

Workshop/Tutorial T1 (Full Day)

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 and Presenters

Youmin Zhang

Department of Mechanical, Industrial and Aerospace Engineering

Concordia Institute of Aerospace Design and Innovation (CIADI)

Concordia University

1455 Maisonneuve Blvd. W.

Montreal, Quebec H3G 1M8, Canada

Phone: +1 (514) 848-2424 ext. 5225

Email: 1) ymzhang@encs.concordia.ca; 2) Youmin.Zhang@concordia.ca

Web: <http://users.encs.concordia.ca/~ymzhang/>

Didier Theilliol

CRAN UMR 7039, CNRS

University of Lorraine

54506 Vandoeuvre-les-Nancy, France

Phone : +33 383 684 465; Fax: +33 383 684 462

Email: Didier.Theilliol@univ-lorraine.fr

Web: http://page-perso.cran.uhp-nancy.fr/Perso_Theilliol/CV_Theilliol_CRAN.htm

Xiang Yu

Department of Mechanical, Industrial and Aerospace Engineering

Concordia University

1455 Maisonneuve Blvd. W.

Montreal, Quebec H3G 1M8, Canada

Phone: +1 (514) 802-6918

Email: 1) xiang.yu@concordia.ca; 2) xiangyu1110@gmail.com

Tutorial Summary

Unmanned systems including Unmanned Aerial Vehicles or Unmanned Aircraft Systems (UAVs or UAS), Unmanned Ground Vehicles (UGVs), and Unmanned Surface/Underwater Vehicles (USVs/UUVs) have received increased attention during the last years due to their utilization in diverse applications such as surveillance, search and rescue missions, geographic studies, military and security, etc. Sense and Avoid (S&A) is required to enable UASs integration into airspace, while Fault-Tolerant Control (FTC) and Fault-Tolerant Cooperative Control (FTCC) techniques contribute to guaranteeing safety of unmanned systems. Based on prior and ongoing research and development, and experience gained at the Diagnosis, Flight Control and Simulation Lab (DFCSL) and Networked Autonomous Vehicles Lab (NAVL) at Concordia University, this tutorial presents state-of-the-art techniques in S&A, Fault Detection and Diagnosis (FDD), FTC, as well as FTCC of multiple vehicles with applications in forest fire monitoring and detection, and power line inspection. Different types of unmanned systems are used including UAVs, UGVs, and USVs. Remote sensing techniques are used, as well as applications to wind turbines/farm and smart grids in renewable energy fields.

An overview of past, current and future research activities and research outcomes on S&A, FDD, FTC, and FTCC and their applications to quadrotor rotary and fixed-wing UAVs will be presented. Linear and nonlinear techniques for modeling, fault diagnosis, fault-tolerant control, path and trajectory planning/re-planning, cooperative/formation flight guidance, navigation and control, based on a quadrotor helicopter UAV and fixed-wing UAV test beds at NAVL, as well as USVs, worldwide, will be discussed. A review of existing vision-based automated forest fire detection and power line inspection systems using UAVs and key issues will also be presented.

Tutorial Outline

- 09:00 – 9:45: Introduction to Sense and Avoid (S&A), Fault Detection and Diagnosis (FDD), Fault-tolerant Control (FTC), and Fault-tolerant Cooperative Control (FTCC): Motivation, Concept, History, Existing and Future Developments
- 9:45 – 10:30: Developments on FDD, FTC and FTCC with Applications to Fixed-wing and Quadrotor UAVs Testbeds
- 10:30 – 10:45: Coffee Break
- 10:45 – 11:00: Design of FTC Methods Based on Reliability
- 11:00 – 11:45: New Development on UAV Sense and Avoid (S&A) Techniques
- 11:45 – 14:00: Lunch Time
- 14:00 – 14:45: Forest Fire Detection for Real-time Monitoring Using UAVs
- 14:45 – 15:00: Coffee Break
- 15:00 – 15:45: An Overview and New Development on Remote Sensing and Computer Vision Technologies Used for Automatic Power Line Inspection with UAVs
- 15:45 – 16:30: FTCC of Multiple UAVs-UGVs in the Presence of Actuator Faults During Forest Fire Monitoring Mission
- 16:30 – 17:15: Guidance, Navigation and Control (GNC) of Unmanned Surface Vehicles: From Design to Implementation
- 17:15 – 17:30: Summary, Discussion, and Feedback

Intended Audience

- Graduate students and researchers, managers, practitioners and developers interested in UAVs/UGVs/USVs, sense and avoid, remote sensing, fault-tolerant and cooperative control, fault diagnosis, health management, fault-tolerant guidance, navigation and control, and applications to forest fire, power line, pipeline monitoring and fault/damage detection etc.

Tutorial References

- **Y. M. Zhang** and J. Jiang (2008), Bibliographical Review on Reconfigurable Fault-tolerant Control Systems, *Annual Reviews in Control*, vol. 32, no. 2, Dec. 2008, pp. 229-252 (Ranked No. 1 in the “Most Cited Articles” cited since 1996 in the journal and the “Highly Cited Paper” (top 1% paper) at Web of Science).
- **Y. M. Zhang**, A. Chamseddine, C. A. Rabbath, B. W. Gordon, C.-Y. Su, S. Rakheja, C. Fulford, J. Apkarian, and P. Gosselin (2013), Development of Advanced FDD and FTC Techniques with Application to an Unmanned Quadrotor Helicopter Testbed, *Journal of the Franklin Institute*, vol. 350, no. 9, pp. 2396-2422 (Ranked #1 in the “Most Downloaded Articles” in the journal, as of 2014-02-28).
- A. Chamseddine, **D. Theilliol**, I. Sadeghzadeh, **Y. M. Zhang**, and P. Weber (2014), Optimal Reliability Design for Over-actuated Systems Based on the MIT Rule: Application to an Octocopter Helicopter Testbed, *Reliability Engineering & System Safety*, 132, pp. 196-206.

- X. Qi, J. T. Qi, **D. Theilliol**, **Y. M. Zhang**, J. D. Han, and D. L. Song (2014), A Review on Fault Diagnosis and Fault Tolerant Control Methods for Single-rotor Aerial Vehicles, *Journal of Intelligent and Robotic Systems*, vol. 73, no. 1-4, pp. 535-555.
- **X. Yu** and **Y. M. Zhang** (2015), Sense and Avoid Technologies with Applications to Unmanned Aircraft Systems: Review and Prospects, *Progress in Aerospace Sciences*, vol. 74, pp. 152-166.
- C. Yuan, **Y. M. Zhang**, Z. X. Liu (2015), A Survey on Computer Vision Based Technologies for Automatic Forest Fire Detection Using UAVs and Remote Sensing Techniques, *Canadian Journal of Forest Research*, vol. 45, no. 7, pp. 783-792.
- Y. Fu, **X. Yu**, and **Y. M. Zhang** (2016), An Advanced Sense and Collision Avoidance Strategy for Unmanned Aerial Vehicles in Landing Phase, *IEEE Aerospace and Electronic Systems Magazine*, vol. 31, no. 9, pp. 40-52 (An Invited Paper in a Special Issue: Sense and Avoid for Unmanned Aircraft Systems: Part II, Sept. Issue, 2016).
- Z. X. Liu, C. Yuan, **Y. M. Zhang**, and J. Luo (2016), A Learning-Based Fault Tolerant Tracking Control of an Unmanned Quadrotor Helicopter, *Journal of Intelligent and Robotic Systems*, vol. 84, no. 1, 145-162.
- X. Qi, J. T. Qi, **D. Theilliol**, D. L. Song, **Y. M. Zhang**, J. D. Han (2016), Self-Healing Control Design under Actuator Fault Occurrence on Single-rotor Unmanned Helicopters, *Journal of Intelligent and Robotic Systems*, vol. 84, no. 1, pp. 21-35.
- F. R. Lopez-Estrada, J-C. Ponsart, **D. Theilliol**, **Y. M. Zhang**, and C. M. Astorga-Zaragoza (2016), LPV Model-based Tracking Control and Robust Sensor Fault Diagnosis for a Quadrotor UAV, *Journal of Intelligent and Robotic Systems*, vol. 84, no. 1, pp. 163-177.
- Z. X. Liu, C. Yuan, **X. Yu**, and **Y. M. Zhang** (2016), Leader-Follower Formation Control of Unmanned Aerial Vehicles in the Presence of Obstacles and Actuator Faults, *Unmanned Systems*, vol. 4, no. 3, pp. 197-211.
- **X. Yu**, Z. X. Liu, and **Y. M. Zhang** (2016), Fault-tolerant Formation Control of Multiple UAVs in the Presence of Actuator Faults, *International Journal of Robust and Nonlinear Control*, vol. 26, no. 12, pp. 2668-2685.
- Z. X. Liu, **Y. M. Zhang**, **X. Yu**, C. Yuan (2016), Review on Guidance, Navigation, and Control Design Methodologies of Unmanned Surface Vehicles, *Annual Reviews in Control*, vol. 41, pp. 71-93.
- X. Wang, and **Y. M. Zhang** (2016), Insulator Identification from Aerial Images Using Support Vector Machine (SVM) with Background Suppression, in *Proceedings of the 2016 International Conference on Unmanned Aircraft Systems (ICUAS'16)*, June 7-10, 2016, Arlington, USA.
- X. Wang, and **Y. M. Zhang** (2016), A Survey on Remote Sensing and Computer Vision Technologies for Automatic Power Line Inspection Using Unmanned Aerial Vehicles (UAVs), Presented at the *12th International Conference on Intelligent Unmanned System (ICIUS'16)*, August 23-25, 2016, Xi'an, China.
- K. A. Ghamry, **Y. M. Zhang** (2016), Fault-Tolerant Cooperative Control of Multiple UAVs for Forest Fire Detection and Tracking Mission, Presented at the *3rd International Conference on Control and Fault-Tolerant Systems (SysTol'16)*, Sept. 7-9, 2016, Barcelona, Spain
- K. A. Ghamry and **Y. M. Zhang** (2016), Cooperative Control of Multiple UAVs for Forest Fire Monitoring and Detection, Presented at the *12th IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications*, August 29-31, 2016, Auckland, New Zealand.
- K. A. Ghamry, Y. Q. Dong, M. A. Kamel, and **Y. M. Zhang** (2016), Real-Time Autonomous Take-off, Tracking and Landing of UAV on a Moving UGV Platform, Presented at the *24th Mediterranean Conference on Control and Automation*, Athens, Greece, June 21-24, 2016.
- M. A. Kamel, **X. Yu**, **Y. M. Zhang** (2016), Fault-Tolerant Cooperative Control of WMRs under Actuator Faults Based on Particle Swarm Optimization, Presented at the *3rd International*

Conference on Control and Fault-Tolerant Systems (SysTol'16), Sept. 7-9, 2016, Barcelona, Spain.

- **X. Yu**, Z. X. Liu, and **Y. M. Zhang** (2017), Fault-Tolerant Flight Control Design with Finite-Time Adaptation under Actuator Stuck Failures, *IEEE Transactions on Control Systems Technology*, vol. 25, no. 4, 1431-1440.
- P. Li, **X. Yu**, X. Y. Peng, Z. Q. Zheng, and **Y. M. Zhang** (2017), Fault-Tolerant Cooperative Control for Multiple UAVs Based on Sliding Mode Techniques, *SCIENCE CHINA Information Sciences*, vol. 60, no. 7, 070204.
- B. Wang and **Y. M. Zhang** (2017), Adaptive Sliding Mode Fault-Tolerant Control for An Unmanned Aerial Vehicle, *Unmanned Systems*, vol. 5, no. 4, pp. 209-221.
- Z. X. Liu, C. Yuan, and **Y. M. Zhang** (2017), Active Fault-Tolerant Control of Unmanned Quadrotor Helicopter Using Linear Parameter Varying Technique, *Journal of Intelligent and Robotic Systems*, vol. 88, no. 2-4, pp. 415-436.
- W. Ghadir, J. Habibi, A. G. Aghdam, and **Y. M. Zhang** (2017), Non-prespecified Starting Depot Formulations for Minimum-Distance Trajectory Optimization in Patrolling Problem, *Journal of Intelligent and Robotic Systems*, vol. 87, no. 3-4, pp. 699-710.
- M. A. Kamel, K. A. Ghamry, and **Y. M. Zhang** (2017), Real-Time Fault-Tolerant Cooperative Control of Multiple UAVs-UGVs in the Presence of Actuator Faults, *Journal of Intelligent and Robotic Systems*, vol. 88, no. 2-4, pp. 469-480.
- C. Yuan, Z. X. Liu, and **Y. M. Zhang** (2017), Aerial Images-Based Forest Fire Detection for Firefighting Using Optical Remote Sensing Techniques and Unmanned Aerial Vehicles, *Journal of Intelligent and Robotic Systems*, vol. 88, no. 2-4, pp. 635-654.
- M. A. Kamel, **X. Yu**, and **Y. M. Zhang** (2018), Fault-Tolerant Cooperative Control Design of Multiple Wheeled Mobile Robots, *IEEE Transactions on Control Systems Technology*, vol. 26, no. 2, pp. 756-764.
- B. Wang and **Y. M. Zhang** (2018), An Adaptive Fault-Tolerant Sliding Mode Control Allocation Scheme for Multicopter Helicopter Subject to Simultaneous Actuator Faults, *IEEE Transactions on Industrial Electronics*, vol. 65, no. 5, pp. 4227-4236.
- Y. Y. Guo, B. Jiang, and **Y. M. Zhang** (2018), A Novel Robust Attitude Control for Quadrotor Aircraft Subject to Actuator Fault and Wind Gusts, *IEEE/CAA Journal of Automatica Sinica*, vol. 5, no. 1, pp. 292-300.
- Y. H. Qu, Y. T. Zhang, and **Y. M. Zhang** (2018), A Global Path Planning Algorithm for Fixed-wing UAVs, *Journal of Intelligent and Robotic Systems*, In Press, DOI: 10.1007/s10846-017-0729-9.
- **X. Yu**, X. B. Zhou, and **Y. M. Zhang** (2018), Collision-Free Trajectory Generation and Tracking for UAVs Using Markov Decision Process in a Cluttered Environment, *Journal of Intelligent and Robotic Systems*, In Press, DOI: 10.1007/s10846-018-0802-z.
- C. Yuan, Z. X. Liu, and **Y. M. Zhang** (2018), Learning-based Smoke Detection for Unmanned Aerial Vehicles Applied to Forest Fire Surveillance, *Journal of Intelligent and Robotic Systems* (Accepted)
- H. Badihi, **Y. M. Zhang**, and H. Hong (2015), Active Power Control Design for Supporting Grid Frequency Regulation in Wind Farms, *Annual Reviews in Control*, vol. 40, pp. 70-81.
- H. Badihi, **Y. M. Zhang**, and H. Hong (2017), Fault-Tolerant Cooperative Control in an Offshore Wind Farm Using Model-Free and Model-Based Fault Detection and Diagnosis Approaches, *Applied Energy*, vol. 201, pp. 284-307.
- H. Badihi, **Y. M. Zhang**, P. Pillay, and S. Rakheja (2017), Application of FMRAC to Fault-Tolerant Cooperative Control of a Wind Farm with Decreased Power Generation due to Blade Erosion/Debris Build-Up, *International Journal of Adaptive Control and Signal Processing*, In Press, DOI: 10.1002/acs.2836.