1.6

Encirclement of Moving Targets Using Relative Range and Bearing Measurements, pp. 43-50

Jain, Puneet	BYU
Peterson, Cameron	Brigham Young University

This paper presents a controller that uses relative range and bearing measurements to steer unmanned aerial vehicles (UAVs) to circular trajectories around a constant velocity target. Estimates of the range rate and angular rate to the target are used to improve the error in the range and bearing. For moving targets, their velocity is also estimated and used in the control law. Theoretical proofs using Lyapunov theory for stationary targets and feedback linearization for moving targets are provided. Numerical simulations show vehicles converging to circular formations around both stationary and moving targets.

WeA2	Heritage A
Swarms I (Regular Session)	
Chair: Pack, Daniel	University of Tennessee at Chattanooga
Co-Chair: Tsourdos, Antonios	Cranfield University

10:00-10:20	WeA2.1

Software Defined Network Based Architecture to Improve Security in a Swarm of Drones, pp. 51-60

Guerber, Christophe	ENAC
Larrieu, Nicolas	ENAC
Royer, Mickaël	ENAC

With the trend of developing more and more applications for Unmanned Aerial Vehicles (UAV), several research projects have considered new missions where single UAVs are replaced by swarms of drones. Although today regulations do not take into account such scenarios, implementation of an efficient security policy appears mandatory before operating a swarm of drones in open spaces. Consequently, this paper introduces an architecture for providing security features through the use of software defined network (SDN) technologies. To validate our approach, we compare the routing performance of our architecture with a classical solution based on the AODV routing protocol and the use of iptables rules. The results confirm the suitability of a SDN solution in this context. Finally, we present how it may be used to improve network security for a swarm of cooperative drones.

10:20-10:40	WeA2.2

Efficient Decentralized Task Allocation for UAV Swarms in Multi-Target Surveillance Missions, pp. 61-68

Li, Teng	Cranfield University
Shin, Hyo-Sang	Cranfield University
Tsourdos, Antonios	Cranfield University

This paper deals with the large-scale task allocation problem for Unmanned Aerial Vehicle (UAV) swarms in surveillance missions. The task allocation problem is proven to be NP-hard which means that finding the optimal solution requires exponential time. This paper presents a practically efficient decentralized task allocation algorithm for UAV swarms based on lazy sample greedy. The proposed algorithm can provide a solution with an expected optimality ratio of at least p for monotone submodular objective functions and of $p(1 - p)$ for non-monotone submodular objective functions. The individual computational complexity for each UAV is $O(pr^2)$, where $p \in (0,0.5]$ is the sampling probability, r is the number of tasks. The performance of the proposed algorithm is testified through digital simulations of a multi-target surveillance mission. Simulation results indicate that the proposed algorithm achieves a comparable solution quality to state-of-the-art algorithms with dramatically less running time. Moreover, a trade-off between the solution quality and the running time is obtained by adjusting the sampling probability.

10:40-11:00	WeA2.3

Cooperative Target Tracking by Altering UAVs' Linear and Angular Velocities, pp. 69-78

Ma, Lili	New York City College of Technology

This paper addresses cooperative target tracking of a moving ground vehicle using a fleet of unmanned aerial vehicles (UAVs). This work extends our earlier results on two aspects. First, a different formation pattern, i.e., a uniform spacing formation, is incorporated into the cooperative target tracking task. Different from the balanced circular formation achieved earlier where all UAVs spread evenly over a circle, all UAVs can now spread evenly over a portion of a circle, instead of the full circle. The second extension is regarding how formations are achieved. In our past work, cooperative target tracking was obtained by altering each UAV's yaw rate, while each UAV's linear velocity was assumed to be constant. In the proposed new approach, tracking is still achieved by altering each UAV's yaw rate. Formation, on the other hand, is obtained by adjusting each UAV's linear velocity. Both the balanced circular formation and the uniform spacing formation can be obtained by either approach. MatLab simulations are presented to show the effectiveness of these two approaches in achieving both formations.

11:00-11:20	WeA2.4

A Fast, Robust and Decentralized Approach for Altitude De-Confliction of Multiple UAVs, pp. 79-85

Cao, Jiawei	National University of Singapore
Teo, Rodney	Temasek Laboratories, National University of Singapore
Huang, Sunan	National University of Singapore
Ren, Qinyuan	Zhejiang University

Multiple unmanned aerial vehicles (UAVs) are now able to complete a wide range of applications. The de-confliction of flight plans of multiple UAVs is essential in providing conflict-free plans for greater efficiency in completing the missions. Centralized de-confliction approaches have been proposed but they are limited by the requirement of a central agency. Therefore, this paper introduces a novel decentralized approach for altitude de-confliction of multiple UAVs. Simulation studies are conducted to show that this approach is fast and robust in handling dynamic changes during the mission.

11:20-11:40	WeA2.5

A Hybrid Algorithm for Modifying and Tracking Connectivity in UAV Teams, pp. 86-92

Trimble, James	University of Tennessee at Chattanooga
Pack, Daniel	University of Tennessee at Chattanooga
Ruble, Zachary	University of Tennessee Chattanooga

Algebraic connectivity is the second-smallest eigenvalue of the Laplacian matrix and can be used as a metric for the robustness and efficiency of a network. This connectivity concept applies to teams of multiple unmanned aerial vehicles (UAVs) performing cooperative tasks, such as arriving at a consensus. As a UAV team completes its mission, it often needs to control the network connectivity. The algebraic connectivity can be controlled by altering edge weights through movement of individual UAVs in the team, or by adding and deleting edges. The addition and deletion problem for algebraic connectivity, however, is NP-hard and caused multiple heuristic methods to be developed. A leading method, the greedy perturbation heuristic, is efficient but not always effective. An alternative method, the bisection method, is highly effective but less efficient. The primary contributions of this paper are identification of a set of features and a classifier for predicting when the greedy perturbation heuristic is successful, and presentation of a hybrid algorithm which combines these two methods to provide both effectiveness and efficiency.

11:40-12:00	WeA2.6

UAVs Formation Control with Dynamic Compensation Using Neuro Adaptive SMC, pp. 93-99

Rosales, Claudio Dario	University

Gimenez, Javier — CONICET
Rossomando, Francisco — CONICET - Universidad Nacional De San Juan
Soria, Carlos — Universidad Nacional De San Juan
Sarcinelli-Filho, Mário — Federal University of Espirito Santo
Carelli, Ricardo — Universidad Nacional De San Juan

This paper proposes a neuro-adaptive controller evolving in a sub-actuated formation. A formation controller based on the null space approach is defined to obtain the references for local controllers for each one of the quadrotors defined to the transportation task. Formation controller takes into account the transport of a cable-suspended load with two quadrotors considering collision avoidance, wind perturbations, and proper distribution of the load weight. A neuro-adaptive sliding mode control (SMC) controller is defined with the objective to achieve the references obtained by the formation controller. These adjustment laws were obtained through the Lyapunov stability criterion. Finally, numerical simulation shows the excellent performance of the proposed technique for trajectory tracking tasks in unknown navigation environment.

WeA3 Heritage C

Risk & Reliability (Regular Session)

Chair: Ciarletta, Laurent — Université De Lorraine, Loria

Co-Chair: Jensen, Kjeld — University of Southern Denmark

10:00-10:20 WeA3.1

Improving Redundancy and Safety of UTM by Leveraging Multiple UASs, pp. 100-110

Schwalb, Edward — MSC Software
Schwalb, Joseph

Reliability is one key challenge facing safe widespread integration of UASs within controlled airspaces. We explore architectures and operational concepts which can compensate for partial failures and bridge the reliability gap. Our exploration leads to an operational approach which leverages multiple UASs to achieve redundancies. We show the significant benefits of the approach to simultaneously reduce impact of localization errors, achieve better resilience under degraded communications, gracefully remove from airspace UAS compromised by cyber attacks, and improve conflict management. Our analysis is supported by a UTM simulation. The realism improvements of our simulation stem from implementation of Firmware In the Loop (FITL), Intent Control Loop (ICL) and of execution contingencies as concurrent high priority activities. Whereas the scope of the reliability challenges at the UTM level are immense, we hope that our approach can serve as a starting point.

10:20-10:40 WeA3.2

Monitor-Centric Mission Definition with Sophrosyne, pp. 111-119

Viard, Louis — Université De Lorraine
Ciarletta, Laurent — Université De Lorraine, Loria
Moreau, Pierre-Etienne — Université De Lorraine, CNRS, LORIA

The operations of Cyber-Physical Systems -- such as Unmanned Aircrafts -- are drastically evolving. Worked up legislations are enabling new kinds of tasks in complex environments, inducing a change of policy in mission definition. Handling the consequent risks not only calls for verification of both the system and its mission, but it also requires to keep watch on the gap between the real world and the models that were used to get these guarantees. Furthermore, fallback missions ought to be specified to mitigate the occurrence of undesired events.

We introduce Sophrosyne, a Domain-Specific Language for CPS operation that integrates monitors and alternative behaviors definition as part of the specification of missions. A simple geofence-related case study showcases how Sophrosyne eases the management of tangled fallbacks.

10:40-11:00 WeA3.3

*Game Theoretic Strategies for an Unmanned Aerial Vehicle Network Host under DDoS Attack**

Mairaj, Aakif — University of Toledo
Majumder, Subhrajit — University of Toledo
Javaid, Ahmad Y — The University of Toledo

Game theory involves the mathematical modeling of the strategic interaction between rational entities. One such example is the interaction between a hacker and the defense mechanisms of its target. There have been different kinds of attacks on an Unmanned Aerial Vehicle (UAV or drone) Network (UAVNet) or a Flying ad hoc network (FANET) in the recent past. The rational solution to such problems is identifying the strategies that can be chosen by the attacker, and selecting a defensive response that is most apt and intelligent while considering all the choices that a target's defensive mechanisms can make. This paper is an attempt to identify a game like situation, when a single UAV is under a DDoS attack, while a genuine UAVNet is trying to communicate with it. Two different cases of this common attack are simulated, namely, UDP flooding, and ICMP (Ping) flooding. In both cases, the intensity of these attacks is gauged with different choices made by the attacker and the target alike. Finally, the decisions that are conducive to the attacker and the victim are identified.

11:00-11:20 WeA3.4

A Methodology for Evaluating Commercial Off the Shelf Parachutes Designed for sUAS Failsafe Systems, pp. 120-128

Tofterup, Vincent Klyverts — University of Southern Denmark
Jensen, Kjeld — University of Southern Denmark

Many Small Unmanned Aerial Systems (sUAS) are incapable of meeting the safety requirements to provide a sufficient low risk of a fatality while operating above populous areas or gatherings. A recognized mitigation of this risk is a failsafe system that in the event that the sUAS is unable to maintain stable flight, terminates the flight and activates an emergency parachute. This paper proposes a methodology for assessment of Commercial Off the Shelf parachutes for sUAS failsafe systems. The methodology encompasses the evaluation criteria for the selection of parachutes based on a user-defined Maximum Takeoff Weight and the failure scenario tests for assessment of reliability and efficiency. The current standard specification on parachutes for sUAS published by the American Society of Testing and Materials has inspired the failure scenario tests. These failure scenario tests consist of a bench/destructive test and a full power cut test. The multirotor used for test of the proposed methodology is a ~2kg hexarotor. The results suggest the use of one specific parachute. Furthermore, the deployment time and impact energy have been estimated to be 1.2s and 21J, respectively. This impact energy suggests a probability of fatality of less than 0.01. This work is the first step towards selecting and evaluating parachute systems for sUAS. The proposed next steps are the refinement of the assessment of parachutes and increase of parachutes included in the failure scenario tests. Additionally, this will lead to the development of parachute recovery systems for sUAS with manual and autonomous triggering.

11:20-11:40 WeA3.5

Embedding Consequence Awareness in Unmanned Aerial Systems with Generative Adversarial Networks, pp. 129-134

Zhang, Guoxiang — University of California, Merced
Alcala, Jose — MESA Lab, University of California, Merced
Ng, Jeffrey — University of California, Merced
Chen, Mighty — MESA Lab, University of California, Merced

Wu, Xiangyu	UC Berkeley
Mueller, Mark Wilfried	UC Berkeley
Chen, YangQuan	University of California, Merced

Small unmanned aerial systems (sUAS) are becoming more prevalent, driven by consumer interest and their potential for revolutionizing aspects of commercial applications, such as delivery of urgent goods. The expected ubiquity of such systems raises concerns about their safety, and the ability of such autonomous systems to operate safely in densely populated areas (where their value will be greatest). In this paper, we outline a new framework aiming to add an additional layer of safety to aerial systems operated by a human pilot or autopilot by monitoring the UAVs environment for visual cues, and monitoring the human pilot for signs of distraction. The system will endow a UAS with the ability to reason about its safety, and the consequences of safety failures during its operation. The UAS will furthermore continuously reason about possible safety maneuvers in response to likely failures – in the event of an emergency, the vehicle can then execute its last safe maneuver, thus reducing the systems impending danger. Embedding consequence awareness in sUAS is an obvious appeal to safer and more insurable missions. For pilot skill level awareness, a method utilizing generative adversarial networks, which improves pilot skill level classification accuracy in our experiments, is proposed to compensate limited training data availability.

WeA4	Savannah
Control Architectures I (Regular Session)	
Chair: Sarcinelli-Filho, Mário	Federal University of Espirito Santo
Co-Chair: Kuchwa-Dube, Chioniso	University of the Witwatersrand

10:00-10:20 WeA4.1

Quadrotor-Based Aerial Manipulator Altitude and Attitude Tracking Using Adaptive Super-Twisting Sliding Mode Control, pp. 135-142

Kuchwa-Dube, Chioniso	University of the Witwatersrand
Pedro, Jimoh Olarewaju	University of the Witwatersrand

This paper presents the altitude and attitude tracking for a quadrotor-based aerial manipulator using adaptive super-twisting sliding mode control. The aerial manipulator model is derived analytically using the Newton-Euler formulation for the quadrotor and the recursive Newton-Euler formulation for the manipulator. The adaptive super-twisting sliding mode control for altitude and attitude tracking of the aerial manipulator is then presented. The controller is tested via simulation for altitude and attitude tracking with manipulator motion, including added disturbances and noise. The results for the adaptive super-twisting sliding mode control show better tracking performance, reduced chattering, and reduced control effort when compared to a standard super-twisting sliding mode control.

10:20-10:40 WeA4.2

Robust Control Architecture for Wind Rejection in Quadrotors, pp. 143-152

Verberne, Johannes	Embry-Riddle Aeronautical University
Moncayo, Hever	Embry-Riddle Aeronautical University

Current efforts at the Advanced Dynamics and Control Laboratory (ADCL) at Embry-Riddle Aeronautical University (ERAU) are focusing on the implementation of robust control laws for disturbance rejection in quadrotors. This paper describes the development of two types of control architectures in an effort to reject or minimize wind effects in quadrotor UAVs. The design of a novel extension of the classic Non-Linear Dynamic Inversion (NLDI) control architecture for wind disturbance rejection is presented. This is followed by the application of adaptive artificial neural networks (ANN) to augment the classic NLDI control law designed to correct inversion errors caused by wind disturbance. Models are presented along with a simulation environment for various wind generated forces and moments. Monte Carlo numerical simulations are performed to analyze the performance of the classic NLDI, extended NLDI and NLDI with ANN augmentation under wind conditions. Results show that the NLDI with ANN augmentation outperforms the classic and extended NLDI controllers.

10:40-11:00 WeA4.3

Input Shaped Trajectory Generation and Controller Design for a Quadrotor-Slung Load System, pp. 153-161

Fielding, Sean	McGill University
Nahon, Meyer	McGill University

Quadrotor-slung load systems offer a versatile method for transporting payloads. With these systems, it is particularly important to mitigate and manage unwanted payload swinging through the careful design of flight trajectories and controllers. Tracking input shaped trajectories for instance is an effective way to minimize post-flight swinging for rest-to-rest maneuvers by allowing some swinging motions during flight. In this paper, we first present a computationally simple method to generate input shaped quadrotor flight trajectories for non-rest-to-rest maneuvers. We then propose a controller to track these shaped trajectories and permit the associated payload swinging while also rejecting unwanted swinging disturbances. The path planner and controller are implemented in simulation and the performance of the controller is compared against two simpler controllers for an input shaped U-turn maneuver both with and without an initial swinging disturbance. The results of these simulations demonstrate the effectiveness of our path planner, while also showing that the proposed controller outperforms both baseline controllers considered.

11:00-11:20 WeA4.4

Adaptive Control for a Tilted-Motors Hexacopter UAS Flying on a Perturbed Environment, pp. 162-168

Arizaga-Leon, Jorge Manuel	Tecnologico De Monterrey
Castaneda, Herman	Tecnologico De Monterrey
Castillo, Pedro	Unviersité De Technologie De Compiègne

This manuscript presents the modeling and control for a tilted-motor hexacopter unmanned aircraft system, which is subject to external perturbations. A tilt angle for each rotor on the rotorcraft is considered allowing a fully-actuated system, capable to exert horizontal forces. Given the robustness properties and the management of control effort, the controller design is based on adaptive sliding mode technique providing stabilization and tracking of desired trajectories under a perturbed environment. Finally, numerical simulations show the feasibility and advantages of the proposed scheme.

11:20-11:40 WeA4.5

Architecture-Independent Quaternion-Based Attitude Planning and Control Allocation for Multirotors, pp. 169-177

Borges Farçoni, Leonardo	University of São Paulo
Terra, Marco Henrique	University of Sao Paulo at Sao Carlos
Inoue, Roberto Santos	Federal University of São Carlos

This paper presents an architecture-independent framework for multirotor simulation based on a dynamic model for non-reversible rotors, a quaternion-based attitude planning, and null-space-based control allocation algorithm. This approach can be of use when investigating different multirotor architectures' characteristics and control algorithms for them, avoiding spending effort on attitude planning and control allocation for each different case. The framework is compared to current solutions by pointing out the advantages of the approach used here. Simulation results of three different architectures are presented aiming to explore the algorithm's robustness, without change, to arbitrary and non-symmetric rotor positions; under, fully or

over-actuated architectures; and differently-sized rotors.

11:40-12:00 WeA4.6

Trajectory-Tracking of a Heterogeneous Formation Using Null Space-Based Control, pp. 178-186

Ernandes, Valentim — Universidade Federal De Vicosa
Sarcinelli-Filho, Mário — Federal University of Espirito Santo
Brandao, Alexandre Santos — Federal University of Vicosa

This work discusses a trajectory tracking task accomplished by a formation of two heterogeneous robots, namely a Pioneer 3-DX (UGV) and an AR.Drone 2.0 quadcopter (UAV). The control paradigm considers the formation as a virtual structure, here represented by a 3D straight line linking the two agents. The formation is characterized by the distance between the two robots and two angles, measured between the linking-line and the YZ and XZ planes. In this approach, the formation position coincides with the UGV position. The transformation between the robot to formation variables allows characterizing the motion and shape of the formation starting from the movement of the robots, or vice-versa. Then, a controller guides the formation and manages two conflicting subtasks (reach the desired robot position or keep the formation shape), whose priority is defined by the null space-based approach. Finally, real experiments validate the proposed approach during trajectory-tracking tasks for three scenarios, one assigning the highest priority to the formation position, another to the formation shape, and a last one, without any priority. In addition, we evaluated the formation behavior in failure situations in one of the robots.

WeB1 Heritage B

Path Planning II (Regular Session)

Chair: Rothmund, Sverre Velten — Norwegian University of Science and Technology

Co-Chair: Morrison, James R. — KAIST

15:00-15:20 WeB1.1

A 3D Mobility Model for Autonomous Swarms of Collaborative UAVs, pp. 187-195

Falomir, Ema — University of Bordeaux, THALES DMS France
Chaumette, Serge — LaBRI, Univ. Bordeaux / NFC-Interactive
Guerrini, Gilles — Thales DMS France

Collaboration between several Unmanned Aerial Vehicles (UAVs) can produce high-quality results in numerous missions, including surveillance, search and rescue, tracking or identification. Such a combination of collaborative UAVs is referred to as a swarm. These several platforms enhance the global system capabilities by supporting some form of resilience and by increasing the number and/or the variety of the embedded sensors. Furthermore, several UAVs organized in a swarm can (should the ground control station support this) be considered as a single entity from an operator point-of-view. We aim at using such swarms in complex and unknown environments, and in the long term, allow compact flights.

Dynamic path planning computation for each UAV is a major task to perform their mission. To define this path planning, we have implemented a three-dimensional (3D) mobility model for swarms of UAVs using both the Artificial Potential Fields (APF) principle and a global path planning method. In our model, the collaboration between the platforms is made by sharing information about the detected obstacles. To provide a significant validation of our mobility model, we have simulated real-world environments and real-world sensors simulator OMNeT++.

15:20-15:40 WeB1.2

Robust Multi-UAV Route Planning Considering UAV Failure, pp. 196-203

Patel, Ruchir — University of Maryland, College Park
Rudnick-Cohen, Eliot — University of Maryland, College Park
Azarm, Shapour — University of Maryland, College Park
Herrmann, Jeffrey — University of Maryland

This paper describes a robust multi-UAV route planning problem in which any one of the vehicles could fail during plan execution at any visited location. The UAVs must visit a set of fixed locations; if one UAV fails, the other vehicles must cover any unvisited locations. The objective is to optimize the worst-case cost. This paper formulates the problem with a min-sum objective (minimizing the total distance traveled by all vehicles) and a min-max objective (minimizing the maximum distance traveled by any vehicle). A Genetic Algorithm (GA) was used to find approximate robust optimal solutions on seven instances. The results show that the GA was able to find solutions that have better worst-case cost than the solutions generated by other approaches that were tested.

15:40-16:00 WeB1.3

Routing Problems for Reconnaissance Patrolling Missions, pp. 204-211

Rajan, Sudarshan — Texas A&M University
Sundar, Kaarthik — Texas A&M University
Gautam, Natarajan — Texas A&M University

This article introduces routing problems that arise in reconnaissance patrolling missions, where the focus is on improving the fidelity of information gathered from targets. The general problem is a multi-stage stochastic program where at each stage, additional nearby satellite targets might have to be visited to collect more information depending on the uncertainty associated with the information gathered from the original targets. In this paper, a preliminary two-stage version of a simple variant of the general problem is formulated and solved. Statistical bounds on the quality of the solution obtained for the two-stage problem are computed and the approach is compared with a deterministic counterpart. Finally, a plethora of relevant problem variants and future research directions are discussed.

16:00-16:20 WeB1.4

Risk-Based Obstacle Avoidance in Unknown Environments Using Scenario-Based Predictive Control for an Inspection Drone Equipped with Range Finding Sensors, pp. 212-221

Rothmund, Sverre Velten — Norwegian University of Science and Technology
Johansen, Tor Arne — Norwegian University of Science and Technology

This paper develops an obstacle avoidance strategy for inspection drones equipped with simple range finding sensors, such as radar or sonar. The obstacle avoidance strategy uses scenario-based model predictive control where the predicted outcomes of a set of possible control actions are evaluated. The action with the best predicted outcome amongst the safe options is chosen. The resulting behaviour is deemed safe if the probability of collision at each time-step in the prediction is lower than a given maximal accepted probability. The probability of collision is calculated by combining a probability density function of the position of the drone with an obstacle probability map generated by the range finding sensors. This constraint is checked at each step over the prediction horizon thus ensuring that the control action will give rise to safe behavior. The algorithm is implemented in a 2D case and tested with a simple model for the range finding sensors. Simulations show that the drone is able to avoid obstacles and that the drone will change speed or take detours to avoid flying in potentially dangerous areas to mitigate risk. The algorithm is designed for avoiding obstacles along a pre-planned path. The pre-planned path is assumed to be generally good, but might be unsafe or not take some unknown obstacles into account. If the

pre-planned path goes through a larger convex area or does not take a large obstacle into account, then this algorithm might not find a way around the obstacle and the drone will stop at a safe distance. The path of the drone must then be re-planned taking these obstacles into account. The resulting obstacle avoidance strategy guarantees safe behavior, which enables higher level controllers or human planners to plan a path based on lacking.

16:20-16:40	WeB1.5

Flight Patterns for Clouds Exploration with a Fleet of UAVs, pp. 222-228

Verdu, Titouan	ENAC, Université De Toulouse
Hattenberger, Gautier	ENAC
Lacroix, Simon	LAAS/CNRS

Modeling the cloud micro-physics processes is essential to improve our understanding in climate changes and reduce the uncertainties in weather predictions. Aircrafts, remote sensing and ground-based infrastructures provide either sparse or large spatial measurements that are not sufficient to develop fine cloud models. UAVs have shown their ability to collect relevant cloud in-situ measures and can be even more efficient when deployed in fleets. However, collecting relevant cloud data call for specific trajectories: this paper introduces a series of flight patterns dedicated to cloud exploration by a fleet of UAVs. The patterns definition comprises both a priori geometric information and real-time reactions to collected data. Results in simulated clouds assess their relevance for cloud in situ data collection.

16:40-17:00	WeB1.6

On Systems of UAVs for Persistent Security Presence: A Generic Network Representation, MDP Formulation and Heuristics for Task Allocation, pp. 229-236

Kim, Minjun	KAIST
Morrison, James R.	KAIST

We develop a task allocation method for persistent UAV security presence (PUSP). UAVs accompany customers and thereby provide security services to them. Key features incorporated are randomness in the arrival of customers and travel durations. We formalize our system as a general network consisting of nodes, arcs, UAVs and routes. From the network, we automatically generate a Markov decision process (MDP) model and simulator. The MDP formulation can be solved exactly only for small problems. In such cases, we employ classic value iteration to obtain optimal polices. To address larger systems consisting of more resources, we develop a greedy task assignment heuristic (GTAH) and simplified MDP heuristics (SMH). Numerical studies demonstrate that the GTAH is approximately 10% suboptimal and that the SMH is about 4% suboptimal with regard to small-scale problems. For larger problems (~10^90 states), the performance of the SMH is approximately 3% better than that of the GTAH.

WeB2	Heritage A
Swarms II (Regular Session)	
Chair: Castaneda, Herman	Tecnologico De Monterrey
Co-Chair: Castillo, Pedro	Unviersité De Technologie De Compiègne

15:00-15:20	WeB2.1

A Computational Tool to Assess Communications' Range and Capacity Limits of Ad-Hoc Networks of UAVs Operating in Maritime Scenarios, pp. 237-243

Oliveira, Tiago	Portuguese Air Force
Agamyrzyansc, Anna	Portuguese Air Force
Correia, Luis	IST/INESC-ID, University of Lisbon

This paper presents a new computational tool that can be applied to the analysis of communications range and capacity limits of a team of Unmanned Aerial Vehicles (UAVs) operating in ad-hoc networks. The proposed tool is implemented using a modular approach and provides the maximum range of the UAV network, depending on the number of UAVs, on the video data rate of each UAV, and on the number of simultaneous video transmissions. Two application scenarios in maritime environments are specifically considered: 1) collaborative search and tracking of targets and 2) circular formation flight for detection of external threats to ship convoys. Numerical simulations are presented, allowing to characterize the performance of the network. Preliminary flight test results using two ANTEX-X02 UAVs from the Portuguese Air Force (PoAF) are also included.

15:20-15:40	WeB2.2

Probabilistic Search and Track with Multiple Mobile Agents, pp. 244-253

Papaioannou, Savvas	KIOS CoE, University of Cyprus
Kolios, Panayiotis	University of Cyprus
Theocharides, Theocharis	University of Cyprus
Panayiotou, Christos	University of Cyprus
Polycarpou, Marios M.	University of Cyprus

In this paper we are interested in the task of searching and tracking multiple moving targets in a bounded surveillance area with a group of autonomous mobile agents. More specifically, we assume that targets can appear and disappear at random times inside the surveillance region and their positions are random and unknown. The agents have a limited sensing range, and due to sensor imperfections, they receive noisy measurements from the targets. In this work we utilize the theory of random finite sets (RFS) to capture the uncertainty in the time-varying number of targets and their states and we propose a decision and control framework, in which the mode of operation (i.e. search or track) as well as the mobility control action for each agent, at each time instance, are determined so that the collective goal of searching and tracking is achieved. Extensive simulation results demonstrate the effectiveness and performance of the proposed solution.

15:40-16:00	WeB2.3

Backstepping-Based Controller for Flight Formation, pp. 254-260

Flores Palmeros, Pedro	Cinvestav IPN
Castillo, Pedro	Unviersité De Technologie De Compiègne
Castanos, Fernando	Cinvestav Del IPN

A Backstepping controller based on SE(3) for achieving multi-agents consensus and flight formation of a drones fleet is developed in this paper. The controller is obtained using the nonlinear model of the quadrotor and derived with virtual inputs to converge the fleet to desired references. The stability analysis of the controller is analyzed and proved with the Lyapunov theory. Emulations of the control algorithm are carried out for validating the well performance of the closed-loop system.

16:00-16:20	WeB2.4

Containment Control Based on Adaptive Sliding Mode for a MAV Swarm System under Perturbation, pp. 261-266

Katt, Carlos	Tecnologico De Monterrey
Castaneda, Herman	Tecnologico De Monterrey

This paper addresses an adaptive containment control for a MAV swarm system, which is subject to perturbations. The graph theory formulation is using to establish the roles of leaders and followers as well as their interaction, and then, an adaptive sliding mode controller is proposed in order to keep the containment in presence of external disturbances on their desired relative positions with respect to the leaders while tracking a time variant trajectory. The advantage of this control method relies on its robustness while drive its adaptive gain as uncertainties/perturbations appear. Simulations results illustrate the feasibility and advantages of the proposed strategy.

16:20-16:40	WeB2.5

Time-Delay Control of a Multi-Rotor VTOL Multi-Agent System towards Transport Operations, pp. 267-274

Alvarez Muñoz, Jonatan Uziel	Université De Grenoble, GIPSA-Lab
Castillo Zamora, Jose de Jesus	IPSA & Laboratoire Des Signaux Et Systèmes
Escareno Castro, Juan Antonio	XLIM Research Institute - University of Limoges
Boussaada, Islam	IPSA & Laboratoire Des Signaux Et Systèmes
Méndez-Barrios, César Fernando	Universidad Autónoma De San Luis Potosí
LABBANI, Ouiddad	XLIM Research Institute - ENSIL-ENSCI - University of Limoges

The present work deals with a consensus control for a multi-agent system composed by a mini Vertical Take-off and Landing (VTOL) rotorcrafts by means of a controller based on time-delay parametrization. The VTOL system modeling is presented using the quaternion parametrization to develop the attitude-stabilizing law of the aerial robots. The vehicle position dynamics are extended to the multi-agent case where a time-delayed PID control is designed in order to achieve general consensus in terms of formation control of the system. Finally, a detailed simulation study is presented to validate the effectiveness of the proposed control strategy, where it also considered a collective interaction.

16:40-17:00	WeB2.6

Formation Control and Navigation of a Quadrotor Swarm, pp. 275-282

Fernando, Malintha	Indiana University
Liu, Lantao	Indiana University

We investigate the formation control of a team of homogeneous quadrotor aerial vehicles. We formulate the multi-quadrotor formation as a rigid body that moves in the space with 4 degrees of freedom, which greatly reduces the modelling complexity. By combining a high-level coordination layer with the low-level control layer, aggressive formation motion can be achieved. The quadrotor formation is navigated to move in 3D space by following a reference trajectory that is outlined by a series of discrete waypoints specified as external inputs. We have validated our method through both simulations and real quadrotor experiments. Our results show that the quadrotor formation can move as fast as $2.5m/s$ within a confined indoor environment where the designated formations are always well maintained.

WeB3	Heritage C
UAS Applications I (Regular Session)	
Chair: Vitzilaios, Nikolaos	University of South Carolina

15:00-15:20	WeB3.1

Discrete-Time Control of LineDrone: An Assisted Tracking and Landing UAV for Live Power Line Inspection and Maintenance, pp. 283-289

Hamelin, Philippe	Hydro-Québec
Mirallès, François	Hydro-Québec
Lambert, Ghislain	Hydro-Québec
Lavoie, Samuel	Hydro-Québec
Pouliot, Nicolas	Hydro-Québec
Montfrond, Matthieu	Hydro-Québec
Montambault, Serge	Hydro-Québec

This paper presents the design of a discrete-time control algorithm for power line tracking and assisted landing of Hydro-Quebec's LineDrone robot, a multirotor unmanned aerial vehicle (UAV) designed to land on and roll along live power lines. The algorithm automatically aligns the UAV with the cable while the pilot remains in control of the vertical and longitudinal positions, hence facilitating landing by having fewer degrees of freedom on which the pilot must focus. Emphasis is placed on the design of the discrete-time control law, which results in a closed-form algebraic solution of gains for given transient specifications. The proposed control system is also designed to meet the requirements of operation near live lines, which means that the system is immune to electromagnetic interference. The proposed control algorithm is experimentally validated on LineDrone hybrid UAV under real outdoor conditions.

15:20-15:40	WeB3.2

Autonomous Aerial Robotic Exploration of Subterranean Environments Relying on Morphology-Aware Path Planning, pp. 290-296

Papachristos, Christos	University of Nevada Reno
Khattak, Shehryar	University of Nevada, Reno
Mascarich, Frank	University of Nevada, Reno
Dang, Tung	University of Nevada, Reno
Alexis, Kostas	University of Nevada, Reno

In this work the challenge of autonomous navigation, exploration and mapping in underground mines using aerial robots is considered. Despite the paramount importance of underground mine accessing, the relevant challenges of sensor degradation (darkness, dust, smoke) and broadly stringent navigation conditions due to particularly narrow geometries across very long drifts render typical navigation and planning methods insufficient. Towards a comprehensive solution, we present and extensively field test a variety of robot realizations implementing different sensor fusion and path planning strategies inside underground mine settings. We conclude and propose an optimized multi-modal sensor fusion approach combined with a local environment morphology-aware exploration path planning strategy that in their combination provide superior results in terms of navigation resourcefulness and resilience, exploration efficiency and mapping accuracy despite the large set of challenging conditions encountered.

15:40-16:00	WeB3.3

Building Mosaics Using Images Autonomously Acquired by a UAV, pp. 297-304

Amorim, Lúcio André	Corpo De Bombeiros Militar Do Espírito Santo
Vassallo, Raquel	Federal University of Espirito Santo
Sarcinelli-Filho, Mário	Federal University of Espirito Santo

In this work we discuss an application related either to firefighting or to precision agriculture, which consists in building mosaics from aerial images acquired by an Unmanned Aerial Vehicle - a UAV, specifically a quadrotor. The odometry of the vehicle is used to help estimating the position of each new image to be included in the mosaic, and, thus, matching features present in the overlapping areas of the images. Navigation and image acquisition are done autonomously, with a pre-set route in which a set of waypoints is defined. Images are acquired while the quadrotor keeps itself hovering in each waypoint, after testing such a possibility against the option correspondent to get images with the quadrotor flying between two of them. For choosing between these two cases the mosaics are built and compared, leading to the decision of using the images acquired with the quadrotor hovering over each waypoint. To improve the mosaics built, information provided by a GPS module onboard the UAV about the position from where each image is acquired is also included in the mosaic, to allow getting better information about the area under inspection, which can be, for instance, an area in which fire outbreaks are being searched or a farming area being inspected.

16:00-16:20	WeB3.4

Planning System for Integrated Autonomous Infrastructure Inspection Using UAVs, pp. 305-312

Ramon Soria, Pablo	University of Seville
Perez Jimenez, Manuel	Universidad De Sevilla
Arrue, B.C.	Escuela Superior De Ingenieros, Universidad De Sevilla
Ollero, Anibal	Universidad De Sevilla

Structural inspection is a critical task nowadays. The huge amount of civil infrastructures and industrial facilities makes tedious the task of continuously track their health. This task requires several resources and takes excessive time to operators. This article contributes with a complete system to facilitate the automation of infrastructure inspection using Unmanned Aerial Vehicles (UAVs). The system autonomously controls the UAV towards a set of inspection points chosen by the operators, allowing them to inspect unreachable locations in seconds. A planning algorithm computes the best location to observe the target point and calculates feasible safe trajectories for the UAV to reach each of the locations. All the system is packed into an human-machine interface which facilitates the inspection tasks.

16:20-16:40	WeB3.5

Dynamic Structural Health Monitoring Using a DIC-Enabled Drone, pp. 313-319

Kalaitzakis, Michail	University of South Carolina
Kattil, Sreehari Rajan	University of South Carolina
Vitzilaios, Nikolaos	University of South Carolina
Rizos, Dimitris	University of South Carolina
Sutton, Michael	University of South Carolina

The structural assessment of infrastructure components, such as bridges and railroad tracks, is crucial for their safe operation. The process is expensive and time-consuming given the large amount of structures that require systematic inspection. Over the last decades, non-contact measurement techniques have been developed that allow remote evaluation of a structure that is accurate and not labor intensive. One of the techniques in this field is Digital Image Correlation (DIC), that has proven to be an accurate method to measure 2D and 3D shape and deformation fields in structures. In current applications, DIC makes use of a stationary stereo vision camera system that is rigidly placed close to the inspected object. In this paper, an autonomous system of a drone equipped with a DIC camera system, that successfully performs remote structural evaluation of a railroad tie, is presented. This development significantly increases the portability of DIC, resulting in faster deployment of DIC/Drone measurement systems that can reach remote locations and perform fast and accurate structural health monitoring.

16:40-17:00	WeB3.6

UAV Aided Dynamic Routing of Resources in a Flood Scenario, pp. 320-327

KASHYAP, ABHISHEK	Indian Institute of Science, Bangalore
Ghose, Debasish	Indian Institute of Science
Prathyush, Purushothama Menon	University of Exeter
Sujit, P. B	IIITD
Das, Kaushik	TATA Consultancy Service

This paper addresses the problem of dynamic routing of resources in a fast-changing flood scenario using land vehicles aided by Unmanned Aerial Vehicles (UAVs). The road network of the area is modelled as a graph network with travel time and road capacities and vehicles containing the resources are routed through the roads from the relief centers, or source nodes, to the disaster affected areas, or destination nodes, by considering the goods as a dynamic flow in the road network. The quickest flow algorithm is initially implemented to solve this basic transportation problem. A team of UAVs survey the flooded area to check the safety of the chosen routes and monitor the status of the vehicles over time. Changes in the routing parameters, which can hinder the transportation process, are communicated and the goods are re-routed by considering the current position of the vehicles spread on the road network as individual sources in the problem and then by applying the earliest arrival flows algorithm for a multiple source problem. Simulations are performed on virtual and real street environments considering various scenarios which show the effectiveness of the methodology.

WeB4	Savannah
Control Architectures II (Regular Session)	
Chair: Sharma, Rajnikant	University of Cincinnati

15:00-15:20	WeB4.1

Design and Implementation of an Artificial Neural Network Wavelet for Load Transportation with Two Unmanned Aircraft Systems, pp. 328-335

Juarez Vargas, Cesar Eduardo	Autonomous University of Hidalgo State
Suárez Cansino, Jóel	Autonomous University, Hidalgo
Espinoza Quesada, Eduardo Steed	Center for Research and Advanced Studies of the National Polytec
GARCIA CARRILLO, Luis Rodolfo	Texas A&M University - Corpus Christi
Ramos-Velasco, Luis Enrique	Universidad Politécnica Metropolitana De Hidalgo, México
Lozano, Rogelio	University of Technology of Compiègne

This paper deals with the problem of enabling a team of two Unmanned Aircraft Systems to perform an autonomous load transportation task. We propose a strategy whose main objective is to ensure a stable flight of the team of agents when cooperatively transporting the load. The strategy is based on the implementation of a neural network controller and a neural network estimator, using wavelet activation functions in combination with a cooperative multi-agent control approach. To show the effectiveness and applicability of the proposed framework, a real time experimental implementation is presented. Additionally, a comparison with respect to a classic control law is also provided, demonstrating the superior performance attained when adopting the proposed controller.

15:20-15:40	WeB4.2

Robustness Studies on Quadrotor Control, pp. 336-344

Brossard, Jérémy	ÉTS
Bensoussan, David	ETS University of Quebec
Landry, René Jr.	Superior Technology School
Hammami, Maher	Faculté Des Sciences De Sfax - Tunisie

A new control method (B control) that guarantees fast and robust control for unstable invertible plants has been recently proposed and tested. This method enables getting a time response with minimal overshoot and settling time equal to rise time while keeping good stability margins. Demonstration of this control method has been published. In the present work, we apply this control method to a non-linear model of a quadcopter. The fastest orientation dynamic of the drone is controlled separately from the translation dynamic which is slower. The performance of this B controller is compared to a µ-synthesis and PID controller. MatLab simulations show slightly better performances for B control compared to µ-synthesis in the time domain. However, µ-synthesis gives better results for steady flight in the presence of perturbations when compared to B controller, although it involves higher motor velocities. PID performance in the time domain is less than satisfactory as it evolves excessive gains.

15:40-16:00	WeB4.3

Flight Control Methods for Multirotor UAS, pp. 345-353

Ackerman, Kasey — NASA Langley Research Center
Gregory, Irene — NASA Langley Research Center
Hovakimyan, Naira — UIUC

This paper presents several control methodologies for multirotor aircraft. It details simple control laws for body-axis rate or quaternion attitude tracking and provides an interpretation of control gains in terms of natural frequency and damping of the closed-loop system. Additionally, it describes a method for tuning the control gains via LQR. Control laws for translational dynamics, based on a nonlinear path-following control architecture, are also presented. Vertical and horizontal tracking are partially decoupled by dynamically scaling the thrust command, and an attitude protection method is added to prevent commands that would result in undesirable vehicle attitudes. The path-following input and error definition are modified to achieve position tracking, velocity tracking, or path-following control.

16:00-16:20 WeB4.4

A Survey of Artificial Neural Networks with Model-Based Control Techniques for Flight Control of Unmanned Aerial Vehicles, pp. 354-363

Gu, Weibin — University of Denver
Valavanis, Kimon — University of Denver
Rutherford, Matthew — University of Denver
Rizzo, Alessandro — Politecnico Di Torino

Model-based control (MBC) techniques have been successfully developed for flight control applications of unmanned aerial vehicles (UAVs) in recent years. However, their heavy reliance on the fidelity of the plant model coupled with high computational complexity make the design and implementation process challenging. To overcome such challenges, attention has been focused on the use of artificial neural networks (ANNs) to study complex systems since they show promise in system identification and controller design, to say the least. This survey aims to provide a literature review on combining MBC techniques with ANNs for UAV flight control, with the goal of laying the foundation for efficient controller designs with performance guarantees. A brief discussion on frequently-used ANNs is presented along with their time complexity. Classification/comparison of existing dynamic modeling and control techniques is provided. Challenging research questions and an envisaged control architecture are also posed for future development.

16:20-16:40 WeB4.5

Centroid Vectoring Control Using Aerial Manipulator: Experimental Results, pp. 364-369

Ivanovic, Antun — University of Zagreb
Car, Marko — University of Zagreb
Orsag, Matko — University of Zagreb
Bogdan, Stjepan — University of Zagreb

This paper addresses the issues of aerial manipulation and its dynamic center of mass variations by deriving a control principle capable of exploiting this disturbance as a means to stabilize the Unmanned Aerial Vehicle (UAV). A complete mathematical model of an aerial robot consisting of rotorcraft UAV body and a generic multiple degree of freedom manipulator is derived and presented. Previously developed control scheme utilizing both the rotor speed control and centroid vectoring through the mid-ranging approach is augmented with a standard position control loop. The proposed control approach is tested and verified in manual and autonomous flight experiments. We present the results of centroid vectoring control on a trajectory tracking example alongside which we provide comparison with state-of-the-art approaches.

16:40-17:00 WeB4.6

Robust and Synchronous Nonlinear Controller for Autonomous Formation Flight of Fixed Wing UASs, pp. 370-379

Cordeiro, Thiago — University of Brasilia
Ferreira, Henrique Cezar — University of Brasilia
Ishihara, João Yoshiyuki — University of Brasília

A robust and synchronous formation flight controller is developed for fixed wing unmanned aerial systems (UASs) in a leader-follower architecture. The controller is composed of a nonlinear dynamic inversion recently developed in literature and a robust sliding mode controller and takes into account exchanges of data among neighbor vehicles. A Lyapunov candidate function demonstrates the stability of the proposed controller. A simulation evaluates three configurations of the proposed controller: a non-synchronous configuration that uses the discontinuous and chattering generating sign function, a non-synchronous configuration using the continuous saturation function that avoids chattering at the cost of lower steady state performance and finally the synchronous version using the saturation function. These configuration variants are compared to a linear controller of the literature. It is shown that, for the proposed controller, the use of the saturation function provides significant chattering reduction without much performance penalty. It is also shown that the synchronous variant increases the performance of the formation shape error transient response at the cost of decreased formation position error transient response performance.

WeC1 — Heritage B

Fault Diagnosis, Accommodation and Fault-Tolerant Control
(Regular Session)

Chair: Hasan, Agus — University of Southern Denmark

17:00-17:20 WeC1.1

Interactive Multiple Neural Adaptive Observer Based Sensor and Actuator Fault Detection and Isolation for Quadcopter, pp. 380-388

Lee, Woo-Cheol — Korea Advanced Institute of Science and Technology
Choi, Han-Lim — Korea Advanced Institute of Science and Technology

This paper presents a fault detection and identification (FDI) method that can simultaneously deal with motor and sensor faults in a quadcopter. The method integrates Neural Adaptive Observers (NAOs) that predicts the errors in the dynamic model due to fault into an Interactive Multiple Model (IMM) framework. Two NAOs are constructed to deal with two different categories of faults -- sensor faults and actuator faults, which are represented as two different models in the IMM filter. The stability of the proposed FDI scheme is theoretically analyzed, and validity of the method is demonstrated on a virtual physics engine environment.

17:20-17:40 WeC1.2

Observer-Based Super Twisting Controller Robust to Wind Perturbation for Multirotor UAV, pp. 389-397

Hamadi, Hussein — Université De Technologie De Compiègne
Lussier, Benjamin — University of Technology of Compiègne
Fantoni, Isabelle — CNRS
Francis, Clovis — Lebanese University
Shraim, Hassan — Consulting Company

Control design for multi rotors UAV is an important challenge for engineers and scientists, due to the fact that the standard configurations are under-actuated, highly nonlinear, and unstable systems. In this paper, a wind force compensation strategy is proposed for a quadrotor. This strategy relies on a second order sliding mode controller based on the super twisting algorithm (STA) with an observer. Second order sliding mode technique ensures robustness to external disturbances and time varying, parametric and nonlinear uncertainties. Integration of an observer in the closed-loop system is needed for states reconstruction and the estimation of unknown external forces such as the wind effect. The effectiveness of the proposed strategy is compared to an adaptative gain controller through simulation and validated in real experiments on a quadrotor.

17:40-18:00	WeC1.3

Model-Based Fail-Safe Module for Autonomous Multirotor UAVs with Parachute Systems, pp. 398-404

Hasan, Agus	University of Southern Denmark
Tofterup, Vincent Klyverts	University of Southern Denmark
Jensen, Kjeld	University of Southern Denmark

This paper presents development of model-based fail-safe modules for autonomous multirotor Unmanned Aerial Vehicles (UAVs) with safety parachute systems. The module is based on the adaptive eXogenous Kalman filter for actuator fault diagnosis. We assume all states can be measured, such that the primary goal of the filter is not the state estimation from the measurements, but the accurate reconstruction of the multirotor dynamics in real-time. Numerical simulations show the proposed diagnostic filter can be used to estimate the magnitude of the actuator faults accurately. Furthermore, based on simulated and real data recorded during a hexacopter UAV flight when its actuators experiencing complete failure, the experiment results demonstrate the effectiveness of the approach.

18:20-18:40	WeC1.5

Actuator Fault Diagnosis and Fault Tolerant Control Using Intelligent-Output-Estimator Applied on Quadrotor UAV, pp. 405-412

Al Younes, Younes	Higher Colleges of Technology
Noura, Hassan	Islamic University of Lebanon
Rabhi, Abdelhamid	MIS
El Hajjaji, Ahmed	Univ. De Picardie-Jules Verne

Actuator fault is a prominent system's issue that attracts the researchers' attentions. One type of actuator fault is a constant Loss-of-Effectiveness (LoE). In this paper, two systematic algorithms are presented. The first algorithm is designed to detect and diagnosis the actuator fault. This Fault-Detection-and-Diagnosis (FDD) approach relies on an estimator design that is called intelligent Output-Estimator (iOE). The proposed iOE is intended to improve the estimation of the actuator fault based on the Model-Free technique. The second algorithm works online after detecting, isolating and estimating the actuator fault. This Active-Fault-Tolerant-Control (AFTC) algorithm will use the estimated actuator value in a reconfigured control design to compensate for the fault. Real-time flight tests are applied on the Qball-X4 quadrotor. Different LoE actuator-fault scenarios are presented in this paper to validate the proposed algorithms.

18:40-19:00	WeC1.6

Fault-Tolerant Adaptive Neural Control of Multi-UAVs against Actuator Faults, pp. 413-418

Yu, Ziquan	Northwestern Polytechnical University
Zhang, Youmin	Concordia University
Qu, Yaohong	Northwestern Polytechnical University
Su, Chun-Yi	Concordia Univ
Zhang, Yintao	Concordia University
Xing, Zhewen	Northwestern Polytechnical University

This paper is concerned with the fault-tolerant cooperative control (FTCC) problem of multiple unmanned aerial vehicles (multi-UAVs) in the communication network. By exploiting neural network (NN) to approximate the nonlinear terms existing in the highly nonlinear multi-UAVs system, a distributed neural adaptive control scheme is proposed when only a subset of follower UAVs has access to the leader UAV's states. To solve the problem of ``explosion of complexity'' in traditional backstepping architecture and reduce the number of online updating parameters of NN, dynamic surface control (DSC) and minimal learning parameter techniques are employed to reduce the computational complexity. Furthermore, by combining graph theory and Lyapunov approach, it is proved that velocities and altitudes of all follower UAVs can track the velocity and altitude of the leader UAV. Finally, simulation results are presented to verify the effectiveness of the proposed control scheme.

WeC2	Heritage A
Regulations (Regular Session)	
Chair: Bassi, Eleonora	Politecnico Di Torino

17:00-17:20	WeC2.1

Drones Are Flying Outside of Segregated Airspace in Poland – New Rules for BVLOS UAVs Operations, pp. 419-424

Konert, Anna	Lazarski University in Warsaw
Kasprzyk, Piotr	Lazarski University in Warsaw

Poland was one of the first European countries to adopt rules for the operation of drones at national level. During the first years, the regulator was more focused on VLOS operations. BVLOS were only allowed to operate in segregated airspace. The new law significantly simplifies the procedures by allowing for certain types of BVLOS operations to be operated outside of segregated airspace, at very low levels. This paper will analyze how national legislation is dealing with new technology, focusing on the new law on BVLOS operations.

17:20-17:40	WeC2.2

A Survey of Unmanned Aircraft System Technologies to Enable Safe Operations in Urban Areas, pp. 425-434

Bloise, Nicoletta	Politecnico Di Torino
Primatesta, Stefano	Politecnico Di Torino
Antonini, Roberto	Company
Fici, Gian Piero	TIM
Gaspardone, Marco	TIM
Guglieri, Giorgio	Politecnico Di Torino
Rizzo, Alessandro	Politecnico Di Torino

The use of Unmanned Aerial Systems (UASs) is emerging more and more in recent years for many civil applications. They provide great opportunities in urban areas and, in particular, they will be involved in smart cities, bringing many advantages in terms of lower cost and operational flexibility. In this paper, we propose a survey of UAS technologies to enable safe flight operations in urban areas. The main goal of this paper is to investigate the most efficient solution to perform UAS missions and to manage aerial traffic in a future congested sky. The development of new mobile Internet technologies, the progress of UAS technology and the necessity to perform automatic/autonomous flight missions open new opportunities to UAS operations. Moreover, a revision of current UAS regulations is necessary. After a survey of UAS technologies, we discuss how the combination of an autonomous vehicle in Beyond Visual Line-of-Sight mode and a wireless connection with a mobile Internet connection could improve the UAS operations.

17:40-18:00	WeC2.3

European Drones Regulation: Today's Legal Challenges, pp. 435-442

Bassi, Eleonora	Politecnico Di Torino

The drone legal framework represents a multilevel and complex field of EU law. The new 2018 Regulation sets up a centralized system, in which the main ruling powers are devolved to the European Commission and EASA. Still, the provisions of the EU regulation have to be complemented with further legal fields, which regard public security legislations, telecommunication law, rules on product liability, criminal and insurance law, up to privacy and data protection, and their harmonization. Whilst the European Commission shall complement the provisions of the regulation with a set of implementing and delegated acts, the paper suggests that a number of key issues are fated to remain open. They regard different kinds of concerns related to the collection and use of drone data, much as problems related to privacy safeguards, telecommunications and

cyber-security breaches, registration and identification of both UAVs, and their pilots and operators, down to matters of liability and the enforcement of the new provisions. Article 140 of the Regulation has established the time within which the whole legal framework for the use of drones within the Single European Sky strategy shall be at full speed: 12 September 2023. This means, depending on the viewpoints, too much or too few times. In any event, a lot of work is waiting for us.

18:00-18:20	WeC2.4

Risk Assessment Based on SORA Methodology for a UAS Media Production Application, pp. 443-451

Capitán, Carlos	University of Seville
Capitan, Jesus	University of Seville
Castaño, Ángel Rodríguez	University of Seville
Ollero, Anibal	Universidad De Sevilla

This paper describes the application of the SORA (Specific Operational Risk Assessment) methodology to perform a risk assessment of an operation for aerial cinematography to be conducted with an autonomous small team of UAS developed in the EU-funded MULTIDRONE project. The purpose of applying SORA, which is the methodology developed by JARUS (Joint Authorities for Rule-making on Unmanned Systems), is to obtain regulatory approval to conduct these UAS flights for filming rowing/cycling races in rural scenarios. The paper goes through all steps in SORA, evaluating operational risks and discussing mitigation actions in the system. A positive evaluation is estimated for the operation proposed, which will ease technology transfer for the MULTIDRONE system and its future integration into airspace operations.

18:20-18:40	WeC2.5

Towards a Tool for Assessing UAS Compliance with the JARUS SORA Guidelines, pp. 452-458

Terkildsen, Kristian Husum	University of Southern Denmark
Jensen, Kjeld	University of Southern Denmark

The Unmanned Aerial Systems (UAS) legislation in the European Union will expectedly become unified by 2020. This legislation divides UAS operations into three categories, one of which is the Specific category, in which operations of higher risk will be placed. Permission for UAS operations in the Specific category is granted based on a Specific Operations Risk Assessment (SORA). The risk assessment categorizes operations into Specific Assurance and Integrity Levels (SAILs), which determines the level of the requirements for the operation such as operational procedures, training of the remote crew, UAS specification and maintenance etc. However, a conceptual gap exists between the defined technology requirements for UAS and the available UAS platforms. In this work, a prototype assessment tool based on the SORA defined technology requirements has been developed. The tool is a web-based questionnaire, which pulls the questions from a data structure and stores the answers in a database for analysis. Upon completion of the questionnaire, the user receives an automatically generated evaluation report. The evaluation report points out the areas of inadequacy and provides suggestions for mitigating these. The tool in its current state has been used to evaluate four commonly used UAS. The four UAS have been tested for SAIL II through IV, and the results show that only one of the selected UAS complies with SAIL II. Future work is to refine the tool including the list of questions and the UAS evaluation report generator, based on feedback from UAS domain experts and to expand it to cover fixed-wing UAS.

WeC3	Heritage C
UAS Applications II (Regular Session)	
Chair: Lozano, Rogelio	University of Technology of Compiègne

17:00-17:20	WeC3.1

Comparative Study for Coordinating Multiple Unmanned HAPS for Communications Area Coverage, pp. 459-466

Anicho, Ogbonnaya	Liverpool Hope University
Charlesworth, Philip	Liverpool Hope University
Baicher, Gurvinder	Liverpool Hope University
Nagar, Atulya	Liverpool Hope University
Buckley, Neil	Liverpool Hope University

This work compares the application of Reinforcement Learning (RL) and Swarm Intelligence (SI) based methods for resolving the problem of coordinating multiple High-Altitude Platform Stations (HAPS) for communications area coverage. Swarm coordination techniques are essential for developing autonomous capabilities for multiple HAPS/UAS control and management. This paper examines the performance of artificial intelligence (AI) capabilities of RL and SI for autonomous swarm coordination. In this work, it was observed that the RL approach showed superior overall peak user coverage with unpredictable coverage dips; while the SI based approach demonstrated lower coverage peaks but better coverage stability and faster convergence rates.

17:20-17:40	WeC3.2

Water Take-Off and Landing - Hybrid Copter Approach for Maritime CONOPs, pp. 467-473

Galante, João	Universidade Do Porto - Faculdade Engenharia
Manuel, Ribeiro	Universidade Do Porto - Faculdade Engenharia
de Nobrega, Roberto	Universidade Do Porto - Faculdade Engenharia
Neiva, Jorge	Universidade Do Porto - Faculdade Engenharia
Ferreira, António Sérgio	University of Porto
Sousa, Joao	Universidade Do Porto - Faculdade Engenharia

With the rise in the use of multi-vehicles teams, for maritime operations, new challenges and opportunities arise regarding the complexity and logistics of these scenarios. One way to cope with said complexity is to imbue some of these systems with the versatility of operating in more than one physical medium (air/water/land) during its normal mission cycle, maximizing their possible mission roles. The ability of having a vehicle which can operate both in the air and on the water can further expand and facilitate maritime operations by allowing new sampling, deployment and even communication scenarios. This work follows the iterations of a specific vehicle concept, through its various phases, and tracks the developments and challenges necessary to adapt a Remotely Piloted Aircraft Systems (RPAS) to become capable of water take-off & landing, and explores its applicability as a viable operational mobile communication gateway for underwater and surface assets.

17:40-18:00	WeC3.3

Three Dimensional UAV Path Following Using SDRE Guidance, pp. 474-482

Singh, Mandeep	IIIT Delhi
Manoharan, Amith	IIIT Delhi
Ratnoo, Ashwini	Indian Institute of Science
PB, Sujit	Indraprastha Institute of Information Technology Delhi

Path following is an essential requirement for unmanned aerial vehicles. Typically, these paths are in three dimensions and the shape of the paths are application dependent. Mapping applications require stationary paths, while moving target tracking with a stand-off distance involves a moving reference path. A path following strategy is required that can be used for stationary and moving path following applications and is robust to wind disturbances. In this paper, we propose an adaptive optimal guidance strategy using SDRE approach. Comparison of the guidance law is ascertained, and the approach is evaluated under different wind and target motion

conditions. The guidance law shows robust performance up to 10 m/s wind speed and can follow different geometric reference paths.

18:00-18:20 WeC3.4

Satellite and UAV Data for Precision Agriculture Applications, pp. 483-489

Mancini, Adriano	Universita' Politecnica Delle Marche
Frontoni, Emanuele	Università Politecnica Delle Marche
Zingaretti, Primo	Università Politecnica Delle Marche

The evolution behind Agriculture 4.0 relies on the intelligent use of data collected by using advanced technologies mounted on board of tractors, mobile ground robots, unmanned aerial vehicles and satellites. Today a field could be monitored over a season owing to data acquired by using drones and satellite with different spectral, spatial and temporal resolution. Data are used in precision agriculture scenarios to monitor the growth, detect the presence of weeds, identify areas affected by nitrogen/water stress but the common factor is the high demand for updated data. This paper evaluates different data-sources as Landsat-8, Sentinel-2, PlanetScope and UAV on a test-site characterized by areas that have different vigor considering different agronomic management thesis. A comparison over the sub-areas by using different approach enables the understanding of how these heterogeneous data-sources could work together also supporting the decision of agronomists. The evaluation shows that data acquired at a close time could be compared but there are some potential issues that require attention in post-processing as the geometric accuracy to ensure a proper co-registration and georeferencing.

18:20-18:40 WeC3.5

Attitude and Altitude Control for a Fixed Wing UAV Applied to Photogrammetry, pp. 490-494

Hernandez, Jorge Luis	CINVESTAV IPN
Gonzalez-Hernandez, Ivan	CINVESTAV IPN
Lozano, Rogelio	University of Technology of Compiègne

The use of autonomous vehicles in daily life is more commonly every day, we can find it in security missions, agriculture, windmills inspection and one of its main uses the processes of photogrammetry, because the new systems and technologies to perform the last one could give errors of centimeters in a topographic map. The studies of large areas are carried out with fixed-wing UAV, so it is necessary to ensure that the vehicle could follow a desired path even in presence of external disturbances, in order to avoid uncovered or wrong defined areas during the post-processing. In this article we analyzed and compared by simulation the use of a non-linear control technique with a PID control to stabilize the airplane's attitude and height, to prove that in some cases only a linear control technique is enough to stabilize the UAV and also probe that the amount of energy to control the UAV is similar in both techniques. So the majority of computational resources can be assigned to object detection and collision avoidance tasks, for vehicles under 5 kilograms.

WeC4	Savannah
Control Architectures III (Regular Session)	
Chair: Azimov, Dilmurat	University of Hawaii at Manoa
Co-Chair: Zhang, Fu	University of Hong Kong

17:00-17:20 WeC4.1

Nonlinear Model Predictive Attitude Control for Fixed-Wing Unmanned Aerial Vehicle Based on a Wind Frame Formulation, pp. 495-504

Reinhardt, Dirk	Norwegian University of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology

Exploiting the physical limitations on the maneuverability of a fixed-wing Unmanned Aerial Vehicle (UAV) and simultaneously respecting its flight envelope and actuator constraints is a demanding task for which Nonlinear Model Predictive Control (NMPC) is well-suited. This paper presents an NMPC for attitude control of a fixed-wing UAV which is based on the vehicle model in a wind frame formulation and includes critical flight variables such as relative speed and angle of attack in its control objective and constraint formulation. The proposed controller is evaluated in a simulation study and compared against a set of conventional PID Controllers.

17:20-17:40 WeC4.2

Integrated Optimal Control and Explicit Guidance for Quadcopters, pp. 505-514

Kawamura, Evan	University of Hawaii: Manoa
Azimov, Dilmurat	University of Hawaii at Manoa

This goal of the research study is to create a framework for autonomous control technology for unmanned aerial vehicles with real-time target-relative guidance capabilities. This study and results presented in this paper aims to develop guidance and control functions and their integration for applications. Control functions are developed in the context of the optimal control problem. Optimal control formulation leads to trivial and nontrivial cases for finding state and co-state vectors. Integrated optimal control and explicit guidance are utilized for a quadcopter traveling to a point of interest at an agricultural field. Ardupilot and Mission Planner are the platforms used to provide simulated gyroscope and accelerometer data, which are inputted into a simulation of the integrated control and guidance. The simulation compares classical PID control against optimal control with explicit guidance to show that the quadcopter accurately reaches its desired location at the desired velocities.

17:40-18:00 WeC4.3

Deep Reinforcement Learning Attitude Control of Fixed-Wing UAVs Using Proximal Policy Optimization, pp. 515-525

Bøhn, Eivind	SINTEF, Norwegian University of Science and Technology
Coates, Erlend M.	Norwegian University of Science and Technology
Moe, Signe	Norwegian University of Science and Technology, SINTEF
Johansen, Tor Arne	Norwegian University of Science and Technology

Contemporary autopilot systems for unmanned aerial vehicles (UAVs) are far more limited in their flight envelope as compared to experienced human pilots, thereby restricting the conditions UAVs can operate in and the types of missions they can accomplish autonomously. This paper pro- poses a deep reinforcement learning (DRL) controller to handle the nonlinear attitude control problem, enabling extended flight envelopes for fixed-wing UAVs. A proof-of-concept controller using the proximal policy optimization (PPO) algorithm is developed and is shown to be capable of stabilizing a fixed-wing UAV from a large set of initial conditions to reference roll, pitch and airspeed values. The training process is outlined and key factors for its progression rate are considered, with the most important factor found to be limiting the number of variables in the observation vector and including values for several pre- vious time steps for these variables. The trained reinforcement learning (RL) controller is compared to a proportional-integral- derivative (PID) controller and is found to converge in more cases than the PID controller, with comparable performance. Furthermore, the RL controller is shown to generalize well to unseen disturbances in the form of wind and turbulence, even in severe disturbance conditions.

18:00-18:20 WeC4.4

Enabling Bidirectional Thrust for Aggressive and Inverted Quadrotor Flight, pp. 526-533

Jothiraj, Walter	McGill University
Miles, Corey	McGill University
Bulka, Eitan	McGill University
Sharf, Inna	McGill University
Nahon, Meyer	McGill University

Quadrotors have become the most common and highly popularized small aerial vehicles among robotics researchers, consumers and commercial users. Traditionally, these platforms have been designed with each of the four propellers to spin in the designated direction (two clockwise and two counter-clockwise) to produce unidirectional thrust---this allows the vehicle to oppose gravity when in its nominal hover orientation. In this paper, we present a quadrotor which is capable of bidirectional thrust actuation: it is generated by reversing the direction of the driving motors and hence propeller spins. This configuration is motivated by the desire to increase the vehicle's agility, as well as to imbue it with functionalities not available to the standard unidirectional thrust platforms. We present the dynamics model of a quadrotor with bidirectional thrust, the controller adapted to this configuration, and details of the implementation of the bidirectional capability in hardware and software, using the state-of-the-art Pixhawk micro-controller and PX4 flight stack. The transient thrust characteristics of a symmetric propeller are experimentally determined, highlighting the maximum rate of change and dead-zone specific to bidirectional thrust. Results starting from simulation, to hardware-in-the-loop testing, to experiments conducted with an outdoor platform are presented for a half flip maneuver, demonstrating the performance and upside-down hovering of the vehicle.

18:40-19:00 WeC4.6

Full Attitude Control of an Efficient Quadrotor Tail-Sitter VTOL UAV with Flexible Modes, pp. 534-542

XU, WEI	University of Hong Kong
Gu, Haowei	Hong Kong University of Science and Technology
Qin, Youming	University of Hong Kong
Lin, Jiarong	The University of Hong Kong
Zhang, Fu	University of Hong Kong

In this paper, we present a full attitude control of an efficient quadrotor tail-sitter VTOL UAV with flexible modes. This control system is working in all flight modes without any control surfaces but motor differential thrusts. This paper concentrates on the design of the attitude controller and the altitude controller. For the attitude control, the controller's parameters and filters are optimized based on the frequency response model which is identified from the sweep experiment. As a result, the effect of system flexible modes is easily compensated in frequency-domain by using a notch filter, and the resulting attitude loop shows superior tracking performance and robustness. In the coordinated flight condition, the altitude controller is structured as the feedforward-feedback parallel controller. The feedforward thrust command is calculated based on the current speed and the pitch angle. Tests in hovering, forward accelerating and forward decelerating flights have been conducted to verify the proposed control system.

WeP5 Foyer

Poster Papers (Poster Session)

Chair: Morrison, James R. KAIST

13:00-18:00 WeP5.1

Robust Flight Control of a Tri-Rotor UAV Based on Modified Super-Twisting Algorithm, pp. 543-548

Paiva, Enrique	Universidad Nacional De Asunción, Facultad De Ingeniería
Rodas, Jorge	Universidad Nacional De Asunción, Facultad De Ingeniería
Kali, Yassine	École Mohammadia d'Ingénieurs, University of Mohammed V
Gregor Recalde, Raul Igmar	Universidad Nacional De Asunción, Facultad De Ingeniería
Saad, Maarouf	Ecole De Technologie Superieure

This paper presents a robust nonlinear controller for finite-time high-accuracy position and attitude trajectory tracking of a tri-rotor unmanned aerial vehicle affected by disturbances. The proposed control method is a modified super-twisting algorithm with double closed-loop feedback regulation based on a proportional-integral-derivative sliding surface. This algorithm is one of the most effective algorithms of second order sliding mode due to its robustness, high precision, finite time convergence even when the system trajectories are far from the sliding surface. The proposed controller also offers a chattering reduction or elimination, which is one of the main drawbacks of sliding mode controllers. Stability conditions are presented based on Lyapunov theory. Numerical simulations are performed on the considered tri-rotor to prove the efficiency of the proposed nonlinear control scheme.

13:00-18:00 WeP5.2

On Coordination in Multiple Aerial Engagement, pp. 549-554

Strickland, Laura	Georgia Institute of Technology, Georgia Tech Research Institute
Squires, Eric	Georgia Tech Research Institute
Day, Michael	Georgia Tech Research Institute
Pippin, Charles	Georgia Tech Research Institute

A potential approach for engaging an adversarial force of fixed-wing UAVs is to counter it with a similar force. There are open questions, however, regarding the numbers and characteristics necessary for the defending UAV team in such a scenario. In this paper, we consider the importance of coordination in such a mutli-UAV aerial engagement. We introduce a legacy-tactic-inspired autonomous UAV behavior that uses simple coordination between team members for opponent targeting and test it in simulated engagements against a team of non-coordinating UAVs that use simple nearest-enemy guidance logic. Extensive simulations were performed, varying tactical behavior, team size, and weapon effectiveness. Results show that both relative team size and autonomous behavior are significant factors in engagement outcome.

13:00-18:00 WeP5.3

Planning for Decentralized Formation Flight of UAV Fleets in Uncertain Environments with Dec-POMDP, pp. 555-560

de Oliveira Floriano, Bruno Rodolfo	Universidade De Brasilia
Borges, Geovany Araújo	University of Brasília
Ferreira, Henrique Cezar	University of Brasilia

The increasingly interest in cooperative flight of unmanned aerial vehicles (UAVs), alongside the development of sophisticated embedded systems, made possible for numerous algorithms to control multi-agent systems of fling vehicles. However, many of these algorithms still require high communications between vehicles, or with a central unit, as well as reliable sensors. The Decentralized Partially Observable Markov Decision Process (Dec-POMDP) is a model for decentralized planning of multi-agent systems, considering uncertain observations and low communication reliability. Although this framework has been used for UAV systems, formation flight is still a problem not considered in this scenario. This paper proposes the use of the Dec-POMDP planning algorithm for high-level decision making in UAV formation flight, making use of existent flight controllers in an inner-loop, allowing computational feasibility. Simulation results show that the proposed method allows for decentralized formation tracking, with communication restrictions, as well as collision avoidance and time-varying formations.

13:00-18:00 WeP5.5

Smart City Investments: A Rapid Decision Framework for Public Private Partnerships, pp. 561-566

Rayi, Paul Sujith Syracuse University
Bothra, Rishie Lavendra Syracuse University
Wallace, Stephen Syracuse University
Venkatesh, Murali Syracuse University School of Information Studies

The city of Syracuse in New York announced an ambitious smart city plan which, when fully implemented, promises to make it the most connected city in the northeastern US. Thanks to a strategic investment by the State of New York, the city is home to what is billed as the world's first Drone Corridor for R&D. We outline a decision framework (The Syracuse Wheel) for public private partnership to help city leaders and private investors navigate the exciting implications stemming from these two strategic developments and the city's environment to augment the priority areas of Autonomous Mobility and Connectivity. The Wheel positions Syracuse as a prime market for visionary Public Private Partnership (PPP) proposals given its infrastructure and assets specific to Unmanned Aerial Systems (UASs) and Autonomous Vehicle Testing. The research also suggests ways to mitigate the problems associated with data governance and IP governance that various large-scale PPPs have faced in the past. We conclude with a decision-making framework which facilitates a fast-track approval mechanism for investment proposals from private entities as Syracuse prepares for its future as leading-edge Smart City and UAS R&D hub.

13:00-18:00 WeP5.6

Sense-And-Avoid System Development on an FPGA, pp. 567-571

Kóta, Fülöp Faculty of Information Technology and Bionics, Pázmány Péter Cat
Zsedrovits, Tamás Pázmány Péter Catholic University
Nagy, Zoltán Faculty of Information Technology and Bionics, Pázmány Péter Cat

In this paper, the first steps of development towards a collision avoidance system for UAV are introduced. The system is based on camera sensors controlled by an FPGASoC, running an image processing algorithm, controlling a quadcopter to avoid mid-air collisions with other aircraft. The algorithm was already tested in a real mid-air close encounter scenario between two UAVs, but in that scenario, the implementation platform was a GPU-based SoC which had serious limitations concerning processing frame rate and power consumption. Our aim is to realize the same algorithm with higher framerate and lower power consumption. The paper introduces fundamental considerations for the selection of tools used during this process.

ThA1	Heritage B
Path Planning III (Regular Session)	
Chair: Darbha, Swaroop	Texas a & M Univ
Co-Chair: Choi, Youngjun	Georgia Institute of Technology

10:00-10:20 ThA1.1

Cooperative Search Area Optimization Using Multiple Unmanned Aerial Vehicles in a GPS-Denied Environment, pp. 572-579

Misra, Sohum — University of Cincinnati
Biswas, Srijanee — University of Cincinnati
Minai, Ali — University of Cincinnati
Sharma, Rajnikant — University of Cincinnati

This paper addresses the problem of maximizing surveillance area coverage using multiple Unmanned Aerial Vehicles (UAVs) in an obstacle-laden and Global Positioning System (GPS)-denied environment. The UAVs should achieve this objective using the shortest possible routes while staying inside the designated search space and avoiding the obstacles. To attain a desired area coverage, we divide the NP-hard multi-objective optimization problem of planning optimal routes for all UAVs into 3 parts: (a) optimizing search area coverage, (b) performing obstacle avoidance, and (c) using Cooperative Localization (CL) for state estimation. We demonstrate the efficiency of our algorithm through extensive simulations.

10:20-10:40 ThA1.2

Randomized Continuous Monitoring of a Target by Agents with Turn Radius Constraints, pp. 580-587

Stephens, Shawn — Air Force Institute of Technology, WPAFB, OH
Manyam, Satyanarayana Gupta — Infoscitex Corporation
Casbeer, David — Air Force Research Laboratories
Cichella, Venanzio — UIUC
Kunz, Donald — Air Force Institute of Technology

We consider a scenario where a target needs to be monitored continuously by a set of agents. The agents are equipped with sensors fixed to their bodies and the sensors have a finite footprint. The mission requires the target to lie in the sensor footprint of at least one agent at any time. Due to the finite footprint, an agent can monitor the target only when its range and orientation with respect to the target is within certain limits. The agents considered here have kinematic motion constraints and limits on their speed. This constraint mandates the use of multiple agents to monitor the target sequentially in order to achieve continuous monitoring. To reduce the predictability of their paths, the agents randomly generate successive monitoring positions. We present strategies for scheduling and path planning which assure continuous monitoring; the path planning is done using B'ezier curves subject to curvature constraints, boundary constraints and length constraints. We also present an efficient computation methodology to enforce maximum curvature and path length constraints using only the control points of the curves.

10:40-11:00 ThA1.3

A Multi-UAS Trajectory Optimization Methodology for Complex Enclosed Environments, pp. 588-596

Barlow, Sarah — Georgia Institute of Technology
Choi, Youngjun — Georgia Institute of Technology
Briceno, Simon — Georgia Tech
Mavris, Dimitri — Georgia Institute of Technology

This paper explores a multi-UAV trajectory optimization methodology for confined environments. One potential application of this technology is performing warehouse inventory audits; this application is used to evaluate the methodology's impact on minimizing total mission times. This paper investigates existing algorithms and improves upon them to better address the constraints of warehouse-like environments. An existing inventory scanning algorithm generates sub-optimal, collision free paths for multi-UAV operations, which has two sequential processes: solving a vehicle routing problem and determining optimal deployment time without any collision. To improve the sub-optimal results, this paper introduces three possible improvements on the multi-UAV inventory tracking scenario. First, a new algorithm logic which seeks to minimize the total mission time once collision avoidance has been ensured rather than having separate processes. Next, an objective function that seeks to minimize the maximum UAV mission time rather than minimizing the total of all UAV mission times. Last, an operational setup consisting of multiple deployment locations instead of only one. These algorithms are evaluated individually and in combination with one another to assess their impact on the overall mission time using a representative inventory environment.

11:00-11:20 ThA1.4

Efficient Computation of Optimal UAV Routes for Persistent Monitoring of Targets, pp. 597-606

Hari, Sai Krishna Kanth — Texas A & M University, College Station
Rathinam, Sivakumar — Texas A & M University
Darbha, Swaroop — Texas A & M Univ
Kalyanam, Krishna — PARC
Manyam, Satyanarayana Gupta — Infoscitex Corporation
Casbeer, David — Air Force Research Laboratories

In this article, we consider a routing problem that arises in the scenario of persistently monitoring a set of targets using an unmanned vehicle. A UAV is tasked with monitoring a set of targets, by frequently visiting them for data collection. The UAV has a limited fuel capacity, which is specified in terms of the number of visits it makes, at the end of which it must be recharged at a depot. The problem considered here is to plan an optimal sequence of visits (to targets) for the UAV, such that the maximum time between consecutive revisits to the targets is minimized. The problem is a generalization of the Traveling Salesman Problem (TSP) and is computationally challenging; It is significantly difficult to compute optimal solutions using standard formulations. However, the authors recently developed a set of theoretical results characterizing the structure of optimal solutions for this problem. Using these results, in this article, we propose a new formulation to solve the problem. Extensive numerical simulations suggest that the average computation time required to solve the problem using the proposed formulation is within a fraction of a second on a standard laptop (here, a MacBook Pro with Intel Core i7 processor and 16 GB RAM was used).

11:20-11:40 ThA1.5

Bounding Algorithms for Persistent Monitoring of Targets Using Unmanned Vehicles, pp. 607-613

Hari, Sai Krishna Kanth — Texas A & M University, College Station
Rathinam, Sivakumar — Texas A & M University
Darbha, Swaroop — Texas A & M Univ
Kalyanam, Krishna — PARC
Manyam, Satyanarayana Gupta — Infoscitex Corporation
Casbeer, David — Air Force Research Laboratories

Persistent monitoring of targets in civil and military applications require a team of Unmanned Vehicles to visit the targets repeatedly over time. The vehicles visit the targets and transmit the collected information to the base station for further processing. The frequency of monitoring any given target is intuitively specified by its target revisit time, $i.e.$, the maximum time elapsed between any two successive visits to the target. The persistent monitoring problem considered in this article is as follows: Given m vehicles and k allowed visits to n targets, find an optimal path for each vehicle

such that each target is visited at least once, each target is visited at most by one vehicle and the maximum revisit time over all the targets is minimized. This problem is a generalization of the min-max, multiple Traveling Salesman Problem and is NP-Hard. Bounds on the optimal revisit times are provided for the case when the number of visits is large. Specifically, it is shown that the optimal revisit time for any number of visits is lower and upper bounded by the optimal revisit times corresponding to n+m visits and n+m+1 visits. Optimal revisit times are also developed for the single vehicle problem with tighter bounds. These results are practically useful in reducing the computational burden as one only needs to solve two problems for any large number of visits to find a good feasible solution.

11:40-12:00	ThA1.6

System Design and Resource Analysis for Persistent Robotic Presence with Multiple Refueling Stations, pp. 614-621

Park, Hyorin	KAIST, Department of Industrial and Systems Engineering
Morrison, James R.	KAIST

Despite the capabilities of unmanned aerial vehicles (UAVs), it is not possible to conduct long-term missions with a just few UAVs due to fuel restrictions. This requires a system that includes multiple UAVs and automated recharging stations for an automatic and persistent service. In order to construct a persistent presence system such as local surveillance and monitoring, it is important to determine the design of the mission and the number of resources required. In this paper, a system consisting of multiple target areas and multiple stations is considered. There are two types of stations: refueling and main stations for maintenance. UAVs can travel further using the refueling stations. A decision-free Petri net model for persistency is developed for cyclic paths including multiple immobile targets and stations. From the Petri net model, we derive a closed-form function for the minimum number of resources in the persistent system. A mathematical model that has the objective function derived from the Petri net is developed. To resolve the computational issue, a genetic algorithm (GA) is used to solve the problem. As the result, the minimum number of resources required, and the mission path are derived.

ThA2	Heritage C
UAS Applications III (Regular Session)	
Chair: Johansen, Tor Arne	Norwegian University of Science and Technology

10:00-10:20	ThA2.1

Feasibility Study for a MEDEVAC Electric UAS Capability, pp. 622-627

Pickell, William	United States Military Academy
Kopeikin, Andrew	US Military Academy
Bristow, Elizabeth	United States Military Academy
Bluman, James	United States Military Academy

This study examines the feasibility of integrating medical subsystems into an existing Unmanned Aircraft System (UAS) platform to facilitate medical evacuation (MEDEVAC) from combat environments. The implementation of a MEDEVAC-capable UAS is found to be a feasible and logical expansion of current MEDEVAC assets. A comprehensive review of current fully- or semi-autonomous electric vertical takeoff and landing (eVTOL) UAS technologies is conducted to select a candidate aircraft. A conceptual design of the MEDEVAC UAS, configured with equipment needed to sustain a casualty during evacuation is created. The smaller form factor of the system opens the opportunity to pre-deploy MEDEVAC assets to forward combat posts, improve response times, and offer evacuation options when manned assets are denied. The predicted range performance of the system supports such a concept of operation.

10:20-10:40	ThA2.2

Multi-UAV Based Autonomous Wilderness Search and Rescue Using Target Iso-Probability Curves, pp. 628-635

Kashino, Zendai	University of Toronto
Nejat, Goldie	University of Toronto
Benhabib, Beno	University of Toronto

The application of unmanned aerial vehicles (UAVs) to searches of lost persons in the wilderness can significantly contribute to the success of the missions. Maximizing the effectiveness of an autonomous multi-UAV search team, however, requires optimal task allocation between the team members, as well as the planning of the individual flight trajectories. This paper addresses this constrained resource-allocation optimization problem via the use of iso-probability curves that represent probabilistic target-location information in a search region growing with time. The optimization metric used is the allocation of the search effort proportional to the target location likelihood. The proposed method also avoids redundancy in coverage while planning the UAV trajectories.

Numerous simulated search experiments, two of which are detail herein, were carried out to demonstrate our method's effectiveness in wilderness search and rescue (WiSAR) planning using a multi-UAV team. Extensive comparative studies were also conducted to validate the tangible superiority of our proposed method when compared to existing WiSAR techniques in the literature.

10:40-11:00	ThA2.3

Cooperative Load Transportation Using Three Quadrotors, pp. 636-642

Pizetta, Igor	Federal University of Espirito Santo
Brandao, Alexandre Santos	Federal University of Vicosa
Sarcinelli-Filho, Mário	Federal University of Espirito Santo

Unmanned aerial vehicles (UAV) provide a wide range of applications, amongst which is load transportation. However, they have low payload capabilities, in general. Then, whenever a heavier load should be transported it is necessary to use a team of UAVs to accomplish the task. In this work, a team of three UAVs in a formation are used to carry a cargo heavier than the capacity of a single vehicle. A nonlinear control strategy based on feedback linearization is used to guide each aircraft in positioning and trajectory tracking tasks while keeping the formation stable, compensating the disturbances caused by the load and the cross effect of cable tensions.

11:00-11:20	ThA2.4

Colored-Noise Tracking of Floating Objects Using UAVs with Thermal Cameras, pp. 643-652

Helgesen, Haakon Hagen	Norwegian University of Science and Technology
Stendahl Leira, Frederik	Norwegian University of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology

Tracking of floating objects using a fixed-wing UAV equipped with a thermal camera requires precise knowledge about the position and attitude of the UAV. Errors in the navigation estimates reduce the accuracy of the tracking system. Navigation errors are usually correlated in time and can propagate colored noise into the tracking filter. This work analyzes two approaches that seek to mitigate colored noise and they are compared experimentally with a third approach which assumes that the noise in the tracking system is purely white. Two independent flight experiments have been carried out where a small marine vessel was used as target. Thermal images of the target were captured, and the position and velocity of the target have been estimated in an Earth-fixed coordinate system only using the images. The results show that objects can be tracked with an accuracy of a few meters when measurements are available, and that the estimates do not drift significantly in periods without measurements. Moreover, the results demonstrate that colored noise need to be accounted for in the measurement model to estimate the

covariance precisely and maintain filter consistency, which is critical in multi-target tracking.

11:20-11:40	ThA2.5

A Solution for Searching and Monitoring Forest Fires Based on Multiple UAVs, pp. 653-658

Zhang, Yintao	Concordia University
Zhang, Youmin	Concordia University
Yu, Ziquan	Northwestern Polytechnical University

Forest fires usually appear in complicated terrain, as a result, ground vehicles are obviously inaccessible to these fire areas. In recent years, Unmanned Aerial Vehicles (UAVs) have been paid increasing attention and become a very promising solution to forest fires searching and monitoring. This paper explores the application of UAVs in the wild forest fires searching and fire frontier monitoring mission. First, the FARSITE fire model is used to simulate the realistic wild fire behavior. After that, the fire search problem is solved with Genetic Algorithm (GA). Then, a cooperative fire monitoring algorithm is investigated. Finally, simulation results show the effectiveness of the proposed searching and monitoring methods.

11:40-12:00	ThA2.6

Anomaly Detection and Cognizant Path Planning for Surveillance Operations Using Aerial Robots, pp. 659-665

Dang, Tung	University of Nevada, Reno
Khattak, Shehryar	University of Nevada, Reno
Papachristos, Christos	University of Nevada Reno
Alexis, Kostas	University of Nevada, Reno

In this paper we address the problem of unsupervised anomaly detection and cognizant path planning for surveillance operations using aerial robots. Through one-class classification exploiting deep learned features on image data and a Bayesian technique to fuse, encode and update anomaly information on a real-time reconstructed occupancy map, the robot becomes capable of detecting and localizing anomalies in its environment. Provided this information, path planning for autonomous exploration of unknown areas and simultaneous maximization of the entropy of sensor observations over abnormal regions is developed. The method is verified experimentally through field deployments above a desert-like environment and in a parking lot. Furthermore, analysis results on the suitability of different deep learning-based and hand-engineered features for anomaly detection tasks are presented.

ThA3	Heritage A
Micro and Mini UAS (Regular Session)	
Chair: Chao, Haiyang	University of Kansas

10:00-10:20	ThA3.1

A Novel Quadcopter with a Tilting Frame Using Parallel Link Mechanism, pp. 666-675

Sakaguchi, Akinori	Osaka University
Takimoto, Takashi	National Institute of Technology, Kitakyushu College
Ushio, Toshimitsu	Osaka University

This paper is concerned with a novel quadcopter with a tilting capability using a parallel link mechanism. The proposed quadcopter consists of the tilting frame and a main body, and an angle between them is called a tilt angle. A ratio of the current width to the maximum one of the quadcopter is called a folding ratio. Using only one servo motor, it can tilt in the pitch direction and be folded vertically within a user-specified ranges of the tilt angle and the folding ratio, respectively. We show a procedure of determining design parameters of the tilting frame to satisfy specifications given by the user. Due to the tilting mechanism of the frame, the proposed quadcopter is not well-controlled as the tilt angle approaches 90 or -90 degree. Therefore, we focus on a stabilization problem for the quadcopter at a desired tilt angle specified by a user around 90 or -90 degree and propose a novel reference tilt angle generator based on the pitch angle. In simulations, we show an effectiveness of the proposed strategy for the reference tilt angle by comparing it with a conventional PID controller under the existence of a disturbance.

10:20-10:40	ThA3.2

Direct Position Control of an Octarotor Unmanned Vehicle under Wind Gust Disturbance, pp. 676-683

Baldini, Alessandro	Università Politecnica Delle Marche
Felicetti, Riccardo	Università Politecnica Delle Marche
Freddi, Alessandro	Università Politecnica Delle Marche
Longhi, Sauro	Università Politecnica Delle Marche
Monteriù, Andrea	Università Politecnica Delle Marche

In this paper we present the design of a direct position control law of an octarotor under the presence of wind gust. The nominal control law is designed on a Newton-Euler model using a feedback linearization technique, where a double integral control law is chosen in order to decouple the controlled variables' dynamics. Then, the wind gust effect is attenuated through an additive correction term, which is based on disturbance observer. An exogenous system is considered in order to estimate the wind gust derivatives, and the overall closed loop boundedness is discussed. Numerical simulations are then reported in order to show the effectiveness of the control scheme, where the observer-based technique is compared with the nominal one.

10:40-11:00	ThA3.3

Smooth Saturation Function-Based Position and Attitude Tracking of a Quad-Rotorcraft Avoiding Singularity, pp. 684-695

Dasgupta, Ranjan	Tata Consultancy Services Ltd

A nonlinear hierarchical framework is proposed to design a smooth saturation function-based position and attitude tracking control of a quad-rotorcraft. The design is based on full state space Euler-Lagrange (E-L) model of the vehicle. A rigorous stability analysis proves that the overall closed-loop system is semi-globally asymptotically stable (SGAS). In addition, a strategically designed smooth saturated position controller extracts singularity-free attitude reference while a smooth saturated attitude controller guarantee non-singular attitude tracking. Numerical simulation shows the performance of the proposed controller.

11:00-11:20	ThA3.4

Error-State LQR Control of a Multirotor UAV, pp. 696-703

Farrell, Michael David	Brigham Young University
Jackson, James	Brigham Young University
Nielsen, Jerel	Utah State University
Bidstrup, Craig	Brigham Young University
McLain, Timothy W.	Brigham Young University

We propose an implementation of an LQR controller for the full state tracking of a time-dependent trajectory with a multirotor UAV. The proposed LQR formulation is based in Lie theory and linearized at each time step according to the multirotor's current state. We show experiments in both simulation and hardware that demonstrate the proposed control scheme's ability to accurately reach and track a given trajectory. The implementation is shown to run onboard at the full rate of a UAVs estimated state. To the best of our knowledge, this is the first implementation of an LQR controller based in Lie theory for a multirotor UAV and the first hardware implementation of a full rate, state dependent LQR controller for a multirotor UAV.

11:20-11:40	ThA3.5

A Fuzzy Gain Scheduling Control Algorithm for Formation Flight of Multi-UAVs, pp. 704-712

Rojo Rodriguez, Erik Gilberto	Universidad Autonoma De Nuevo Leon
Ollervides Vazquez, Edmundo Javier	CIIIA-FIME-UANL; TecNM-Instituto Tecnologico De La Laguna
Zambrano-Robledo, Patricia	CIIIA-FIME-UANL
Garcia Salazar, Octavio	CIIIA-FIME-UANL

This paper presents a consensus-based coordination protocol, using a fuzzy logic gain scheduling algorithm, for the formation flight of multiple quadrotors UAVs. The Newton-Euler approach is used to present the equations of motions for the multiple quadrotors UAVs. The formation flight consists of a distributed approach. Real-time experiments are presented in order to test the capabilities of the online tuning of consensus parameters, as well as a comparison with a fixed gain protocol. In effect, the variable gain consensus protocol shows a smoother output while maintaining a robust performance against induced wind gusts, in comparison with fixed gain coordination approach.

11:40-12:00 ThA3.6

Model Based Roll Controller Tuning and Frequency Domain Analysis for a Flying-Wing UAS, pp. 713-720

Flanagan, Harold	University of Kansas
Chao, Haiyang	University of Kansas
Hagerott, Steven G.	Textron Aviation

System identification and model-based controller design is an increasingly important area for UAS research. As UASs are used in more challenging conditions, it is critical to have accurate system identification, controller design, and controller validation for improved aircraft safety. The roll controller of a flying-wing UAS is examined in this paper including aircraft system identification, controller design, and controller validation. This paper also introduces a new procedure for utilizing frequency domain analysis to identify and validate the lateral directional models and roll controller design of a UAS. Good agreement is observed between simulated roll controller performance and UAS flight test results, which showed the effectiveness of the overall system identification and control design practice.

ThA4	Savannah
Energy Efficient UAS (Regular Session)	
Chair: Ollero, Anibal	Universidad De Sevilla
Co-Chair: Bezzo, Nicola	University of Virginia

10:00-10:20 ThA4.1

A Simple Model for Gliding and Low-Amplitude Flapping Flight of a Bio-Inspired UAV, pp. 721-729

Martín-Alcántara, Antonio	University of Seville
Grau, Pedro	Robotics, Vision and Control Group, University of Seville
Fernandez-Feria, Ramón	Fluid Mechanics, Andalucía Tech., University of Málaga
Ollero, Anibal	Universidad De Sevilla

Inspired by the efficiency of soaring birds in crossing very large distances with barely flap their wings, this work presents a simple model of UAV that, adopting the capabilities of these animals, could improve the existent multi-rotor devices, not only in efficiency but also in safety and accessibility. Thus, simple analytical approximations to reproduce the behavior of flapping wings UAVs are explored, expecting their integration in on-board CPUs to be solved in real-time flight episodes. A comparison between gliding and wing flapping with these models indicates that the thrust generated by wingstrokes should be controlled in further studies in order to mitigate the oscillations along the path of the vehicle. The geometric parameters of the ornithopter are found to be decisive in this sense, so special attention should be paid during the design stage.

10:20-10:40 ThA4.2

Multiphysical Modeling of Energy Dynamics for Multirotor Unmanned Aerial Vehicles, pp. 730-739

Michel, Nicolas	UC Davis
Sinha, Anish Kumar	University of California Davis
Kong, Zhaodan Kong	University of California, Davis
Lin, Xinfan	University of California, Davis

Energy performance, e.g. flight time and range, is currently a major challenge limiting the electric multirotor unmanned aerial vehicle (UAV). Improving UAV energy performance through design, control, and planning has received increasing attention lately. The basis for these efforts is an in-depth understanding of the underlying governing dynamics, which involves the aerodynamics of the rotor-propeller assembly, electro-mechanical dynamics of the motor and motor controller, electrical dynamics of the battery, and the rigid body dynamics of UAV. A system-level model incorporating all these dynamics, and more importantly, their coupling is missing in current literature. The goal of this paper is to fill this critical gap in the state of art. We first develop sub-models for each sub-system dynamics based on first principles, and then integrate them based on input-output coupling to formulate a system-level model. The model is capable of predicting the response of critical system variables and their mutual impact during the UAV flight operation. One key observation is that battery voltage can drop by ~16% due to the energy consumed by propulsion, which in turn causes ~14% decrease in rotor speed and ~24% decline in torque and thrust (under the same actuation command) over the course of flight.

10:40-11:00 ThA4.3

Propulsion System Modeling for Small Fixed-Wing UAVs, pp. 740-749

Coates, Erlend M.	Norwegian University of Science and Technology
Wenz, Andreas Wolfgang	Norwegian University of Science and Technology
Gryte, Kristoffer	Norwegian University of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology

This paper presents a model of an electrical propulsion system typically used for small fixed wing unmanned aerial vehicles (UAVs). Such systems consist of a power source, an electronic speed controller and a brushless DC motor which drives a propeller. The electrical, mechanical and aerodynamic subsystems are modeled separately and then combined into one system model, aiming at bridging the gap between the more complex models used in manned aviation and the simpler models typically used for UAVs. Such a model allows not only the prediction of thrust but also of the propeller speed and consumed current. This enables applications such as accurate range and endurance estimation, UAV simulation and model-based control, in-flight aerodynamic drag estimation and propeller icing detection. Wind tunnel experiments are carried out to validate the model, which is also compared to two UAV propulsion models found in the literature. The experimental results show that the model is able to predict thrust well, with a root mean square error (RMSE) of 2.20 percent of max thrust when RPM measurements are available, and an RMSE of 4.52 percent without.

11:00-11:20 ThA4.4

Grid-Based Coverage Path Planning with Minimum Energy Over Irregular-Shaped Areas with UAVs, pp. 750-759

Cabreira, Tauã	Universidade Federal De Pelotas
Di Franco, Carmelo	University of Virginia
Ferreira Jr., Paulo R.	Universidade Federal De Pelotas
Buttazzo, Giorgio	Scuola Superiore Sant'Anna

Grid-based methods have been proposed to solve the Coverage Path Planning problem using Unmanned Aerial Vehicles in irregular-shaped areas since simple geometric flight patterns, such as the back-and-forth, are inefficient in this type of scenario. However, the grid-based methods usually apply simplistic cost functions and demand high computational time leading to inefficient and expensive paths, making them not usable in real-world scenarios. This paper introduces an energy-aware grid-based approach aimed at minimizing energy consumption during mapping missions over irregular-shaped areas. Our work was built upon a previously proposed grid-based approach. Here we introduce an energy-aware cost function based on an accurate energy model. The proposed approach was able to save up to 17% of energy in real flight experiments, proving that the original cost function was not capable of finding the optimal solution in terms of real energy measurements. Additional simulation experiments were also performed to state the energy savings in different irregular-shaped scenarios. As a further contribution, we also applied two pruning techniques to the original approach dropping the computation time up to 99%.

11:20-11:40 ThA4.5

Exploiting Ground and Ceiling Effects on Autonomous UAV Motion Planning, pp. 760-769

Gao, Shijie	University of Virginia
Di Franco, Carmelo	University of Virginia
Carter, Darius	University of Virginia
Quinn, Daniel	University of Virginia
Bezzo, Nicola	University of Virginia

Micro aerial vehicles (MAVs) and in particular quadrotors have gained a lot of attention because of their small size, stable, robust, and diverse sensing capabilities that make them a perfect test bed in several safety critical operations. Shrinking these vehicles is desirable since agility increases. However, it entails smaller power sources and hence less flight time. Adding sensors on these systems also implies more energy consumption due both to the added weight and the supplied energy to the sensors. In this work, we build a framework to leverage the flow dynamic effects near surfaces to recognize grounds and ceilings during operations and to plan a trajectory while minimizing energy consumption. Our proposed framework leverages data from real experiments to model the behavior of the system near surfaces and graph theoretical approaches for energy efficient motion planning. As a result, this study indicates that i) we can detect surfaces during operations without the need of extra onboard sensors and ii) we can minimize energy consumption up to 15% when the system can fly near ground or ceiling surfaces. The proposed framework is validated with experimental results on a quadrotor UAV.

11:40-12:00 ThA4.6

Mission Planning Strategy for Multirotor UAV Based on Flight Endurance Estimation, pp. 770-778

Schacht Rodríguez, Ricardo	Centro Nacional De Investigacion Y Desarrollo Tecnologico
Ponsart, Jean-Christophe	Université De Lorraine
Garcia Beltran, Carlos Daniel	Centro Nacional De Investigación Y Desarrollo Tecnológico
Astorga-Zaragoza, Carlos	TecnolÓgico Nacional De MÉxico - Cenidet
Theilliol, Didier	University of Lorraine

In order to extend the flight capabilities and to improve the energy consumption of multirotor UAV, a mission planning strategy dependent on flight endurance estimation is presented. The flight endurance usually represents the time from take-off to landing and it is closely related to energy capabilities of the power source on-board. To execute a mission for a certain application requires an accurate measurement or estimation of the total flight endurance during the progress of the mission or even before to launch it to determine the flight limitations. In that sense, this paper proposes a mission planning strategy based on flight endurance estimation considering model-based Prognosis techniques for known and outdoor environments. By considering the mathematical model of propulsion system (Brushless DC motors and battery) an endurance model able to determines the total flight endurance before to launch a mission is proposed. Then, by means of a model-based Prognosis approach the flight endurance is estimated during the flight and the remaining mission time is computed in order to verify if the initial mission requirements are satisfied or not to fulfill the mission

ThB1	Heritage B
Path Planning IV (Regular Session)	
Chair: Morrison, James R.	KAIST
Co-Chair: Ahmadian, Navid	University of Houston

13:30-13:50 ThB1.1

A Study on 3D Optimal Path Planning for Quadcopter UAV Based on D Lite*, pp. 779-785

Kim, Hyowon	Pusan National University
Jeong, Jinseok	Pusan National University
Kim, Namyool	Pusan National University
Kang, Beomsoo	Pusan National University

Since unmanned aerial vehicle (UAV) for industries are operated in complex low altitude environments, planning feasible paths is a necessary feature to achieve mission goals. D* Lite is applicable for industrial complex that uncertainties exist. This paper focuses on 3D path planning for quadcopter UAV based on D* Lite. Simulation results show that the algorithm can be applied in cluttered static and dynamic environments including unknown obstacles. In addition, when some waypoints exist, the proposed algorithm is able to optimize the global path by determining visit order. Therefore, this study is expected to contribute to increase the application of UAVs in industrial fields.

13:50-14:10 ThB1.2

Collision-Free Multi-UAV Flight Scheduling for Power Network Damage Assessment, pp. 786-790

Ahmadian, Navid	University of Houston
Lim, Gino	University of Houston
Torabbeigi, Maryam	University of Houston
Kim, Seon Jin	Republic of Korea Army

This paper discusses the unmanned aerial vehicles (UAVs) flight scheduling problem in the context of power networks damage assessment. We propose a mixed-integer programming model to determine the optimal collision-free schedule for multiple UAVs. It is essential to perform the damage assessment procedure in the least amount of time in order to quickly repair the network. Hence, our goal is to minimize the make span which equals the total operation time of the UAVs until the last task (i.e., the lengthiest) is complete. As the power networks are complex structures, there is a high probability of collision among the inspecting UAVs. To address this issue, we separate the arrival times of two UAVs so that no more than one UAV can be around each node at a given time interval. Using the proposed model, the optimal flight scheduling is provided for a randomly generated graph instance. The results of the numerical instance indicate that our approach reduces the possibility of collision between UAVs by creating a gap between their arrival time to each node.

14:10-14:30 ThB1.3

Multi-UAS Path-Planning for a Large-Scale Disjoint Disaster Management, pp. 791-799

Choi, Younghoon	Georgia Institute of Technology
Choi, Youngjun	Georgia Institute of Technology
Briceno, Simon	Georgia Tech
Mavris, Dimitri	Georgia Institute of Technology

A UAS-based disaster management method has been adopted to monitor the disaster impact and protect human lives since it can be

rapidly deployed, execute an aerial imaging mission, and provide a cost-efficient operation. In the case of a wildfire disaster, a disaster management is highly complex because of large-scale wildfires that can occur simultaneously and disjointly in a large area. In order to effectively manage these large-scale wildfires, it requires multiple UAS with multiple ground stations. However, conventional UAS-based management methods rely on a single ground station that can have a limitation to handle the large-scale wildfire problem. This paper presents a new path-planning framework for UAS operations including a fleet of UAVs and multiple ground stations. The framework consists of two parts: creating coverage paths for each wildfire and optimizing routes for each UAV. To test the developed framework, this paper uses representative wildfire scenarios in the State of California.

14:30-14:50	ThB1.4

A UAV Resolution and Waveband Aware Path Planning for Onion Irrigation Treatments Inference, pp. 800-804

Niu, Haoyu	UC, Merced
Zhao, Tiebiao	MESA LAB at UC Merced
Wang, Dong	USDA ARS Parlier
Chen, YangQuan	University of California, Merced

In the past few years, unmanned aerial vehicles (UAVs), also called drones, have been widely used in precision agriculture applications, such as water stress estimation, pest monitoring, and crop yield estimation, because of the development of UAV technology and remote sensing sensors. However, how to collect data effectively can still be a big challenge. Many UAV tunable parameters can have significant impact on data quality and the data analysis, such as flight height, flight time, overlapping, and airspeed. And, little work has been done regarding to how to extract high-resolution multispectral or thermal images with limited ground-truth measurements. Therefore, in this paper, a UAV resolution and waveband aware design was conducted in order to optimally collecting remote sensing aerial images with drones. Then, the flight mission design was tested in an onion field at USDA (United States Department of Agriculture) during the growing season in 2017. Based on the research results, drones successfully provide farmers and researchers the fundamental knowledge of irrigation management to identify irrigation non-uniformity. Using multispectral and thermal images collected by drones, we are able to apply supervised learning methods to find the relationship between image features and onions irrigation treatments. It also found out that how drones' flight height or resolution settings affect the accuracy of estimating onions irrigation treatment. Different spectral bands combination also has effect on onion irrigation treatment prediction.

14:50-15:10	ThB1.5

Data Quality Aware Flight Mission Design for Fugitive Methane Sniffing Using Fixed Wing SUAS, pp. 805-810

Hollenbeck, Derek	MESA Lab at UC Merced
Dahabra, Moataz	MESA Lab at UC Merced
Christensen, Lance	JPL
Chen, YangQuan	University of California, Merced

This paper describes a data quality aware framework for developing a repeatable flight mission design for fugitive methane sniffing missions using fixed wing small unmanned aerial systems (sUAS) in rural areas. The design outlines general aircraft requirements & performance characteristics as well as overviews required sensors and their performance & data quality considerations. Using Gaussian plume models, atmospheric stability and detection experiments from previous works - we outline a mission design that focuses on detection of downwind plume using a two-flux plane flight path. This mission design aims to aid future efforts in improving flux quantification accuracy, uncertainty and comparison between individual experiments.

15:10-15:30	ThB1.6

A Unified Framework for Reliable Multi-Drone Tasking in Emergency Response Missions, pp. 811-819

Terzi, Maria	KIOS Research and Innovation Center of Excellence, University of Cyprus
Kolios, Panayiotis	University of Cyprus
Panayiotou, Christos	University of Cyprus
Theocharides, Theocharis	University of Cyprus

In this paper a unified framework is presented for coordinated multi-drone tasking in emergency response missions. As elaborated hereafter, response missions consist of a number of distinct tasks that can be assigned among the available agents to expedite the response operations. The proposed framework enables the development and execution of algorithms that jointly schedule and route drone agents across the field to complete their tasks and successfully address the mission goals considering the agent limitations. The key design challenges of implementing the proposed framework are discussed. Finally, initial simulation and experimental results are presented providing evidence of the real life applicability and reliability of the proposed framework.

ThB2	Heritage C
UAS Applications IV (Regular Session)	
Chair: Quagliotti, Fulvia	Politecnico Di Torino

13:30-13:50	ThB2.1

Patrolling a Terrain with Cooperative UAVs Using Random Walks, pp. 820-829

Caraballo de la Cruz, Luis Evaristo	University of Seville
Díaz-Báñez, José-Miguel	University of Seville
Fabila-Monroy, Ruy	Cinvestav
Hidalgo-Toscano, Carlos	Cinvestav

A group of UAVs can be used to efficiently patrol a terrain, in which each robot flies around an assigned area and shares information with the neighbors periodically in order to protect or supervise it. To ensure robustness, previous works propose sending a robot to the neighboring area in case it detects a failure. In order to add unpredictability and to improve on the efficiency in the deterministic patrolling scheme, this paper presents random strategies to cover the areas distributed among the agents. We evaluate these strategies using three metrics: the idle-time, the isolation-time and the broadcast-time. The idle-time is the expected time between two consecutive observations of any point of the terrain. The isolation-time is the expected time that a robot is isolated (that is, without communication with any other robot). The broadcast-time is the expected time elapsed from the moment a robot emits a message until it is received by all the other robots of the team. Simulations show that the random strategies outperform the results obtained with the deterministic protocol.

13:50-14:10	ThB2.2

Rapid and Automated Urban Modeling Techniques for UAS Applications, pp. 830-839

Choi, Youngjun	Georgia Institute of Technology
Pate, David	Research Engineer
Briceno, Simon	Georgia Tech
Mavris, Dimitri	Georgia Institute of Technology

Urban models for testing UAV path-planning algorithms commonly apply simple representations using cuboid or cylindrical shapes which may not capture the characteristics of a urban environment. To address this limitation of existing urban models, this paper presents two urban modeling techniques for an unmanned aircraft flight simulation in an urban environment. The first proposed urban modeling technique is an airborne LiDAR source-based approach that incorporates machine learning algorithms to identify the number of buildings and characterize them from the LiDAR information. The second proposed urban modeling technique is an artificial urban modeling technique without any airborne LiDAR resources that applies an adaptive spacing method, an iterative algorithm to define an artificial urban environment. Unlike the LiDAR source-based approach that creates an approximated urban model, the adaptive spacing-based urban modeling algorithm generates an artificial urban environment that is visually different from a reference city but has similar the characteristics to it. To demonstrate the two proposed urban modeling techniques, numerical simulations are conducted using open-source datasets to construct several realistic urban models.

14:10-14:30 ThB2.3

Communication Technology for Unmanned Aerial Vehicles: A Qualitative Assessment and Application to Precision Agriculture, pp. 840-847

Neji, Najett — Université Paris Saclay
Mostfa, Tumader — Université Paris Saclay

In this paper, we develop a generic approach to determine the best technology to carry the communication between an Unmanned Aerial Vehicle (UAV) and a ground control station (GCS). For this, we consider that the UAV is performing its task under nominal conditions. Based on related work, we select the most relevant criteria of interest. Then, we compare technologies performances in the 2.4 GHz and 5.8 GHz ISM bands, using a multi-criteria analysis. Technology assessment results depend on the use-case and the UAV scenario. In this work, we are focused on the precise agriculture (PA) use-case, and we present the assessment results in both Visual Line of Sight (VLOS), Extended Visual Line of Sight (EVLOS), as well as Beyond Line of Sight (BVLOS) scenarios. The latter is very interesting because the communication UAV - GCS becomes of critical importance.

14:30-14:50 ThB2.4

UAVs at Your Service: Towards IoT Integration with HAMSTER, pp. 848-857

Rodrigues, Mariana — Universidade De São Paulo
Branco, Kalinka Regina Lucas Jaquie Castelo — University of São Paulo

Due to their characteristics, Unmanned Aerial Vehicles (UAVs) are natural candidates to be integrated to the Internet of Things (IoT). However, offering UAV services through the IoT and Cloud Computing is not an easy task. Resources and services made available to clients need to be properly identified and registered; the UAV must be prepared to provide services autonomously to both human and machine clients, which can be very heterogeneous regarding to computational and networking resources; information security and data privacy must be taken into account. In this paper, we present the Service Exchange Management Unit (SEMU), a service provision platform for UAVs that aims to support service exchange taking into account portability and security issues. The platform design and operation are outlined, exposing how SEMU can support UAVs and other types of vehicles to provide services to each other and to external clients, making it possible for them to be integrated in the IoT.

14:50-15:10 ThB2.5

Urban Monitoring of Smart Communities Using UAS, pp. 858-865

Pannozzi, Pierluigi — Polytechnic University of Turin
Valavanis, Kimon — University of Denver
Rutherford, Matthew — University of Denver
Guglieri, Giorgio — Politecnico Di Torino
Scanavino, Matteo — Politecnico Di Torino
Quagliotti, Fulvia — Politecnico Di Torino

Unmanned Aircraft Systems (UAS) have become prevalent for a wide spectrum of civilian applications. Support tools and technologies for UAS-based monitoring of smart cities and communities are under development, where Unmanned Aerial Vehicles (UAVs) are the main means of implementation. UAVs provide the eye-in-the-sky alternative to ground-based monitoring, contributing to safety, early anomaly detection and possibly prediction, and improving everyday quality of life with little disruption of, and interference with, humans. This paper presents a simulated real-world environment and accurate model of the city of Turin (Italy) and implements it in the Gazebo software physics simulator, with the aim of monitoring the city. The environment allows for piloting and navigating UAVs with on-board cameras and other onboard sensors through a Ground Control Station (GCS), or through manual direct piloting. Simulated scenarios illustrate monitoring over the perimeter of the urban area, autonomous flight, partially autonomous flight and manual piloting of the UAV. It is expected that obtained results will pave the way to developing complex simulated world environments where candidate scenarios will be developed and executed before real world testing.

ThB3 Heritage A

Sensor Fusion I (Regular Session)

Chair: Pereira, Guilherme — West Virginia University

13:30-13:50 ThB3.1

Increasing Perception Space of a Ground Standing Robot Via Data Transmission from an Aerial Robot, pp. 866-874

Sohn, Kiwon — University of Hartford
Murshid, Mohammad — University of Hartford

In this paper, an approach to increase perception space of a ground standing robot via data transmission from an aerial robot is presented. Since the collected point cloud data from two robots have different coordinates, a rigid registration-based approach is applied to align the coordinate of the aerial robot's perception space to the ground robot's one. First, the static markers which are attached to the base position of the ground robot are used to compute the transformation. However, they did not work properly when the markers are accidentally invisible due to its kinematic limits. To solve the issue, the dynamic markers which are attached to both fixed (base) and movable links of the ground robot are also studied. To account for kinematic changes of dynamic markers, forward kinematics of the ground robot's limb is iteratively updated and applied to the rigid transformation computation. The both approaches were tested and evaluated through experiments with a full-sized armed robot and a drone in a mock-up of task field.

13:50-14:10 ThB3.2

Perceptual Ability Advancement of a Humanoid with Limited Sensors Via Data Transmission from an Aerial Robot, pp. 875-881

Sohn, Kiwon — University of Hartford
Murshid, Mohammad — University of Hartford

This paper presents an approach to increase the perceptual space of a ground robot (humanoid which has limited sensory abilities) via its accompanying aerial robot's data transmission. First, the robot which has only 2D camera sensor used the hip-sway motion to predict the target's 3D position and orientation in its sensor coordinate. The pose data is refined with a iterative method using the ego-motion estimation of the humanoid. Then, the neighboring drone which is equipped with 3D camera system is controlled to detect the same target object. The measured pose of the target object in the aerial robot's perceptual space is combined with the object's calculated coordinate (which is constructed from the humanoid's 2D sensor). The fusion process enabled the localization of the humanoid in the drone's collected 3D point cloud data of the task environments. The combined coordinates are then used for motion-planning of the humanoid for its safe and effective task manipulation in the field. Through experiments with a small-sized humanoid robot and a drone, the presented approach is tested and evaluated in a mock-up of the task field.

14:10-14:30 ThB3.3

State Estimation for Aerial Vehicles in Forest Environments, pp. 882-890

Chiella, Antonio Carlos Bana Chiella	Federal University of Minas Gerais
Teixeira, Bruno Otávio S.	Federal University of Minas Gerais
Pereira, Guilherme	West Virginia University

Autonomous navigation of unnamed vehicles in a forest is a challenging task. In such environments, due to the canopies of the trees, GNSS-based navigation can be degraded or even unavailable. In this paper we propose a state estimation solution for aerial vehicles based on the fusion of GNSS, AHRS and LIDAR-based odometry. In our LIDAR odometry solution, the trunks of the trees are used in a feature-based scan-matching algorithm to estimate the relative movement of the vehicle. Our method uses a robust adaptive fusion algorithm based on the unscented Kalman filter. Experimental data collected during the navigation of a quadrotor in an actual forest environment is used to demonstrate the effectiveness of our approach.

14:30-14:50 ThB3.4

Deep Learning Based Semantic Situation Awareness System for Multirotor Aerial Robots Using LIDAR, pp. 891-900

Sanchez-Lopez, Jose Luis	SnT, University of Luxembourg
Sampedro, Carlos	University
Cazzato, Dario	Interdisciplinary Centre for Security, Reliability and Trust
Voos, Holger	University of Luxembourg

In this work, we present a semantic situation awareness system for multirotor aerial robots, based on 2D LIDAR measurements, targeting the understanding of the environment and assuming to have a precise robot localization as an input of our algorithm. Our proposed situation awareness system calculates a semantic map of the objects of the environment as a list of circles represented by their radius, and the position and the velocity of their center in world coordinates. Our proposed algorithm includes three main parts. First, the LIDAR measurements are preprocessed and an object segmentation clusters the candidate objects present in the environment. Secondly, a Convolutional Neural Network (CNN) that has been designed and trained using an artificially generated dataset, computes the radius and the position of the center of individual circles in sensor coordinates. Finally, an indirect-EKF provides the estimate of the semantic map in world coordinates, including the velocity of the center of the circles in world coordinates.

We have quantitative and qualitative evaluated the performance of our proposed situation awareness system by means of Software-In-The-Loop simulations using VRep with one and multiple static and moving cylindrical objects in the scene, obtaining results that support our proposed algorithm. In addition, we have demonstrated that our proposed algorithm is capable of handling real environments thanks to real lab experiments with non-cylindrical static (i.e. a barrel) and moving (i.e. a person) objects.

14:50-15:10 ThB3.5

Networked Radar Systems for Cooperative Tracking of UAVs, pp. 901-907

Anderson, Brady	Brigham Young University
Ellingson, Jaron	Brigham Young University
Eyler, Michael	Brigham Young University
Buck, David	Brigham Young University
Peterson, Cameron	Brigham Young University
McLain, Timothy W.	Brigham Young University
Warnick, Karl	Brigham Young University

To enable expanded and safer access for unmanned aerial vehicles in the National Airspace System, a reliable system to detect and track them needs to be established. This paper combines two radar systems into a single network to provide tracking of UAVs across a wide area. Each radar detects the UAV's path and those detections are combined into tracks using a recursive random sample consensus algorithm. Outdoor flight experiments show the ability of the system to track a UAV across two different radar fields of view.

15:10-15:30 ThB3.6

Depth Map Estimation Methodology for Detecting Free-Obstacle Navigation Areas, pp. 908-914

Trejo, Sergio Marcelino	Centro De Investigaciones En Optica
Martínez, Karla	Centro De Investigaciones En Óptica
Flores, Gerardo	Center for Research in Optics

This paper presents a vision-based methodology which makes use of a stereo camera rig and a one-dimension LiDAR to estimate free obstacle areas for a quadrotor navigation. The presented approach fuses information provided by a depth map from a stereo camera rig, and the sensing distance of the 1D-LiDAR. Once the depth map is filtered with a Weighted Least Squares filter (WLS), the information is fused through a Kalman filter algorithm. To determine if there is a free space large enough for the quadrotor to pass through, our approach marks an area inside the disparity map by using the Kalman Filter output information. The whole process is implemented in an embedded computer Jetson TX2 and coded in the Robotic Operating System (ROS). Experiments demonstrates the effectiveness of our approach.

ThB4 Savannah

Airspace Management (Regular Session)

Chair: Ko, Woo-Hyun — Texas A&M University

13:30-13:50 ThB4.1

Optimum Design for Drone Highway Network, pp. 915-921

Hamanaka, Masatoshi	RIKEN

This paper describes a design method for drone highway networks to eliminate the risk of conflict between drones and to improve the overall flight efficiency. Many flight path designing methods have been proposed; however, none of them addresses the issue of flight efficiency. We optimize each path using ant colony optimization and optimize the position of the terminal connecting the paths using particle swarm optimization. Experimental results show that the proposed method improves flight efficiency by 15.6% on average.

13:50-14:10 ThB4.2

Distributed Bidding-Based Detect-And-Avoid for Multiple Unmanned Aerial Vehicles in National Airspace, pp. 922-928

Scott, Drew	University of Cincinnati
Radmanesh, Mohammadreza	University of Cincinnati
Sarim, Mohammad	University of Cincinnati
Deshpande, Aditya	University of Cincinnati
Kumar, Manish	University of Cincinnati
Pragada, Ravikumar	InterDigital Communications

Unmanned Aerial Vehicles (UAVs) have great potential in civilian applications, such as package delivery, agriculture, and disaster management. The number of UAVs in these applications will continue to increase, and thus so does the importance of safely integrating them into the National Airspace System (NAS), with one key component being the management of UAV traffic. Agents may be given pre-planned paths from a mediator traffic management system, but a system must also be implemented to resolve conflicts arising from issues such as deviation from pre-planned paths or uncooperative agents. Deviations can occur from any number of factors, and a proper traffic management framework must be capable of resolving these conflicts. Proposed here is a Detect-and-Avoid (DAA) system that will resolve conflicts between UAVs in the airspace in a distributed bidding-based method. The results show this approach can be scaled to a system with a large number of UAVs, and will provide near-optimal solutions in a dynamic environment.

14:10-14:30 ThB4.3

A Lane-Based Approach for Large-Scale Strategic Conflict Management for UAS Service Suppliers, pp. 929-937

Sacharny, David — University of Utah

Henderson, Thomas — University of Utah

This paper provides a detailed airspace capacity analysis for the Federal Aviation Administration's Unmanned Aircraft System (UAS) Traffic Management (UTM) concept of operations. Prior work has addressed aspects of this problem under specific assumptions about individual behavior of operators (human and autonomous) and the structure of the airspace, however recent discussions held between NASA and industry stakeholders indicate that cooperation will be necessary to minimize the need for tactical collision avoidance. This problem is referred to as Strategic Conflict Management and it imposes constraints on the system that can become computationally intractable. In this paper, an airspace structure inspired by roadway roundabouts, and a computationally tractable trajectory scheduling algorithm for UAS Service Suppliers (USS) are presented to solve this problem.

14:30-14:50 ThB4.4

Probability-Based Collision Detection and Resolution of Planned Trajectories for Unmanned Aircraft System Traffic Management, pp. 938-943

Ko, Woo-Hyun — Texas A&M University

Kumar, P. R. — TAMU

We address the problem of traffic management of an unmanned aircraft system. In an effort to improve the performance with safety, we propose a probability-based collision resolution algorithm. The proposed algorithm analyzes the planned trajectories to calculate their collision probabilities, and modifies individual drone starting times to reduce the probability of collision, while attempting to preserve high performance. Our simulation results demonstrate that the proposed algorithm improves the performance of the drone traffic management by guaranteeing high safety with minimal modification of the starting times.

14:50-15:10 ThB4.5

Evolutionary Optimization-Based Mission Planning for UAS Traffic Management (UTM), pp. 944-950

Tan, Qingyu — Air Traffic Management Research Institute

Wang, Zhenkun — Nanyang Technological University

Yew Soon, Ong — Nanyang Technological University

Low, Kin Huat — Nanyang Technological University

In this work, we propose a route planning scheme for large scale Unmanned Aircraft System (UAS) or multiple-drone operations in complex urban air space. The route planning system consists of a path finding algorithm and a scheduling system for safe and efficient uses of airspace. The work flow of the system is: first, generate shortest paths between origination and destination points via heuristic search and second, schedule the submitted flights to avoid possible conflicts. The scheduling process is performed by Evolutionary Algorithm (EA). Such a system would postpone or delay flight requests that may collide with previous flights and reject the conflicted flights. We also propose a fitness function for the EA to minimize both the total delay of the flight requests and the possibility of UAS collision. To demonstrate the feasibility of the proposed route planning models, preliminary simulations in a local town in Singapore are presented and discussed.

15:10-15:30 ThB4.6

Enable UAVs Safely Flight in Low-Altitude: A Preliminary Research of the Public Air Route Network of UAVs, pp. 951-956

Liao, Xiaohan — Institute of Geographic Science and Natural Resources Research,

Xu, Chenchen — Institute of Geographic Sciences and Natural Resources Research,

Yue, Huanyin — Institute of Geographic Science and Natural Resources Research,

Increasing numbers and industrial applications for UAVs acquire much airspace for low-altitude flights. However, unknow and changeable environment has hindered UAVs' rapid development. To enable UAVs flight safely and legally at low-altitude, this paper proposed a concept of "low-altitude public air route network (LAPAR)" and presented key technologies. Specifically, Firstly, a four-level air route system were proposed; Secondly, a low-altitude flight environment consisting of various constraints of UAV flights, such as climate, buildings, communication and mountains was constructed by modeling and gridding technology; Thirdly, the optimum path was searched by the improved Ant Colony Optimization (ACO) algorithm; Lastly, a network of the public air route was constructed by formulating traffic management regulation for UAV flight in air routes. And a route map in Tianjin has also been obtained. This research can regulate low-altitude air traffic management, improve the utilization of low-altitude airspace resources, and ensure aviation and public safety.

ThC1 — Heritage B

See-And-Avoid Systems (Regular Session)

Chair: Briese, Christoph — Deutsches Zentrum Für Luft Und Raumfahrt E.V

16:00-16:20 ThC1.1

Below Horizon Aircraft Detection Using Deep Learning for Vision-Based Sense and Avoid, pp. 957-962

James, Jasmin — Queensland University of Technology

Ford, Jason — Queensland University of Technology

Molloy, Timothy L. — Queensland University of Technology

The commercial operation of unmanned aerial vehicles (UAVs) would benefit from an onboard capability to sense and avoid (SAA) potential mid-air collision threats in the same manner expected from a human pilot. In this paper we present a new approach for detection of aircraft below the horizon. We address some of the challenges faced by existing vision-based SAA methods such as detecting stationary aircraft (that have no relative motion to the background), rejecting moving ground vehicles, and simultaneous detection of multiple aircraft. We propose a multi-stage vision-based aircraft detection system which utilises deep learning to produce candidate aircraft that we track over time. We evaluate the performance of our proposed system on real flight data where we demonstrate detection ranges comparable to the state of the art with the additional capability of detecting stationary aircraft, rejecting moving ground vehicles, and tracking multiple aircraft.

16:20-16:40 ThC1.2

High-Speed Obstacle-Avoidance with Agile Fixed-Wing Aircraft, pp. 963-972

Bulka, Eitan — McGill University

Nahon, Meyer — McGill University

Agile fixed-wing aircraft aim to bridge the gap between rotor-craft and conventional fixed-wing aircraft, with the capability of maneuverable and even hovering flight like a rotor-craft, and of efficient long distance flight like a conventional fixed-wing aircraft. Avoiding obstacles in unknown environments is a challenging task with these platforms, as they have complicated dynamics and a limited payload, and they fly at high speeds. In this work, we present an obstacle-avoidance strategy that avoids collisions while steering the aircraft to the goal. The strategy does not rely on a prior map of the environment, or the ability to build a map in real-time, and can be run in real-time on-board the aircraft. We utilize a library of optimal

trajectories, both conventional and aerobatic maneuvers, that are solved off-line. A sequence of these trajectories is pieced together to form a collision-free motion plan within the field of view of the depth camera that steers the aircraft towards the goal region. We validate the approach in a high-fidelity simulation environment. The aircraft flies autonomously through a forest-like map to a goal region, using conventional maneuvers such as banked and helical turns, as well as aerobatic maneuvers such as an aggressive turnaround.

16:40-17:00 ThC1.3

Deep Learning with Semi-Synthetic Training Images for Detection of Non-Cooperative UAVs, pp. 973-980

Briese, Christoph	Deutsches Zentrum Für Luft Und Raumfahrt E.V
Günther, Lukas	Deutsches Zentrum Für Luft Und Raumfahrt E.V

This paper presents a method to generate a dataset for training a deep convolutional network to detect a non-cooperative unmanned aerial vehicle in video data. Deep convolutional network have shown a great potential for tasks like object detection and have been continuously improved in the last years. Still, the amount of training data is large and their generation can be complex and time consuming, especially if the appearance of the detected object is not clearly specified. The concept presented here is to train a deep convolutional neural network just with a few two-dimensional images of unmanned aerial vehicle to simplify the process of generating training data. Performance of the trained network is evaluated with data from real experimental flights and compared with hand-labeled ground truth data to validate the correctness. To cover situations when the classifier fails at the detection, the output is integrated in a image processing pipeline for object tracking in order to establish a continuous tracking.

17:00-17:20 ThC1.4

Flight Test Validation of Collision Avoidance System for a Multicopter Using Stereoscopic Vision, pp. 981-987

Ma, Demetria	California State Polytechnic University, Pomona
Tran, Alex	University
Keti, Nick	California Polytechnic University, Pomona
Yanagi, Ryan	Cal Poly Pomona
Knight, Peter	Cal Poly Pomona
Joglekar, Kedar	Cal Poly Pomona
Tudor, Nicholas	California State Polytechnic University, Pomona
Cresta, Burt	California Polytechnic State University Pomona
Bhandari, Subodh	California State Polytechnic University

This paper presents the flight test validation of collision avoidance system for a multicopter using stereovision technique. Stereoscopic vision offers an affordable, accessible, and effective method of collision detection. Using a ZED stereoscopic camera, depth maps were generated using image disparity to calculate the distance between the camera and obstacles in its view. An NVIDIA Jetson TX1 computer aboard the multicopter was used to process the depth maps to detect any obstacles in its flight path. The algorithm partitions the continuously updated depth maps in equal sections to determine the section containing obstacles. Once this section is chosen, a new vector is calculated to determine the “path of least resistance” and communicated to the onboard Pixhawk flight controller using DroneKit. Using these commands, the UAS maneuvers to safely correct its course and avoid the obstacle autonomously. Flight test objectives, procedures, and results are presented.

17:20-17:40 ThC1.5

Three-Dimensional (3D) Dynamic Obstacle Perception in a Detect-And-Avoid Framework for Unmanned Aerial Vehicles, pp. 988-996

Lim, Catrina	Nanyang Technological University
Li, Boyang	Nanyang Technological University
Ng, Ee Meng	Nanyang Technological University
LIU, XIN	Nanyang Technological University
Low, Kin Huat	Nanyang Technological University

In this paper, a 3D dynamic obstacle perception is developed in a detect-and-avoid (DAA) framework for unmanned aerial vehicles (UAVs) or drones. The framework requires only an end point coordinate for collision-free path-planning and execution in an environment with dynamic obstacles. The sense portion of the DAA framework takes data from an mmWave sensor and a depth camera while the detect portion of the framework updates a probabilistic octree when static and dynamic obstacles are sensed. Perception of dynamic obstacle was achieved by implementing an algorithm that clears the sensor's field of vision before computing the occupied voxels and populating the probabilistic octree. The avoidance portion of the framework is based on rapidly-exploring random tree (RRT) but the framework is flexible to allow other types of planners. This work develops the DAA framework for a UAV in a dynamic 3D environment by modifying the MoveIt framework. The framework is implemented on a UAV platform equipped with an on-board computational unit. The simulation and indoor experiments were conducted, which show that the modified DAA framework with dynamic 3D obstacle perception can successfully sense, detect and avoid obstacle. Additionally, the proposed perception method reduced the path re-plan time.

ThC2 Heritage C

UAS Applications V (Regular Session)

Chair: Peterson, Cameron	Brigham Young University
Co-Chair: Brandao, Alexandre Santos	Federal University of Vicosa

16:00-16:20 ThC2.1

The Urban Last Mile Problem: Autonomous Drone Delivery to Your Balcony, pp. 997-1004

Brunner, Gino	ETH Zurich
Szebedy, Bence	ETH Zurich
Tanner, Simon	ETH Zurich
Wattenhofer, Roger	ETH Zurich

Drone delivery has been a hot topic in the industry in the past few years. However, existing approaches either focus on rural areas or rely on centralized drop-off locations from where the last mile delivery is performed. In this paper we tackle the problem of autonomous last mile delivery in urban environments using an off-the-shelf drone. We build a prototype system that is able to fly to the approximate delivery location using GPS and then find the exact drop-off location using visual navigation. The drop-off location could, e.g., be on a balcony or porch, and simply needs to be indicated by a visual marker on the wall or window. We test our system components in simulated environments, including the visual navigation and collision avoidance. Finally, we deploy our drone in a real-world environment and show how it can find the drop-off point on a balcony. To stimulate future research in this topic we open source our code.

16:20-16:40 ThC2.2

Real-Time Single Object Detection on the UAV, pp. 1005-1014

Wu, Hsiang-Huang	PRAIRIE VIEW a and M UNIVERSITY

The demand for mission critical tasks, especially for tracking on the UAVs, has been increasing due to their superior mobility. Out of necessity, the ability of processing large images emerges for object detection or tracking with UAVs because the object cannot be recognized clearly from an image in low resolution when the UAV flies high. As such, the requirements of low latency and lack of internet access under some circumstances become the major challenges. In this paper, we present a modeling method of CNN that is dedicated to single object detection on the UAV without any transfer learning model. Not limited to the features learned by the transfer learning model, the single object can be selected arbitrarily and specifically, even can be distinguished from those other objects in the same category. Our modeling method introduces the inducing neural network that follows the traditional CNN and plays the role of guiding the training in a fast and efficient way with respect to the training convergence and the model capacity. Using the dataset released by DAC 2018, which contains 98 classes and 96,408 images taken by UAVs, we present how our modeling method develops the inducing neural network that integrates multi-task learning drawn from the state-of-the-art works to achieve about 50% of IoU (Intersection over Union of the ground- truth bounding boxes and predicted bounding boxes) and 20 FPS running on NVIDIA Jetson TX2. In the experiment, we collect the images from the drone and train a model for detecting the car. With our model, the drone can do the inference of an image in size of 720x1280 and navigate itself to track the car using the inference result in one second.

16:40-17:00	ThC2.3

Gesture Commands for Controlling High-Level UAV Behavior, pp. 1015-1022

Akagi, John	Brigham Young University
Moon, Brady	Brigham Young University
Chen, Xingguang	Sun Yat-Sen University
Peterson, Cameron	Brigham Young University

In this paper, an accelerometer and gyroscope are used to sense gesture commands, which are then classified using a logistic regression model. Seven gestures were chosen and mapped to specific behaviors that a fixed wing unmanned air vehicle could accomplish. These behaviors specified various searching, following, and tracking patterns that could be used in a dynamic environment. The system was trained to recognize the seven gestures and then tested in a hardware-in-the-loop simulation. The system was able to identify all gestures with an overall accuracy of 90% and with five of the seven gestures being accurately identified at least 94% of the time. Each of the behaviors associated with the gestures was tested in simulation and the ability to dynamically switch between behaviors was proven. The results show that the system can be used as a natural interface to assist an operator in directing an unmanned air vehicle's behavior.

17:00-17:20	ThC2.4

UAS-Based Crack Detection Using Stereo Cameras: A Comparative Study, pp. 1023-1027

Benkhoui, Yasmina	Worcester Polytechnic Institute
Reinhold, Ludwig	Worcester Polytechnic Institute
El Korchi, Tahar	Worcester Polytechnic Institute

Structural health monitoring and inspection of bridges are paramount to evaluating their current conditions and identifying the severity of potential defects. These may be indicative of spalls or reinforcement corrosion. As of today, 25% of all the bridges across the United States are rated structurally deficient or functionally obsolete [1]. Currently, health monitoring of bridges is a human-based visual inspection process, which is labor intensive, costly and potentially unsafe. Safety issues, significant cost, as well as traffic interruption highlight the need to explore a reliable, low-cost, quantitative and safe solution for bridge condition assessment. Drone inspections using Unmanned Aerial Systems (UAS) have recently attracted significant industrial and academic interest. Various technologies are being explored including Lidar, photogrammetry and depth sensors, with the latter being a promising innovative approach for accurate 3D object reconstruction. In this study, we investigate the use of stereo cameras based on passive and active depth calculation for the structural integrity assessment of bridges. We conduct an experiment to determine the RMS error of two different vision sensors: The Intel Realsense D435i and the ZED stereo camera from Stereolabs. Our results show that for our application, the Intel Realsense D435i provides more accurate information.

17:20-17:40	ThC2.5

Rod-Shaped Payload Transportation Using Multiple Quadrotors, pp. 1028-1032

Villa, Daniel Khede Dourado	Federal University of Espírito Santo
Brandao, Alexandre Santos	Federal University of Vicosa
Sarcinelli-Filho, Mário	Federal University of Espirito Santo

Aiming to address and contribute to the subject of load transportation using aerial vehicles, this work presents a cooperative system using two quadrotors to carry a rod-shaped load. The problem was treated as a virtual structure formation, treating the load and quadrotor as a line formation that needs to be accomplished. The load is carried in a cable-suspended manner, and a nonlinear controller based on feedback linearization was employed to fulfill the missions while minimizes the load oscillations. Experiments were conducted utilizing two AR.Drone 2.0 quadrotors, carrying an aluminum rod. The paper presents its results in illustrations and videos, showing the performance of the proposed algorithms and validating the proposals.

ThC3	Heritage A
Sensor Fusion II (Regular Session)	
Chair: Sun, Liang	New Mexico State University

16:00-16:20	ThC3.1

Observability Analysis and Bayesian Filtering for Self-Localization of a Tethered Multicopter in GPS-Denied Environments, pp. 1033-1039

Al-Radaideh, Amer	New Mexico State University
Sun, Liang	New Mexico State University

A main challenge for multicopter unmanned aerial vehicles (UAVs) is to consistently obtain its accurate position. The integration of the Inertial Navigation System (INS) and Global Positioning System (GPS) is a common strategy to compensate the accumulated drifting errors caused by the onboard Inertial Measurement Unit (IMU). In environments where the GPS signal is degraded or unavailable (e.g., cluttered, hostile, urban, and underwater areas), other solutions must be pursued for the multicopter localization. In this paper, a novel approach is presented that estimates the relative position of a multicopter tethered to a ground mobile platform. The proposed approach uses the measurements collected by solely the commercial-of-the-shelf (COTS) IMU onboard the multicopter. The observability analysis of the system is performed to demonstrate the validity of using a Bayesian filter that was developed to account for the uncertainty in the measurements. Simulation were conducted and the results showed that the developed Bayesian filter, with accurate localization estimates, outperforms a Low-Pass-Filtering approach that was developed by the authors before.

16:20-16:40	ThC3.2

An Estimation-Domain Approach to MEMS Multi-IMU Fusion for SUAS, pp. 1040-1045

Givens, Matthew	Utah State University
Coopmans, Calvin	Utah State University
Christensen, Randall	Utah State University

Small unmanned aerial systems (sUAS) require precise inertial state information at high temporal rates for the purposes of stability and navigation as well as to provide accurate attitude estimates to scientific payloads. Common sUAS inertial navigation systems implement a single strapdown inertial measurement unit (IMU), typically made up of an orthogonal triad of linear accelerometers and a similar triad of rate gyroscopes alongside a single GPS/GNSS receiver to accomplish this task. These outputs are fused optimally,

sometimes with other sensors, in an extended Kalman filter (EKF) architecture to generate reliable estimates of the vehicle states. This work develops an estimation-domain fusion strategy for combining the state estimates from multiple inertial navigation systems (INS) for the purposes of sUAS navigation and imaging. The algorithm is implemented in MATLAB and the results are presented.

16:40-17:00	ThC3.3

A Survey of Inertial Sensor Fusion: Applications in sUAS Navigation and Data Collection, pp. 1046-1052

Givens, Matthew	Utah State University
Coopmans, Calvin	Utah State University

Inertial sensor arrays, which in this context means sensor arrays composed of accelerometers, gyroscopes, or a combination of both, have been studied for many years and in many contexts. The literature is vast, highly redundant, and disparate and so it can be difficult to reconcile the many ways this problem has been approached. An outline of each of the different branches of the field of inertial sensor fusion is provided in order to aid newcomers and designers, particularly those who seek to apply past work to small Unmanned Aerial Systems (sUAS). Important works are noted and useful information and techniques are briefly presented.

17:00-17:20	ThC3.4

Robust Thermal-Inertial Localization for Aerial Robots: A Case for Direct Methods, pp. 1053-1060

Khattak, Shehryar	University of Nevada, Reno
Mascarich, Frank	University of Nevada, Reno
Dang, Tung	University of Nevada, Reno
Papachristos, Christos	University of Nevada Reno
Alexis, Kostas	University of Nevada, Reno

GPS-denied localization of aerial robots in sensing-degraded environments and especially in dark, texture-less and dust- or smoked-filled settings is rendered particularly hard. An alternative is to utilize Long Wave Infrared thermal vision which is unaffected by darkness and can penetrate most obscurants. However, utilization of thermal vision is mostly considered in combination with traditional visual-inertial odometry frameworks which are made for grayscale visible-light camera images and fail to utilize the full (e.g. 14-bit) radiometric information of a thermal camera system. Using rescaled thermal images makes the data compatible with existing vision-based odometry solutions yet comes at a cost of information loss which in turn can lead to unreliable tracking of image correspondences and thus to odometry estimation failure. An alternative is to use direct methods exploiting the full radiometric information provided by a thermal camera. This paper presents a comparative study between state-of-the-art visual-inertial odometry frameworks applied on rescaled thermal camera data against full radiometric information-based methods using a modified filter-based estimator and a recently proposed keyframe-based direct technique specifically designed for thermal-inertial localization. In a data-driven manner we demonstrate that direct full radiometric information-based thermal-inertial localization should be the prime selection especially in hard environments with weak thermal gradients. The presented results include comparison both inside a motion captured-controlled environment, and in an underground mine.

17:20-17:40	ThC3.5

A Software in the Loop (SIL) Kalman and Complementary Filter Implementation on X-Plane for UAVs, pp. 1061-1068

Michailidis, Michail	University of Denver
Agha, Mohammed	University of Denver
Rutherford, Matthew	University of Denver
Valavanis, Kimon	University of Denver

The paper presents a software in the loop (SIL) sensor study in simulation environments for traditional Kalman, linear and nonlinear complementary filters, which are derived, tested and implemented on a fixed wing UAV for attitude estimation (pitch, roll and heading angle). An overview of the SIL setup environment between MATLAB/Simulink and the X-Plane flight simulator is given. Kalman filter design in Simulink utilizes a state-space model of the UAV dynamics, while complementary filter combines accelerometer output for low frequency attitude estimation with integrated gyro output for high frequency estimation. Simulation results are provided and discussed under both Gaussian and uniform noise, highlighting the convergence of the designed estimators. It is also shown that the estimator following the nonlinear complementary framework yields a better match to the dynamic evolution of the actual attitude angles of the vehicle over time.

ThC4	Savannah
Airspace Control (Regular Session)	
Chair: Uchiyama, Kenji	Nihon University

16:00-16:20	ThC4.1

Linear Quadratic Formulation of the Target Defense Differential Game, pp. 1069-1075

Pachter, Meir	AFIT/ENG
Casbeer, David	Air Force Research Laboratories
Garcia, Eloy	AFRL

In this paper we revisit the Target Defense Differential Game and recast it as a linear quadratic differential game. In this game there are two players, a Defender and an Attacker; the target is stationary. The Attacker aims at the target trying to avoid the Defender while the Defender protects the target by blocking the Attacker's path to the target and trying to intercept the Attacker as far as possible from the target. The Attacker strives to minimize his distance from the Target at the moment of interception by the Defender. Each player is mindful of its energy expenditure by imposing appropriate quadratic weights on its control inputs. The analytical solution of this linear quadratic differential game is obtained in this paper which can be implemented in closed-loop form to provide robustness against non-optimal maneuvers by the opponent.

16:20-16:40	ThC4.2

Robust Trajectory Tracking for UAS: Dynamics Sliding Mode Approach, pp. 1076-1083

Reynoso, Martin	UPP
Ramos-Velasco, Luis Enrique	Universidad Politécnica Metropolitana De Hidalgo, México
Garcia-Rodriguez, Rodolfo	Metropolitan Polytechnic University of Hidalgo

This paper addresses the problem of Dynamics Sliding Mode Control (DSMC) design from a nonlinear and linear mathematical model of a Quadrotor system.

Conventional Unmanned Aerial Systems (UAS) requires control strategies while executes a mission entrusted, such as the classical work of trajectory tracking. For this purpose, it must remain very close to zero to satisfy the assumption of small angles approximation. However, this requirement may be valid for hover flight, but not for translational flights or aggressive maneuvers. In this paper a trajectory tracking control applied to rotorcraft systems without the classical systematic subdivision is presented to overcome this issue.

Simulations are presented to evaluate the performance and effectiveness of the proposed control scheme. These results show that the proposed strategy enables the UAS to track a desired trajectory while keeping the attitude close to the desired value.

16:40-17:00	ThC4.3

Controller Design Using Backstepping Algorithm for Fixed-Wing UAV with Thrust Vectoring System, pp. 1084-1088

Hirano, Shogo	Nihon University
Uchiyama, Kenji	Nihon University
Masuda, Kai	Nihon University

This paper describes the design method of nonlinear flight controller for a fixed-wing UAV with a thrust vectoring system (TVS) using the backstepping method. The flight dynamics of the UAV exhibits strong nonlinear coupling behavior between its translational and rotational motion. The backstepping algorithm has been successfully applied to controller design for such a nonlinear system. However, the main idea of the method is to use some of the state variables as virtual controls that need un-generatable forces by the UAV. To overcome this problem, we use the TVS that can generate thrust in an arbitrary direction. Numerical simulation is performed to confirm the effectiveness of the proposed control method for a fixed-wing UAV with the TVS.

17:00-17:20	ThC4.4

*Enhanced Hover-Mode Control of a Quad-Rotor Aircraft System Based on Nested Saturation Scheme**

Gonzalez-Hernandez, Ivan	CINVESTAV IPN
Hernandez, Jorge Luis	CINVESTAV IPN
Vazquez-Nicolas, Jesus Manuel	CINVESTAV IPN
Lozano, Rogelio	University of Technology of Compiègne

In this article, a robust nested saturation control scheme is proposed for the efficient attitude stabilization in the nonlinear Quad-rotor aircraft system in order to obtain a enhanced steady flight-mode. The proposed control scheme is based on the use of a classical nested saturation control and suitably extended to the robust stabilization problem in the presence of the external bounded disturbances appearing at the system input. As a result, we present a recursive design method to guarantee the asymptotic stability of the all states in closed-loop system introducing gains $k_1,...,k_n$ to the nested saturation control law to ensure robustness against of undesirable disturbances in the Quad-rotor system. The stability analysis is based on Lyapunov candidate functions for each of the states that constitute the control of the Quad-rotor vehicle and achieve the improved stationary flight. Finally, the analytic results are presented.

17:20-17:40	ThC4.5

Least Square Policy Iteration for IBVS Based Dynamic Target Tracking, pp. 1089-1098

Srivastava, Raunak	Indian Institute of Technology Bombay
Lima, Rolif	TCS Innovation Labs
Das, Kaushik	TATA Consultancy Service
Maity, Arnab	Indian Institute of Technology Bombay

This paper delves into the problem of tracking a maneuvering target based on only vision-based feedback namely Image Based Visual Servoing (IBVS). In the absence of a GPS or any other external sensor, vision proves to be a valuable source of information about the environment. However, it is difficult to perform the tracking using only a monocular vision due to the absence of depth measurement. This restricts the use of traditional IBVS methods as they rely on the interaction matrix which is sensitive to various camera parameters and depth estimate. We thus solve this problem through a learning-based approach and model it as Markov decision process, on which we apply a Reinforcement Learning technique. Least Square Policy Iteration (LSPI) learns the optimal control policies required to keep following the target drone while maintaining a fixed distance from it. The performance of the proposed algorithm is tested and simulated in Gazebo environment.

FrA1	Heritage B
UAV Design (Regular Session)	
Chair: Cawthorne, Dylan	University of Southern Denmark
Co-Chair: Kim, Yongjae	Agency for Defense Development

09:00-09:20 FrA1.1

Design and Shape Optimization of Unmanned, Semi-Rigid Airship for Rapid Descent Using Hybrid Genetic Algorithm, pp. 1099-1107

Singh, Vinay — University of Ottawa
Lanteigne, Eric — University of Ottawa

Airships provide an eco-friendly and cost-effective means to suit sustained airborne operations. Smaller autonomous airships are highly susceptible to adverse atmospheric conditions owing to their under-actuated, underpowered and bulky size relative to other types of unmanned aerial vehicle. To mitigate these limitations, careful considerations of the size and shape must be made at the design stage. This research presents a methodology for obtaining an optimized shape of a semi-rigid airship. Rapid descent of the LTA ship is achieved by means of a moving gondola attached to a rigid keel mounted under the helium envelope from the bow to the mid-section of the hull. The study entails the application of a robust hybrid genetic algorithm (HGA) for a multi-disciplinary design and optimization of an airship capable of rapid descent, with lower drag and optimum surface area. A comprehensive sensitivity analysis was also performed on the basis of algorithmic parameters and atmospheric conditions. With the help of HGA, a semi-rigid airship capable of carrying a payload of 0.25 kg to 1.0 kg and capable of pitching at right angles is conceptually designed. The algorithm is also tested on commercially available vehicles to validate the results.

09:20-09:40 FrA1.2

Preliminary Design, Modeling and Control of a Fully Actuated Quadrotor UAV, pp. 1108-1116

Nigro, MIchelangelo — Università Degli Studi Della Basilicata
Pierri, Francesco — Universita` Degli Studi Della Basilicata
Caccavale, Fabrizio — Universita Degli Studi Della Basilicata

In this paper a preliminary study on a new concept of fully actuated Unmanned Aerial Vehicle (UAV), named ODQuad (Omnidirectional Quadrotor), is presented. By exploiting two additional actuators, the designed UAV can simultaneously modify the tilting angle of all the propellers, in such a way to decouple position and attitude motions. This solution, differently from other fully actuated UAVs with tilted propellers, avoids internal forces and energy dissipation, due to non-parallel propellers' axes. A preliminary mechanical design and the kinematic and dynamic models are developed. Moreover, a motion control scheme, based on a hierarchical two loop, has been designed. Simulations are provided in order to show the feasibility of the concept and the effectiveness of the control scheme.

09:40-10:00 FrA1.3

Value Sensitive Design of a Humanitarian Cargo Drone, pp. 1117-1125

Cawthorne, Dylan — University of Southern Denmark
Cenci, Alessandra — University of Southern Denmark, Department of Philosophy, Institute

Value Sensitive Design (VSD) is an interdisciplinary approach to technological development that systematically incorporates ethical considerations and social impacts as design inputs. Here, the VSD methodology is described, and elements of VSD are applied with a technological focus to analyze an existing prototype humanitarian cargo drone. Then, a new proposed drone design that better supports the values of human welfare (physical, psychological, and material welfare), and environmental sustainability is developed. The new drone is a high-speed fixed-wing drone which uses internal combustion engines and drops its payload via parachute to minimize transportation time and maximize patient physical welfare. It uses lower levels of automation such as manual flight monitoring to increase reliability and safety (physical welfare) and support the local workforce (material welfare). The drone uses much less energy than the technology it replaces, and is therefore much more environmentally friendly, supporting environmental sustainability. This work contributes by being the first to apply VSD methods to the technological development of a specific drone platform, and by demonstrating how drone engineers can use VSD to develop "ethical" drones.

10:00-10:20 FrA1.4

Design of a Class I Unmanned Aircraft for Maritime Surveillance, pp. 1126-1135

Franco, Vasco — Academia Da Força Aérea Portuguesa
Correia, João — Academia Da Força Aérea Portuguesa
Caetano, Joao Vieira — Portuguese Air Force Research Center
Félix, Luís — Academia Da Força Aérea Portuguesa

The current paper's objective is to present the methodology used in the design of a class I unmanned aircraft (UA), intended for maritime surveillance, atmospheric pollution monitoring and search and rescue (SAR) missions. Its development encompasses conceptual and preliminary design, focusing on the integration of systems, performance, aerodynamics, stability, propulsion and composite structural design. Mission requirements are set to comply with the European Maritime Safety Agency's specifications. The approach to conceptual design follows a methodology in which the airplane is conceived in a step-by-step, iterative fashion, making use of empirical data and numerical information. In preliminary design, computational fluid dynamics (CFD) is employed in order to increase the level of accuracy and refine the design. Subsequently, the airframe design is performed through computer aided design (CAD) modelling, endorsed by a numerical stress analysis via a finite element analysis (FEA). As the project's output, a class I unmanned aircraft capable of not only meeting, but also surpassing the demanded mission requirements, is presented.

10:20-10:40 FrA1.5

Design Methodology of a Small Unmanned Airship with Optimized Fins, pp. 1136-1142

Suvarna, Sohan — IITB-Monash Research Academy
Chung, Hoam — Monash University
Pant, Rajkumar — Indian Institute of Technology-Bombay

This paper presents a novel method for the design of a small unmanned airship with stability considerations. Conventional design methods for airship envelope require the structure weight including the fin weight to be fixed before determining the envelope size. One of the shortcomings of the traditional methodology is that the weight budget of the fin drives the fin design. In contrast to the conventional design methods, our method estimates the envelope size and the fin weight budget simultaneously. Our approach also shows how an airship fin could be optimized to improve directional stability. The design of a small unmanned airship is also discussed in this paper to demonstrate the methodology.

10:40-11:00 FrA1.6

Optimal Guidance for Range Maximization of Guided Projectile: The Effects of Autopilot Delay and Fin Deployment Timing on the Flight Range, pp. 1143-1152

Kim, Yongjae	Agency for Defense Development
Kim, Gyeong Hun	Agency for Defense Development
Choi, Jae-Hyun	Agency for Defense Development

This study explores the effect of autopilot delay to the maximum flight range of guided projectile when the guidance command is calculated by optimization technique with considering fin deployment timing. The flight model of the guided projectile in vertical plane is developed, which includes the autopilot dynamics modeled as the first order delay system. The numerically derived optimal guidance command is scheduled to the flight simulation based on the energy height. The simulation results indicate that when we optimize the guidance command without considering the autopilot, the projectile with the time constant of the autopilot larger than 10 is not able to reach the maximum flight range. Even though autopilot delay is taken into account in the optimization process, the time constant of the autopilot may not be larger than $10^{1.5}$, otherwise the gliding performance is severely degraded. Furthermore, we show that the guided projectile with such autopilot delay is capable to reach the maximum range only with proper fin deployment timing no later than the optimal time, which is dependent on the initial state of the projectile.

FrA2	Heritage A
Autonomy I (Regular Session)	
Chair: Bezzo, Nicola	University of Virginia

09:00-09:20	FrA2.1

Singular Trajectories in the Two Pursuer One Evader Differential Game, pp. 1153-1160

Pachter, Meir	AFIT/ENG
Von Moll, Alexander	Air Force Research Laboratory
Garcia, Eloy	AFRL
Casbeer, David	Air Force Research Laboratories
Milutinovic, Dejan	University of California at Santa Cruz

The Two Cutters and Fugitive Ship game posed by Isaacs is revisited again. We discuss and analyze the singular configuration of this two-pursuer one-evader differential game. This paper addresses the question of whether or not either player has the ability to exploit the dispersal surface. Specifically, we investigate the case where the Evader effectively stands still (e.g., by dithering in a small neighborhood). We show that the canonical optimal pursuit policy yields chattering in the discrete-time version of the game. As the timestep approaches zero, the capture time approaches the Value of the game, and thus the Evader is not penalized for standing still. Implications on related scenarios are discussed.

09:20-09:40	FrA2.2

*A K Nearest Neighborhood Based Wind Estimation for Rotary-Wing VTOL UAVs**

Wang, Liyang	Rutgers, The State University of New Jersey
Misra, Gaurav	Rutgers, The State University of New Jersey
Bai, Xiaoli	Rutgers, The State University of New Jersey

09:40-10:00	FrA2.3

Deep RC: Enabling Remote Control through Deep Learning, pp. 1161-1167

Ellingson, Jaron	Brigham Young University
Ellingson, Gary	Brigham Young University
McLain, Timothy W.	Brigham Young University

Human remote-control (RC) pilots have the ability to perceive the position and orientation of an aircraft using only third-person-perspective visual sensing. While novice pilots often struggle when learning to control RC aircraft, they can sense the orientation of the aircraft with relative ease. In this paper, we hypothesize and demonstrate that deep learning methods can be used to mimic the human ability to perceive the orientation of an aircraft from monocular imagery.

This work uses a neural network to directly sense the aircraft attitude. The network is combined with more conventional image processing methods for visual tracking of the aircraft. The aircraft track and attitude measurements from the convolutional neural network (CNN) are combined in a particle filter that provides a complete state estimate of the aircraft. The network topology, training, and testing results are presented as well as filter development and results. The proposed method was tested in simulation and hardware flight demonstrations.

10:00-10:20	FrA2.4

Parameter-Free Regression-Based Autonomous Control of Off-The-Shelf Quadrotor UAVs, pp. 1168-1177

Peddi, Rahul	University of Virginia
Bezzo, Nicola	University of Virginia

Autonomous flight in unmanned aerial vehicles (UAVs) generally requires platform-specific knowledge of the dynamical parameters and control architecture. Recently, UAVs have become more accessible with off-the-shelf options that are well-tuned and stable for user teleoperation but due to unknown model parameters, they are typically not ready for autonomous operations. In this paper, we develop a method to enable autonomous flight on vehicles that are designed for teleoperation with minimal knowledge of the dynamical and controller parameters. The proposed method uses a basic knowledge of the control and dynamic architecture along with human teleoperated trajectories as demonstrations to train a thin-plate spline (TPS) regression model, which is then used to manipulate the pre-trained commands to generate new autonomous input commands for autonomous navigation over new trajectories. A statistical approach is also presented together with a satisfiability modulo theories (SMT) solver to assess the learned prediction error and correct to minimize errors in the input generation. A robust control-based strategy is also proposed to adjust autonomous input commands during run-time for closed loop trajectory tracking. Finally, we validate the proposed approach with trajectory-following experiments on a quadrotor UAV.

10:20-10:40	FrA2.5

Towards Breaching a Still Water Surface with a Miniature Unmanned Aerial-Underwater Vehicle, pp. 1178-1185

Zha, Jiaming	UC Berkeley
Thacher, Eric William	UC Berkeley
Kroeger, Joseph	University of California, Berkeley
Makiharju, Simo	UC Berkeley
Mueller, Mark Wilfried	UC Berkeley

Unmanned aerial-underwater vehicles (UAUVs) provide the potential for working on missions in complex multi-domain environments. To achieve amphibian mobility, current UAUV designs rely on additional mechanical components such as multiple layers of propeller blades, water ballast, buoys or wings. This paper presents a miniature UAUV which has a simple mechanical design that resembles a traditional quadcopter. The paper discusses the dynamic modelling, state estimation and control strategy for this UAUV, as well as a detailed characterization of the quadcopter blades operating in the air and water regimes. A strategy for the UAUV to breach calm water surface is then proposed and experimentally tested. The results demonstrate that the UAUV can successfully breach the still water surface, but also show tracking error and breaching delay that are not fully characterized by the model. This suggests the need to carry out further analysis on the dynamics of the UAUV both underwater and in the transition regime.

10:40-11:00	FrA2.6

A Vision-Based Unmanned Aircraft System for Autonomous Grasp & Transport, pp. 1186-1193

Liu, Xu	Shenyang Institute of Automation, Chinese Academy of Sciences
He, Yuqing	Shenyang Institute of Automation, CAS, P.R.China
Chen, Bo	Shenyang Institute of Automation Chinese Academy of Sciences
Hou, Yongqiang	Northeastern University
Bi, Kaiyuan	Shenyang Jianzhu University
Li, Decai	Institute of Automation Chinese, Chinese Academy of Sciences

The progress in sensor technologies, computer capabilities and artificial intelligence has endowed the unmanned aircraft system (UAS) with more autonomous abilities. Motivated by the 6th International Unmanned Aerial Vehicle Innovation Grand Prix (UAVGP), a UAS with high degree of autonomy was developed to perform the mission of building a simulated tower using prefabricated components. According to the requirement of the competition, the UAS was designed and implemented from the following four parts: 1) navigation and control, 2) recognition and location, 3) grasp and construction, and 4) task planning and scheduling. Different levels of autonomy have been given to the UAS based on these parts. The system hardware was developed on a quadrotor platform by integrating various components, including sensors, computers, power and grasp mechanism. Software which included precise navigation, mission planning, real-time perception and control was implemented and integrated with the developed UAS hardware. The performance in the test environment and actual competition showed that the UAS could perform the mission without human intervention with high autonomy and reliability. This paper addresses the major components and development process of the UAS and describes its application to the practical mission.

FrA3	Heritage C
Navigation I (Regular Session)	
Chair: Campoy, Pascual	Universidad Politecnica Madrid
Co-Chair: Huang, Sunan	National Universtiy of Singapore

09:00-09:20	FrA3.1

Visual Controllers for Relative Positioning in Indoor Settings, pp. 1194-1200

Mejias Alvarez, Luis	Queensland University of Technology
Campoy, Pascual	Universidad Politecnica Madrid

This paper presents an approach to visually control a quadrotor relative to known landmarks. Relative positioning is achieved here by a new decoupled approach to image based visual servoing (IBVS), in which rotational and translational coupling is minimized by introducing a decay function that is proportional to feature location in the image. Simulations and experiments were conducted to validate the proposed method. Results show that our method has benefits over standard decoupled IBVS by ensuring smoother trajectories in the image plane as well as in task space, minimizing the risk of features leaving the image plane.

09:20-09:40	FrA3.2

Towards Automated Under-Canopy Exploration of Plantation Forests, pp. 1201-1208

Lin, Tzu-Jui	University of Auckland
Stol, Karl	University of Auckland

This paper investigates a novel approach for under-canopy exploration of plantation forests by exploiting the semi-structured nature of typical plantation forests by using tree stems as navigation cues within the environment. A simulation-based study is completed with the proposed method compared to the nearest frontier exploration method to determine relative performance using distance traveled as a surrogate for time. Results show our proposed method could explore an equivalent area with a shorter and more consistent travel distance across multiple runs. Testing also suggests further improvements to the strategy are possible within a plantation with culled stems.

09:40-10:00	FrA3.3

Laser-Based Collision Avoidance and Reactive Navigation Using RRT and Signed Distance Field for Multirotor UAVs*, pp. 1209-1217

Lu, Liang	Technical University of Madrid(UPM-CSIC)
Sampedro, Carlos	University
Rodriguez-Vazquez, Javier	Universidad Politecnica De Madrid
Campoy, Pascual	Universidad Politecnica Madrid

Collision avoidance plays a crucial role for autonomous navigation in unknown dynamic environments and still remains an ongoing research problem. In this paper, we present a new collision avoidance algorithm by combining an RRT* path planner with a Signed Distance Field (SDF) based collision checking algorithm, in which the trajectory is optimized by a short cut and Optimal Polynomial Trajectory algorithms. The proposed algorithm is integrated to work in combination with a Model Predictive Control (MPC) based trajectory controller in order to provide a complete system for reactive navigation purposes. A thorough evaluation of the proposed algorithm has been conducted in several simulating scenarios using RotorS Gazebo simulator, showing fast collision checking capabilities in the presence of static and dynamic obstacles. The results show that the proposed algorithm outperforms in 76.93% considering the processing time when tested in a 1000 × 1000 pixels map. The results also demonstrate that the proposed navigation algorithm allows the safe navigation of a multirotor Unmanned Aerial Vehicle (UAV)

10:00-10:20	FrA3.4

Computationally Efficient Visibility Graph–-Based Generation of 3D Shortest Collision-Free Path among Polyhedral Obstacles for Unmanned Aerial Vehicles, pp. 1218-1223

Huang, Sunan	National University of Singapore
Teo, Rodney	Temasek Laboratories, National University of Singapore

Autonomous unmanned aerial vehicles (UAVs) need to dynamically re-plan paths online to avoid newly detected obstacles and no-fly zones. Existing 3D path planning methods are either too computationally intensive for online use or have practical limitations for actual applications. We propose a new method based on visibility graphs that is both computationally efficient for online use and is suitable for actual applications. We consider the 3D space to be composed of many 2D planes that all pass through the current position of the UAV and the destination point. Finding the shortest collision-free path in each plane is a 2D path planning problem which can be solved by using existing visibility graph algorithms. We then collect all the shortest paths generated from each 2D plane and find the shortest path in the whole 3D space. We present the results of the proposed 3D path planning algorithm for two cases to demonstrate that the proposed method is effective.

10:20-10:40	FrA3.5

A Cloud-Based Framework for Intelligent Navigation and Coordination for UASs in Urban Areas, pp. 1224-1233

Primatesta, Stefano	Politecnico Di Torino
Bloise, Nicoletta	Politecnico Di Torino
Antonini, Roberto	Company
Fici, Gian Piero	TIM
Gaspardone, Marco	TIM
Guglieri, Giorgio	Politecnico Di Torino

Rizzo, Alessandro | Politecnico Di Torino

Unmanned Aircraft Systems (UASs) are gaining momentum in recent years due to their mission flexibility and low cost. In this paper, we introduce a Cloud-based framework for intelligent navigation and coordination for UASs in urban environments with the aim to manage a fleet of small UASs in the low airspace. The core of the framework, called Mission Coordinator, is located on Cloud. It uses a priority-based distributed approach to design a safe and collision-free flight mission for each vehicle. Therefore, the aircraft executes the planned mission, while the Mission Coordinator continuously monitors the fleet of UASs. Thanks to the newest mobile technologies, the UAS is connected with the Cloud with unprecedented opportunities. Combined with Cloud technologies, the proposed framework provides an autonomous mission and guarantees safety to people on the ground. Finally, preliminary simulation results corroborate the validity of our approach, demonstrating how our framework is able to manage a fleet of three aerial robots.

10:40-11:00 FrA3.6

A Carrot in Probabilistic Grid Approach for Quadrotor Line Following on Vertical Surfaces, pp. 1234-1241

Liu, Jyi-Shane | National Chengchi University
LEE, Gong-Yi | National Chengchi University

Most current research deals with line following at an aerial position with respect to the target object. We address a task scenario of close-up inspection on vertical surfaces. Line following is a basic component for the close-up inspection process on high rise structures, such as building façade, tower skeleton, and wind turbine blade. The inspection process may also require slower and accurate line following movement for anomaly detection in higher resolution. In this paper, we formulate the problem of accurate line following on vertical surfaces. We propose the carrot in probabilistic grid algorithm for accurate line following on vertical surfaces and work through a refinement for performance improvement. We implemented the carrot in probabilistic grid algorithm on a ready-to-fly quadrotor (micro rotary UAV) and evaluated the line following performance with several forms of geometric line segments on a vertical surface. Experimental results based on extensive actual flight tests show satisfactory performance of the carrot in probabilistic grid algorithm over the benchmark line following algorithm.

FrA4 Savannah

Environmental Issues (Regular Session)

Co-Chair: Chen, YangQuan | University of California, Merced

09:00-09:20 FrA4.1

Visual Servoing for Multirotor Precision Landing in Daylight and After-Dark Conditions, pp. 1242-1248

Wynn, Jesse S. | Lawrence Livermore National Laboratory
McLain, Timothy W. | Brigham Young University

The problem of precision landing for autonomous multirotor UAVs operating during the day and at night is studied. A vision-based approach is proposed and consists of varying-degree-of-freedom image-based visual servoing (VDOF IBVS), and a specialized landing marker. The proposed approach is validated through extensive flight testing outdoors in both daylight and after-dark conditions and is done using a standard off-the-shelf autopilot system.

09:20-09:40 FrA4.2

Pitch and Roll Effects of On-Board Wind Measurements Using SUAS, pp. 1249-1254

Hollenbeck, Derek | MESA Lab at UC Merced
Oyama, Madoka | MESA Lab at UC Merced
Garcia, Andrew | MESA Lab at UC Merced
Chen, YangQuan | University of California, Merced

Small unmanned aircraft systems (sUAS) are becoming more and more used in atmospheric related applications as fixed remote sensors. Utilizing mobile remote sensing in air pollution applications can be beneficial. This work looks at assessing the accuracy of wind speed and direction measurements under pitch and roll maneuvers with on-board ultrasonic anemometer (UA) using sUAS. A low-cost wind tunnel (LCWT) is used as a first approach to assess this accuracy and the experimental results are compared with ground truth measurements to provide a recommendation for use in the field.

09:40-10:00 FrA4.3

Hybrid AutoGyro: Airborne Wind Energy Conversion Using Autorotation, pp. 1255-1260

Flores, Jonathan | Umi Lafmia Cinvestav
Salazar, Sergio | Umi Lafmia Cinvestav
Lozano, Rogelio | University of Technology of Compiègne

Hybrid AutoGyro aircraft with wind energy conversion using autorotation is proposed. The fixed wing addition to classic autogyro assists the aircraft lifting reducing speed minimum wind for the flight. A PID control strategy is used to attitude aircraft stabilization. In order to verify the generation of energy, the relationship between energy and wind speed are recorded during experimental flights.

10:00-10:20 FrA4.4

Modeling of Aerodynamic Disturbances for Proximity Flight of Multirotors, pp. 1261-1269

Jain, Karan | University of California, Berkeley
Fortmuller, Trey | University of California, Berkeley
Byun, Jaeseung | UC Berkeley
Makiharju, Simo | UC Berkeley
Mueller, Mark Wilfried | UC Berkeley

This paper presents a model to predict aerodynamic disturbances during close formation flight of two multirotors. The model is based on a propeller velocity field model and characterization of change in propeller thrust under oncoming flow. Using this model, we predict forces and torques on one mutirotor due to downwash of the other with respect to relative separation of the multirotors. We conduct proximity flight experiments using two types of quadcopters to measure forces and torques using accelerometer and rate-gyro. Predictions from the model and results from experiments match well for vertical separations greater than seven times the vehicle size. This verifies the range of fidelity of the model.

10:20-10:40 FrA4.5

Wildfire Monitoring with Uneven Importance Using Multiple Unmanned Aircraft Systems, pp. 1270-1279

Hu, Xiaolin | Georgia State University
Bent, John | Georgia State University
Sun, Jiawei | Georgia State University

Unmanned Aircraft Systems (UASs) have great potentials in wildfire monitoring to provide real time data to support better wildfire management. This paper focuses on the problem of multi-UAS coordination in wildfire monitoring. To effectively deal with the heterogeneous behavior of wildfire spread, we develop an importance-based coordination method that takes into consideration the different levels of attention needed for monitoring different regions of a fire perimeter. The developed method is compared with a rendezvous-based coordination method and a circling-based coordination method and is evaluated in a wildfire spread simulation environment. Experiment results show that the importance-based coordination is able to direct UASs to visit the active regions of a wildfire more frequently while monitoring the entire fire perimeter.

10:40-11:00 FrA4.6

Asymptotic Stability Controller Design of Three Fixed-Wing

UAVs Formation with Windy Field, pp. 1280-1285

Pu, Zhang	Northwestern Polytechnical University
Huifeng, Xue	School of Automation, Northwestern Polytechnical University
Shan, Gao	School of Automation, Northwestern Polytechnical University

This paper addressed a well-documented open problem on the asymptotic flight-stability of the closed-loop system in the process of the windy field for a three fixed-wing unmanned aerial vehicles (UAVs) formation. The problem of stability can be converted to the analysis of dynamic response and steady-state error. The robust control compared with phononic crystal control method, it can realize the high speed and close cooperative formation of precision combat. Adding phononic crystal is not only capable of reducing the body vibration and steady-state tracking error, but also owns better robustness. The horizontal dynamic analysis of the formation of UAVs is carried out in the presence of external unknown factors. Then, an "integrated" controller is designed to control leader's speed so that "follower" can track the "leader" in the case of decoupling, while maintaining the consensus of relative speed. The simulation results show that the "integrated" control method integrates the advantages of robust control and phononic crystal vibration attenuation.

FrB1	Heritage B
Risk Analysis and Risk-Based Methods for UAS (Invited Session)	
Chair: Bertrand, Sylvain	ONERA
Co-Chair: la Cour-Harbo, Anders	Aalborg University
Organizer: Bertrand, Sylvain	ONERA
Organizer: la Cour-Harbo, Anders	Aalborg University

11:30-11:50	FrB1.1

Feasibility Analysis of UAV Operations for Monitoring of Infrastructure Networks: A Risk-Based Approach (I), pp. 1286-1295

Bertrand, Sylvain	ONERA
Raballand, Nicolas	ONERA
Lala, Stephanie	ONERA
Flavien, Viguier	SNCF Réseau

This paper proposes a method to analyze the feasibility of monitoring missions of infrastructure networks (eg. railways, roads, power lines, etc.) by Unmanned Aerial Vehicles (UAVs). The method consists in evaluating the risk at ground for people due to an UAV flying over each part of the network. Based on a risk categorization defined by probability and exposition time, several metrics are developed to analyze the feasibility of flights in terms of risk. More specifically, these metrics are related to the cumulative length of feasible flight segments and their connectedness. A decision-making process is then defined to automatically classify all the lines of the network in a comprehensive and synthetic way. The whole method takes into account flight regulation and flight operation constraints as well as considerations relative to business interests in asset management of the infrastructure network. An illustration is proposed through a benchmark example on the French railway network.

11:50-12:10	FrB1.2

Modeling Unmanned Aerial System (UAS) Risks Via Monte-Carlo Simulation (I), pp. 1296-1305

Rudnick-Cohen, Eliot	University of Maryland, College Park
Herrmann, Jeffrey	University of Maryland
Azarm, Shapour	University of Maryland, College Park

Unmanned Aerial Systems (UAS) pose a variety of risks to third parties when operating over populated areas, due to the danger posed if the UAS crashes. Two commonly used metrics for assessing the risk of such crashes are the kinetic energy of the UAS at the time of impact and the probability distribution of locations where the UAS could crash. In this paper, a Monte Carlo based approach is presented for simulating UAS crashes in order to calculate these metrics. A surrogate modeling approach for UAS safety metrics is also presented, which is built using the results of the Monte Carlo simulations. The surrogate modeling approach is capable of rapidly evaluating UAS safety metrics for arbitrary UAS design and operating parameters. The proposed approach is demonstrated by modeling the kinetic energies at time of impact and crash probability distributions for UAS with dynamics models similar to that of a Cessna 182.

12:10-12:30	FrB1.3

Planning Unmanned Aerial System (UAS) Takeoff Trajectories to Minimize Third-Party Risk (I), pp. 1306-1315

Rudnick-Cohen, Eliot	University of Maryland, College Park
Azarm, Shapour	University of Maryland, College Park
Herrmann, Jeffrey	University of Maryland

Large unmanned aerial systems (UAS) pose risks when they fly over inhabited areas. This paper presents a motion planning approach to minimize these risks by determining risk optimal motions for a fixed-wing UAS. This approach estimates the crash probability distribution (CPD) of a UAS as a function of its current state in the configuration space, which allows for planning risk optimal UAS maneuvers. This approach also includes several new extensions to the RRT# algorithm for optimal motion planning, including a method for using an initial solution within RRT# and a new method for locally computing the connection radius which RRT# uses to connect configurations together. A new method for handling three-dimensional (3D) Dubins curves for a fixed-wing UAS is also proposed in order to handle the risk objective considered. The approach is tested on an example takeoff trajectory planning problem in which a UAS must climb to a set cruising altitude at a predetermined location and heading; the results illustrate several trade-offs between risk and flight time that make use of how the UAS's CPD varies with its current state.

12:30-12:50	FrB1.4

Compromising Flight Paths of Autopiloted Drones, pp. 1316-1325

Chen, Wenxin	University of Hawaii
Dong, Yingfei	University of Hawaii
Duan, Zhenhai	Florida State University

While more and more consumer drones are abused in recent attacks, there is still very little systematical research on countering malicious consumer drones. In this paper, we focus on this issue and develop effective attacks to common autopilot control algorithms to comprise the flight paths of autopiloted drones, e.g., leading them away from its preset paths. We consider attacking an autopiloted drone in three phases: attacking its onboard sensors, attacking its state estimation, and attacking its autopilot algorithms. Several first-phase attacks have been developed; second-phase attacks (including our previous work) have also been investigated. In this paper, we focus on the third-phase attacks. We examine three common autopilot algorithms and design several attacks by exploiting their weaknesses to mislead a drone from its preset path to a manipulated path. We present the formal analysis of the scope of such manipulated paths. We further discuss how to apply the proposed attacks to disrupt preset drone missions, such as missing a target in searching an area or misleading a drone to intercept another drone, etc. Many potential attacks can be built on top of the proposed attacks. We are currently investigating different models to apply such attacks on common drone missions and also building prototype systems on ArduPilot for real-world tests. We will further investigate countermeasures to address the potential damages.

12:50-13:10	FrB1.5

Safe Decision Making for Risk Mitigation of UAS (I), pp. 1326-1335

Castano, Lina — University of Maryland, College Park
Xu, Huan — University of Maryland

This work entails the development of a theoretical framework for the fast and safe reaction of Unmanned Aerial Systems to flight anomalies. The proposed framework uses behavior trees to design behaviors that have safety properties and uses vehicle states to determine best risk control response. A case study is presented where a fixed-wing UAV experiences four types of hazardous scenarios which consist of different types of aircraft faults and external obstacles. The UAV safely reacts by avoiding obstacles when possible or mitigates the faults by either finding a nearby emergency landing location, or choosing a safe ground impact point far from populated areas. These behaviors have the potential to be used across different aerial robotics platforms, to increase safety amid human error, environmental hazards and aircraft failures.

FrB2	Heritage A
Autonomy II (Regular Session)	
Chair: Rodriguez Cortes, Hugo	CINVESTAV-IPN

11:30-11:50	FrB2.1

Radius of Turn and Flight Path Angle Estimation from Unmanned Aircraft Flight Trajectories, pp. 1336-1343

Benders, Sebastian — DLR Braunschweig
Koch, Simon — Bundeswehr University Munich

The Dubins vehicle model, with its parameters radius of turn and flight path angle, is commonly used for modeling unmanned aircraft trajectories. While Dubins model path planning is state of the art, the reverse direction, extracting Dubins model information from unmanned aircraft trajectories is poorly addressed. This article presents a method to fit the Dubins model parameters radius of turn and flight path angle to streamed aircraft trajectory data in a two-phase approach. In the first step flight phases are detected. Within the second step the corresponding radii of turn and flight path angles are estimated. The method is applied on various flight trajectories of different unmanned aircraft. The evaluation further regards the algorithms run time and states the feasibility for online applications.

11:50-12:10	FrB2.2

A Convolutional Neural Network Vision System Approach to Indoor Autonomous Quadrotor Navigation, pp. 1344-1352

Garcia, Adriano — Binghamton University
Mittal, Sandeep — Binghamton University
Kiewra, Edward — SUNY Binghamton
Ghose, Kanad — SUNY-Binghamton, Dept. of Computer Science

A Convolutional Neural Network (CNN) vision-based approach is demonstrated to enable autonomous flight of a stock unmodified quadrotor drone in hallway environments. The video stream from a monocular front-facing camera on-board a quadrotor drone is fed to Convolutional Neural Network (CNN) environment classifiers at a base station in order to detect upcoming intersections and dead-ends. Detecting these hallway structural features allows our control planning algorithms to take appropriate action in order to stop and turn at intersections or stop before colliding with dead-ends such as walls and doors. The use of CNNs permit intersections and dead-ends to be detected with a high degree of accuracy in a wide variety of indoor environments with varying contrasts, lighting conditions, obstructions, and many other conditions that prevent easy generalization of feature extraction. Overall, our approach allows for real-time navigation at high rates of speed approaching 2 m/s.

12:10-12:30	FrB2.3

Flying through Gates Using a Behavioral Cloning Approach, pp. 1353-1358

Rodriguez Hernandez, Erick — Instituto Politecnico Nacional
Vasquez-Gomez, Juan Irving — Consejo Nacional De Ciencia Y Tecnología
Herrera Lozada, Juan Carlos — Instituto Politécnico Nacional

Drone racing presents a challenge to autonomous micro aerial vehicles (MAV) because usually the track is not known in advance and it is affected by the environment light. In such scenarios, the vehicle has to act quickly depending on the information provided by its sensors. In this work, we want to predict the movement of the drone so that it passes through a gate. Unlike previous approaches where the task is decomposed into perception, estimation, planning, and control, we are proposing a behavioral cloning approach. In this method, a convolutional neural network is trained with the flights of a human operator. So that the output of the trained network is directly the desired MAV state so that it leads the drone through the gate. We have tested the method using a validation set where we obtained a low loss. Furthermore, we have tested the trained network with unseen data obtaining promising results.

12:30-12:50	FrB2.4

Monocular SLAM Position Scale Estimation for Quadrotor Autonomous Navigation, pp. 1359-1364

Rodriguez Cortes, Hugo — CINVESTAV-IPN
Gómez-Casasola, Alejandro — CINVESTAV
Luis Daniel, Nieto-Hernandez — CINVESTAV-IPN

Monocular Simultaneous Localization and Mapping (SLAM) provides a position estimation with an unknown scale factor. The scale factor depends on the initial conditions of the SLAM algorithm so that it is always different. This paper presents a scale factor estimator based on the Immersion and Invariance technique for quadrotor autonomous navigation. The estimator assumes that the quadrotor's linear velocity, attitude and the applied total thrust are measurable. The estimator performance is validated using numerical simulations and experiments.

12:50-13:10	FrB2.5

Gaussian Mixture Model (GMM) Based Dynamic Object Detection and Tracking, pp. 1365-1371

Hariharan Anand, Vishnu — TATA COnsultancy Services
Pushp, Durgakant — TATA COnsultancy Services
Raj, Rishin — TCS Research and Innovation Labs
Das, Kaushik — TATA Consultancy Service

In this paper, we have addressed the problem of real-time detection and tracking of dynamic objects using quad-rotors. We have developed a novel object detection algorithm by analyzing and matching the color and spacial features of the target from monocular image sequences. The proposed object detection algorithm can track the objects with high Frame Per Second (FPS) which is suitable for low-end onboard computers that are used in quad-rotors. In addition, we also estimate the position of the target object in real world so that the drone can track the object accurately. A rigorous experimental analysis is provided to show the efficacy of the proposed approach in indoor as well as outdoor environments.

13:10-13:30	FrB2.6

Towards a Weather Analysis Software Framework to Improve UAS Operational Safety, pp. 1372-1380

Lundby, Tobias — University of Southern Denmark
Christiansen, Martin Peter — University of Southern Denmark
Jensen, Kjeld — University of Southern Denmark

Unmanned Aerial Systems (UAS) operations are evolving towards

autonomous flight beyond visual line of sight (BVLOS), which requires moving assessments normally conducted by the remote pilot to the autonomous software. An important assessment currently conducted by the remote pilot is whether the current weather conditions pose a safety risk to the flight. This work deals with the development of a software framework for analyzing weather data. The developed framework is capable of providing a weather analysis report to a remote supervisor or to an autonomous decision-making software. The software framework has been tested using historical weather data for a full calendar year provided by IBM. The weather data was applied to four different UAS ranging from small UAS to a passenger UAS. The results obtained show that during a full year, flight was possible from 53.9% to 95.8% of the time depending on the UAS. We consider the software framework an important step towards improving the operational safety for autonomous UAS operations under BVLOS conditions.

FrB3	Heritage C
Navigation II (Regular Session)	
Chair: Fossen, Thor I.	Norwegian University of Science and Technology

11:30-11:50	FrB3.1

Approximating UAV and Vision Feature Point Correlations in a Simplified SLAM Problem, pp. 1381-1388

Lewis, Jeffrey	Georgia Institute of Technology
Johnson, Eric	Pennsylvania State University

Navigation with a range sensor and vision aided inertial measurement unit (IMU) estimation is difficult in Global Positioning System (GPS) denied environments. Ignoring vision feature point and vehicle state correlations contributes to inaccuracy and filter inconsistency. Approximation of feature point and vehicle cross correlation terms would allow the accuracy and consistency comparable to a correlated solution whilst reducing operation count and allowing for decoupled filter design. A Monte-Carlo simulation for a two dimensional bearing to feature point approximation of the simultaneous localization and mapping (SLAM) problem was developed. The results of a least absolute shrinkage and selection operator (LASSO) regression were then used to estimate cross covariance terms. A 1000 trial simulation showed that the regression solution was comparable in accuracy and consistency to the fully correlated solution. Future developments have the potential to provide a more accurate, approximately correlated SLAM solution to bound IMU drift for UAVs operating in a GPS denied environment.

11:50-12:10	FrB3.2

Null Space Based Formation Control for a UAV Landing on a UGV, pp. 1389-1397

Mafra Moreira, Mauro Sergio	Federal University of Espírito Santo
Brandao, Alexandre Santos	Federal University of Vicosa
Sarcinelli-Filho, Mário	Federal University of Espirito Santo

This paper proposes a controller to autonomously guide a formation of two mobile robots, a differential drive wheeled ground vehicle and an unmanned aerial vehicle, in tasks of positioning. The controller is designed considering the paradigm of virtual structure, in which the virtual structure is the tridimensional straight line linking the two robots, and adopting the technique of null space, to split the whole control task in two sub-tasks, which are to keep the formation and to move the formation. To do that the formation is described by a set of variables, the formation variables, which are derived from the individual robot positions. To apply the null-space technique, the formation variables are grouped into two sets, one associated to the shape of the virtual structure and the other associated to the position of the virtual structure. The use of the null space technique allows to give higher priority to the sub-task of keeping the formation shape, leaving the sub-task of moving the virtual structure to a new position with a lower priority, thus generating a rigid formation. Although the reverse situation, to give higher priority to the movement of the formation to a new position, generating a flexible formation, is also possible, simulated and experimental results have shown that to give higher priority to keep the shape of the formation is the best solution. The reason is that we are aiming at applications demanding that the position of the aerial robot with respect to the ground one be well known along time, allowing the aerial vehicle to land over the terrestrial one.

12:10-12:30	FrB3.3

Field Test Results of GNSS-Denied Inertial Navigation Aided by Phased-Array Radio Systems for UAVs, pp. 1398-1406

Gryte, Kristoffer	Norwegian University of Science and Technology
Bryne, Torleiv Håland	Norwegian Univ. of Science and Technology
Albrektsen, Sigurd M	SINTEF Digital
Johansen, Tor Arne	Norwegian University of Science and Technology

Unmanned aerial vehicles (UAVs) often depend on global navigation satellite systems (GNSS) and magnetic compasses for navigation, making them exposed to malicious attacks and sensitive to magnetic anomalies, while restricting operations to within GNSS coverage. By rather relying on inertial navigation aided by spherical position measurements from a phased-array radio system (PARS), these vulnerabilities are avoided. The navigation system relies on a multiplicative extended Kalman filter for state corrections, and on outlier rejection to mitigate effects of radio reflections. Field testing shows that, despite the higher levels of noise in the PARS signal, the PARS-based position, velocity and attitude estimates are satisfactory when compared to the autopilot based attitude and velocity and the real-time kinematic (RTK) GNSS position reference solution.

12:30-12:50	FrB3.4

UAV Based Survivor Search During Floods, pp. 1407-1415

Ravichandran, Rahul	Indian Institute of Science, Bangalore
Ghose, Debasish	Indian Institute of Science
Das, Kaushik	TATA Consultancy Service

This paper addresses the problem of searching for survivors in flood affected regions. These search missions are carried out by UAVs (Unmanned Aerial Vehicles) in order to search faster and cover larger distances. The proposed search algorithm receives information regarding survivor location from the ground-based observers. The observers report the location of survivors when the survivor is within its field of view. In such a situation when the location information about the survivor is received by the UAV, the survivor might have moved to a different location when the UAV tries to go to the last spotted location to search. Hence, it is necessary to have a prediction algorithm to estimate the future position of the survivor. The algorithms implemented in this paper is a weightage-based approach and a truncated weight based approach to predict the future location of the survivor. The performance of these algorithms are compared with a tradition lawnmower search pattern. These algorithms are implemented by taking a real life flood scenario and the effectiveness and efficiency of the implemented algorithm is shown by an extensive Monte Carlo simulation.

12:50-13:10	FrB3.5

Robust Navigation System for UAVs in GNSS and Magnetometer-Denied Environments, pp. 1416-1424

Mathisen, Paal Holthe	Norwegian University of Science and Technology
Fossen, Thor I.	Norwegian University of Science and Technology

Navigating in environments where GNSS- and magnetometer measurements are unreliable can lead to a significant decrease in state estimation accuracy. The use of supplementary measurements,

either from optical sensors or otherwise, could enhance the state estimates notably even when at low quality. Using inertial navigation corrected by a multiplicative extended Kalman filter, state estimation is performed on a simulated UAV in motion. This paper has investigated the effect of adding measurements of body-fixed velocity and specific force as reference vectors to the navigation systems of UAVs in GNSS- and magnetometer denied environments. A case study for each of the two measured vectors is performed and compared to a reference flight without dropout of GNSS or magnetometer, and a flight with dropout, but without any additional aiding sensor.

13:10-13:30	FrB3.6

Pose Estimation of UAVs Based on INS Aided by Two Independent Low-Cost GNSS Receivers, pp. 1425-1435

Sollie, Martin Lysvand	The Norwegian University of Science and Technology
Bryne, Torleiv Håland	Norwegian Univ. of Science and Technology
Johansen, Tor Arne	Norwegian University of Science and Technology

Increasing use of UAVs in high-precision applications, such as georeferencing and photogrammetry, increases the requirements on the accuracy of the estimated position, velocity and attitude of the vehicle. Commercial systems that utilize magnetometers in the heading estimates are cheap but are affected by disturbances from both the vehicle itself, nearby metal structures and variations in the Earth's magnetic field. On the other side, commercial dual-antenna satellite navigation systems can provide the required accuracy but are expensive. This paper explores the use of a low-cost setup using two independent GNSS receivers, aiding an inertial navigation system by using pseudo-range, Doppler frequency and carrier phase measurements from two longitudinally separated receivers on a fixed-wing UAV. The sensor integration was based on a multiplicative extended Kalman filter (MEKF). The main contribution of this paper is the derivation of measurement models for the raw GNSS measurements based on the MEKF error state, taking into account antenna lever arms and explicitly including the difference in measurement time between the receivers in the measurement model for double differenced carrier phase. The proposed method is verified using data collected from a UAV flight.

FrB4	Savannah
UAS Testbeds (Regular Session)	
Chair: Theilliol, Didier	University of Lorraine
Co-Chair: Ahmad, Shakeeb	University of New Mexico

11:30-11:50	FrB4.1

A New Facility for UAV Testing in Climate-Controlled Environments, pp. 1436-1444

Scanavino, Matteo	Politecnico Di Torino
Vilardi, Andrea	Eurac Research
Guglieri, Giorgio	Politecnico Di Torino

Environmental conditions have a great influence on aircraft performance. Thrust reduction with altitude and temperature increase is a well-known problem in the aviation industry. For commercial multirotor (UAVs) a systematic approach on performance varying environmental conditions is still an open research field. Many of the existing applications designed for UAVs (e.g. precision agriculture, delivery of instruments or medical supplies) have not been fully exploited by the market so far. This is due to the lack of existing knowledge about flight under variable weather conditions. A bias in the existing tests has been the non-reproducibility of the same climatic conditions. In this paper a dedicated test facility for a systematic study on UAV performance in a climate-controlled laboratory is presented: use cases as well as technical challenges related to the particular environment are discussed. Preliminary tests on thrust performance at different temperatures are reported to provide insight and highlight measurement complexities involved in harsh environmental conditions. Ultimately, this work will facilitate the development of UAV design and safety accounting for weather influence to improve flight stability and controllability.

11:50-12:10	FrB4.2

Pitching Moment Analysis and Adjustment for Tilt-Wing UAV in VTOL Mode, pp. 1445-1450

Sanchez-Rivera, Luz	Umi Lafmia Cinvestav
Lozano, Rogelio	University of Technology of Compiègne
AriasMontano, Alfredo	IPN ESIME Ticoman

This paper presents the pitching moment stability analysis and adjustment for tilt-wing unmanned aerial vehicle (UAV) in hovering flight and vertical take-off and landing (VTOL). The tilt-wing UAVs combine the features of fixed- wing UAVs with VTOL capabilities by tilting the wing and rotor system for the transition between flight modes. Due to its hybrid configuration, the altitude control study, position and attitude, poses a major problem during the entire flight for a given mission. Namely, in the first flight phase the pitching moment could present instabilities with different disturbances, such as wind, that are difficult to compensate. In this paper this problem is analyzed and possible solutions for the stabilization are presented and evaluated in a test bench. These solutions were implemented in new test prototypes demonstrating satisfactory results in outdoor flight tests.

12:10-12:30	FrB4.3

Control of a PVTOL with Tilting Rotors, pp. 1451-1457

Offermann, Alexis	Heudiasyc Lab. 7253, Université De Technologie De Compiègne
Castillo, Pedro	Unviersité De Technologie De Compiègne
De Miras, Jérôme	Université De Technologie De Compiègne

This paper introduces the modeling and control of a Planar Vertical Take Off and Landing (PVTOL) aircraft with tilting rotors. The mathematical model is obtained step by step using the Newton-Euler methodology. Its nonlinear dynamics of this aircraft are analyzed and controlled using a nonlinear and a linear algorithm. The controllers were validated in simulation and main results are depicted in some graphs showing differences between both. Good results are observed when applying the nonlinear controller based on nested saturation.

12:30-12:50	FrB4.4

A Full Distributed Multipurpose Autonomous FlightSystem Using 3D Position Tracking and ROS, pp. 1458-1466

Gargioni, Gustavo	Virginia Polytechnic Institute and State University
Peterson, Marco	Virginia Polytechnic Institute and State University
Persons, Jeffrey	Virginia Polytechnic Institute and State University
Schroeder, Kevin	Virginia Polytechnic Institute and State University
Black, Jonathan	Virginia Polytechnic Institute and State University

This document describes an approach to develop a fully distributed multipurpose autonomous flight system. With a set of hardware, software, and standard flight procedures for multiple unmanned aerial vehicles (UAV), it is possible to achieve a relative low-cost plug and play fully-distributed architecture for multipurpose applications. The resulting system comprises an OptiTrack motion capture system, a Pixhawk flight controller, a Raspberry Pi companion computer, and the Robotic Operating System (ROS) for inter-node communication. The architecture leverages a secondary PID controller with the use of MAVROS, an open-source Python plugin for ROS, for onboard

processing and interfacing with the flight controller. Featuring a procedure that receives the position vector from Optitrack System and returns the desired velocity vector for each time-step. This facilitates ease of integration for researchers. The result is a reliable, easy to use an autonomous system for multipurpose engineering research. To demonstrate its extensiveness, this paper shows experiments of a robotics navigation experiment utilizing the fundamentals of Markov Decision Processes (MDP) running at 60Hz, Wireless and with a network latency below 2ms. This paper reasons why fully distributed systems should be embraced as it maintains the reliability of the system with lower cost and easier implementation for the ground station. Combined with an intelligent choice approach for developing software architecture, it encourages and facilitates the use of autonomous systems for transdisciplinary research.

12:50-13:10	FrB4.5

Real-Time Quadrotor Navigation through Planning in Depth Space in Unstructured Environments, pp. 1467-1476

Ahmad, Shakeeb	University of New Mexico
Fierro, Rafael	University of New Mexico

This paper addresses the problem of real-time vision-based autonomous obstacle avoidance in unstructured environments for quadrotor UAVs. We assume that our UAV is equipped with a forward facing stereo camera as the only sensor to perceive the world around it. Moreover, all the computations are performed onboard. Feasible trajectory generation in this kind of problems requires rapid collision checks along with efficient planning algorithms. We propose a trajectory generation approach in the depth image space, which refers to the environment information as depicted by the depth images. In order to predict the collision in a look ahead robot trajectory, we create depth images from the sequence of robot poses along the path. We compare these images with the depth images of the actual world sensed through the forward facing stereo camera. We aim at generating fuel optimal trajectories inside the depth image space. In case of a predicted collision, a switching strategy is used to aggressively deviate the quadrotor away from the obstacle. For this purpose we use two closed loop motion primitives based on Linear Quadratic Regulator (LQR) objective functions. The proposed approach is validated through simulation and hardware experiments.

13:10-13:30	FrB4.6

ROS-MAGNA, a ROS-Based Framework for the Definition and Management of Multi-UAS Cooperative Missions, pp. 1477-1486

Millán Romera, José Andrés	University of Seville
Perez-Leon, Hector	University of Seville
Castillejo-Calle, Alejandro	University of Seville
Maza, Ivan	Universidad De Sevilla
Ollero, Anibal	Universidad De Sevilla

This paper presents a general framework for the definition and management of cooperative missions for multiple Unmanned Aircraft Systems (UAS) based on the Robot Operating System (ROS). This framework makes transparent the type of autopilot on-board and creates the state machines that control the behaviour of the different UAS from the specification of the multi-UAS mission. In addition, it integrates a virtual world generation tool to manage the information of the environment and visualize the geometrical objects of interest to properly follow the progress of the mission. The framework supports the coexistence of software-in-the-loop, hardware-in-the-loop and real UAS cooperating in the same arena, being a very useful testing tool for the developer of UAS advanced functionalities. To the best of our knowledge, it is the first framework which endows all these capabilities. The paper also includes simulations and real experiments which show the main features of the framework.

ICUAS'19 Keyword Index

ICUAS’ 19 Author Index