Automation and Autonomy for Robotic Spacecraft

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Vision for the Future of Autonomy at JPL

- Space exploration involves spacecraft operating in harsh and unforgiving environments

- JPL is pioneering resilient, self-aware, and autonomous systems able to weigh risk and make decisions locally to ensure that tomorrow’s missions are a success
  - The topic of Autonomous Systems and Artificial Intelligence is identified as a key strategic future capability in the JPL Strategic Implementation Plan

- Key characteristics of future missions:
  - Goal-directed operation, allowing operators to focus on objectives and oversight
  - Self-sufficient planning, scheduling, and control, including internal management of resources and redundancy, coordination of both engineering tasks and science observations, and recovery from anomalies
  - Real-time assessment of situations given set of objectives and utilizing models of system and environment
  - Capabilities for learning and model adaptation based on observations of system and environment
Autonomy and Automation

- Autonomy is the ability of a system to achieve goals while operating independently of external control *(2015 NASA Technology Roadmap)*
  - Requires self-directedness (to achieve goals)
  - Requires self-sufficiency (to operate independently)

- Automation is the replacement of routine manual processes with software/hardware processes that follow a step-by-step sequence *(Autonomous and Autonomic Systems, Truszkowski, et al)*

- JPL currently deploys autonomous systems that:
  - Protect systems from detected faults and hazardous conditions (fault protection)
  - Perform critical events despite the presence of failures (orbit insertion; entry, descent and landing)
  - Increase mission effectiveness and return (auto-navigation, feature detection and science observation re-targeting)
Present Challenges

• Systems must work the first time, in configurations and environments that cannot be fully represented before launch
  • Nature of missions (exploration) also typically means limited data available

• Implementations are time-consuming to develop and difficult to validate
  • Particularly for protection of safety-critical engineering functions
  • This scales poorly as system and environmental complexity grow

• Persistent questions on completeness of design, and adequacy of V&V
  • Addressed by multiple levels of review and cross-cutting analyses

• Autonomous fault recovery limited to specific scenarios and fault cases
  • Due to size of state space and *a priori* elaboration of on-board responses
Autonomy Focus Areas

• Architecture
  • Mission-wide evolvable architecture that enables the integration and deployment of state-of-the-art control and machine reasoning technologies

• Methodology
  • Processes and tools for assembly, coordination, and analysis of information in a systematic fashion that ensures completeness and accuracy, that results in a reliable, affordable, operable system

• Computing
  • High-performance, fault-tolerant, multi-processor computing platform

• Assessments and guarantees of system behavior
  • Enabled by principled design techniques and advancements in simulation and formal methods

• Iterative development
  • Iterative development of operational capabilities in a rapid prototyping facility, progressively increasing the scope of the deployed autonomy platform

• Partnerships and collaborations
  • Leverage external investments in autonomy, artificial intelligence and other related technologies

Resilient Spacecraft Executive Architecture

Model-based Probabilistic Risk Assessment
Approach: Staged Evolution of Capability

• Stage 1: “Resilient System”
  • System performs resource management and health management functions. Executes “tactical” activity plans provided by operations team. Uses and adapts models of internal state. Control via closed-loop commanding. Adapts detailed plan to address minor anomalies.

• Stage 2: “Independent System”
  • System generates tactical activity plan based on science directives (“strategic plan”) provided by science team. Uses and adapts models of internal state and environment. Reduced mission operations team needed.

• Stage 3: “Self-Directed System”
  • System develops science strategic plan and tactical plans based on high-level objectives. Responds to novelty by adjusting plans within context of objectives. Reduced science operations team needed.
Summary

• A close partnership between people and semi-autonomous machines has enabled decades of space exploration, but to significantly expand our reach, our systems must become more capable
  • This need is documented in the comprehensive JPL Strategic Implementation Plan, available to the public here

• We intend to develop and demonstrate self-directed and independent systems capable of performing science missions with high confidence, despite failure or unanticipated circumstances, to
  • improve robustness,
  • increase science return, and
  • greatly expand opportunities for exploration

• Our approach is iterative and evolutionary, establishing the necessary engineering foundations to design autonomous systems with guarantees of behavior
  • Needed capabilities also depend on technology development in areas such as artificial intelligence, machine learning, model-based systems engineering, software development and robotics