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Intelligence in Aerospace Systems

AIAA Intelligent Systems Technical Committee*

THE question of what is an intelligent system (IS) has been the subject of much discussion and debate. Regardless of how one defines intelligence, characteristics of intelligent systems commonly agreed on include 1) Learning – capability to acquire new behaviors based on past experience; 2) Adaptability – capability to adjust responses to changing environmental or internal conditions; 3) Robustness – consistency and effectiveness of responses across a broad set of circumstances; 4) Information Compression – capability to turn data into information and then into actionable knowledge; and 5) Extrapolation – capability to act reasonably when faced with a set of new (not previously experienced) circumstances. The objective of building intelligence into systems is mostly to ensure safe and reliable performance of complex systems with minimal or no human intervention. The complexity of the problems in the aerospace field makes it a very fruitful area of research for developing and applying IS technologies. Research and development emphasizes applications, including military and commercial aerospace as well as supporting ground systems. A broad set of IS technologies exist, such as planning/scheduling algorithms that translate goals or waypoints into detailed activity schedules or trajectories, intelligent data processing that extracts and reasons about pertinent sensor feedback, and learning technologies such as neural networks that enable adaptation to changes in physical system attributes. The goal is for the intelligent system and any human supervisor to maintain awareness of the system and environmental state so that collaborative synthetic-human agent teams can coordinate activities and make informed, rational decisions throughout all phases of a mission. Such real-time monitoring and response capabilities are particularly important when unexpected events or system failures occur.

IS technologies are enabling air and space missions to be more reliable, more ambitious in scope, and less labor-intensive for human operators. Workload has been reduced in the cockpit with intuitive interfaces and capable software tools to support the flight crew. Unmanned air vehicle (UAV) missions are moving toward a model of one operator for multiple vehicles. Direct spacecraft monitoring is required only when an anomaly is detected or a critical activity is in progress. Mission planning software for air and space vehicles is able to reason about and optimize tasks and trajectories for high-risk, high-cost missions. Onboard real-time software can actively process science and surveillance data and dynamically adjust tasks. Guidance, navigation, and control technologies are becoming more robust via adaptation of models and controllers to provide stability and a safe operating envelope. Real-time fault diagnosis and recovery tools are being viewed as essential tools for high-cost, high-payoff air and space vehicles. IS software requires capable verification and validation and deliberation about discrete knowledge and continuous physical models. Results must also be effectively communicated to ground or onboard operator(s) to enhance situational awareness rather than risk surprises from the automation.

IS applications in Aerospace include piloted and unpiloted aircraft, spacecraft, and planetary rovers operating alone or in teams. Although the dynamics and mission goals are quite diverse when comparing air, space, or surface operations, basic IS technologies and architectures can be applied to all of these domains. IS algorithms in nearly all cases increase the level of autonomy for an entire vehicle or subsystem. Planning/scheduling architectures have provided the capability for aerospace vehicles to behave in a goal-oriented fashion, developing plans and adjusting them as required to meet mission goals. The Deep Space-1 (DS-1) Remote Agent project was perhaps the first autonomy architecture tested onboard a spacecraft. Although successful, it also stressed the importance of verification and validation on the ground, particularly because typical planning/scheduling software cannot be tested exhaustively over the set of possible states. The Mars Exploration Rover (MER) pair exceeded expectations in terms of mission lifetime, but although certain operations could have been autonomous, teleoperation was the default mode of operation. Autonomy was demonstrated, however, during the landing process, successfully demonstrating that autonomy can be mission enabling when communication delays and real-time constraints preclude direct human monitoring and control.

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Although tremendous advances have been made in automation of aircraft flight (for instance flight management systems are standard equipment in commercial and military vehicles and are capable of autonomously following a pre-planned flight plan from takeoff through landing) achieving safe operation in changing conditions, such as adverse weather, without human intervention, remains an area of active research. Research being conducted in adaptive flight control using adaptive critics and neural network inner-loop controllers has recently demonstrated robust, stable flight following single or multiple actuator failures. While individual vehicle safety may be at less of a premium for UAV operations, automation has been pushed even further. Military operations require reactive planning for individual UAVs and UAV teams. As a hybrid system marriage of symbolic and continuous trajectories, researchers have introduced the concept of a maneuver automaton to efficiently sequence flight maneuvers backed by provably stable controllers to execute each maneuver and to transition between maneuvers or flight conditions. UAV team activities have also been planned and coordinated with multi-layer architectures that connect high-level symbolic algorithms with a path planner and a reactive plan executor. Emphasis is placed on providing situational awareness of vehicle and mission activities, enabling a single operator or military commander to monitor and manage an entire vehicle team. Verification and validation of IS systems to human flight safety standards is one of the very real challenges currently being addressed by the IS research community.

In the safety-critical domains that dominate the aerospace field, introduction of IS technologies is driven by necessity more than desire to make theoretical progress. Each new technology must be proven in theory and in practice, even though experience is very difficult to obtain for space operations. As we ramp up to an ambitious space exploration program as outlined by President Bush in 2004, IS technologies will play a key role in enabling human and robotic exploration. Robotic technology will be critical to monitor, assemble, and repair structures in space and on the lunar or Martian surface. Mobile robotic inspection vehicles can provide the monitoring capability inside and external to space vehicles. There is extensive research ongoing on autonomy architectures to enable operation of aerial and surface vehicles with minimum human supervision. Use of IS technologies is critical to ensure safe and reliable operation of space vehicles traveling large distances over long periods of time, and for human habitats on extraterrestrial surfaces. With the limited human resources available onboard, it will be extremely important to provide accurate and reliable diagnostic and prognostic information so that corrective actions can be taken in a timely manner. It is important to consider the incorporation of IS technologies into the early conceptual design phases rather than adding them on post facto after designs for vehicles or habitats have been fully developed. Some recent examples of situations which could have been better handled if such IS technologies were incorporated early in the design phases are the air leak in the International Space Station (ISS) and the need to manually inspect the shuttle wings, while in space orbit, for damage. Detecting the location of the air leak in the ISS took a considerable time and effort on part of the resident astronauts thus distracting them from their main purpose of conducting science. In the post-Columbia environment, astronauts can be expected to spend considerable time and effort in using telerobotic devices to inspect shuttle wings for damage, and if damage is detected to make EVA (Extra Vehicular Activity) excursions to repair the damage.

This special *Journal of Aerospace Computing, Information, and Communication* section includes articles that span a broad set of IS technologies considered groundbreaking with respect to fundamental theory, novel application to aerospace systems, or both in many cases. Although, as a result of space limitations, we have been able to touch only the surface of the excellent work being done in IS technology development for aerospace application. We hope that these papers will provide you useful insight into the relevance of IS technologies and the challenges that need to be overcome to advance human capabilities on the ground, in the air, and in space.

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