Tutorial-T4 (Half Day, 4 hours)

WHY ARE UAVS FAILING? A FRAMEWORK TO MAKE THEM SAFE, RELIABLE AND RESILIENT TO EXTREME DISTURBANCES

Organizers

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Tutorial Summary

This Tutorial addresses fundamental issues that have challenged UAV designers, OEMs and the user community for the last decades, despite the exponential growth witnessed in UAV utilization. It is well-documented that more than 40% of all Class A air mishaps are attributed to UAVs, and for this reason, the UAV research community is actively involved in the development and eventual implementation of new methods/tools to endow these critical assets with properties of resilience, reliability and availability.

This Tutorial presents and discusses fundamental issues that relate to UAV design and implementation, and attempts to answer questions such as: Why are UAVs failing? What technologies are required to make them safe and resilient to incipient failures and large environmental disturbances? Basic and fundamental notions of Failure Modes and Effects Criticality Analysis (FMECA) are presented first to set the stage for means to Data Acquisition and Data Mining, followed by recent advances in Fault Detection and Identification (FDI), and, finally, to new and innovative technologies intended to improve the integrity of UAVs and UAV swarms in the execution of complex missions. Technology gaps are discussed along with methods to bridge such gaps, eventually resulting in resilient and safe UAVs.

Detailed Tutorial Outline and Rationale

The starting point of the Tutorial is to discuss and rationalize about why autonomous systems are not really autonomous, followed by recommendations for needed requirements and attributes of autonomy. Next, novel diagnostic and prognostic algorithms are presented with the aim to develop an overarching Prognostics and Health Management (PHM) and Condition Based Management (CBM) architecture for such autonomous systems (and UAVs). Modeling tools from the data-driven and model-based domains are examined. A fault diagnosis and failure prognosis framework is introduced that builds upon mathematically rigorous concepts from estimation theory and utilizes an emerging and powerful methodology in Bayesian theory called Particle Filtering, which is particularly useful in dealing with difficult non-linear and/or non-Gaussian problems. The Particle Filter based diagnosis framework aims to accomplish the tasks of fault detection and identification using a reduced particle population to represent the state probability density function (pdf). This framework provides an estimate of the probability masses associated with each fault mode, as well as a pdf estimate for meaningful physical variables in the system. Once this information is available within the diagnostic module, it is conveniently processed to generate proper fault alarms and to inform about the statistical confidence of the detection routine. The foundation for development and application of PHM/CBM technologies is a thorough understanding of the physics of failure mechanisms as critical systems are subjected to stress conditions. From the physical components/systems themselves to a good understanding of how such systems fail and under what conditions leads to optimum fault diagnosis and prognosis. Once the PHM/CBM framework is established, the next step is to introduce intelligent strategies for corrective action in the event the UAV is subjected to extreme disturbances (failure modes, wind gusts) that may endanger the life of the system. Methods to assess the disturbances and technologies to compensate for the disturbance detrimental effects are introduced. Novel self-organization and control reconfiguration methods are debated to safeguard the vehicle's integrity. Efficient human-machine interfaces are proposed to transfer (and evaluate) automation attributes to the machine.

Thematic Topics

- ***A Framework for UAV Design for Autonomy***: An architectural framework is presented to evaluate platform autonomy/autonomy attributes/autonomous operation based on the fundamental concepts of *trust*, *risk* and *confidence*. The platform reconfiguration problem is considered as an essential component of assured autonomy, which coupled with fault diagnosis, failure prognosis, decision making and contingency management, completes the proposed framework for design for assured autonomy. The design for autonomy framework depends on its constituent modules and requires integration with the aim to assist the designer and/or system operator functioning as a decision support tool and providing urgently needed capabilities to improve safety, reliability, survivability and maintainability of critical assets.
- ***Health Management and Fault-Tolerant Control***: Modern technological systems rely on sophisticated fault-tolerant control techniques to meet increased performance and safety requirements, which include the ability to accommodate system component failures automatically, while maintaining overall system stability and acceptable performance. Such incipient failure conditions of critical components / subsystems may lead to a catastrophic event endangering the life of the platform and resulting in failure of mission completion. Thus, it is essential to estimate on-line, in real-time, the RUL of failing components. A novel approach to fault-tolerance is presented by considering prognostic results as inputs to a Model Based Control strategy that trades off system performance with control activity in order to extend the RUL of the platform so that a detrimental event does not occur within the mission profile.
- ***Reliability Analysis and Life Cycle Management***: Lifecycle management involves all events and operations occurring during the system lifetime such as design, manufacturing, testing, operation, degradation, inspection, maintenance, repair, and failure. It also implies degradation handling through monitoring, inspection, and maintenance intervention. A novel framework is introduced for lifecycle management of engineered systems typically found on a UAV, focusing on reliability concepts. The objective is to develop a system-based architecture that builds upon a suitable system model, innovative prognostic routines that estimate the RUL of systems subject to fault/failure modes, rigorous reliability analysis tools, and appropriate optimization methods that capitalize on optimization and reliability findings and ascertain improvements in system design and/or maintenance.
- ***Human-Machine Interface***: Recent events associated with aircraft mishaps strongly enforce what is called the *automation paradox* **-** progressively move a human's tasks to a machine (automation). The aim is to enhance human reliance on automated (autonomous) systems that are designed and implemented on-board or off-board an aircraft with the expressed goal to monitor critical system components/subsystems, assess their health status and report on incipient (possibly catastrophic) failure modes. The pilot/sensor in-the-loop framework presents major challenges that need to be addressed if issues about the aircraft's integrity are to be effectively managed, including conflicts between the pilot's intent/commands and fault-tolerant control commands/advisories. A rigorous systems engineering process is suggested to analyze and design tools and techniques for platform health management, human-automation interfaces and conflict resolution between the human and automated systems. Innovative technologies are introduced to define and quantify concepts of risk, confidence and trust as

essential to maximize and rely on automated system (autonomy) attributes. The output of the automated system is viewed as a decision support system supported by appropriate explanation modules.

- ***Closing and Q&A***: Open discussion on new challenges: UAV swarms and their impact on mission profiles; directions on future human-machine interfaces, requirements and challenges; training and education; shaping the future in the UAV arena.

Intended Audience

- Graduate students in electrical engineering, mechanical and aerospace engineering;
- Scientists, researchers, practitioners, UAV system designers and engineers;
- UAV practitioners, researchers and developers.

Tutorial Material: *To be delivered to participants via Dropbox invitation and USB jump drive swap.*