Autonomous Systems
NASA Capability Overview

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2018-08-24
Autonomous Systems SCLT

Systems Capability Leadership Team

- Serve as a **community of practice** in autonomous systems
- **Identify barriers** that impact the development and infusion of autonomy capabilities into mission systems
- Identify and **assess the NASA workforce** and facilities needed to advance autonomous systems
- **Recommend research and development** in autonomous systems technology for NASA
- **Recommend investment/divestment** to improve the use of autonomous systems in aeronautics (ARMD), human exploration (HEOMD), science (SMD), and space technology (STMD)

**Structure**

- Lead: **Terry Fong** (STMD)
- Deputy: **Danette Allen** (LaRC)
- Members (34): Center SMEs, (S)CLT leads, Mission Directorate reps
Artificial Intelligence (AI)

- **AI does NOT have a single, simple, universally accepted definition.**
- **AI** is the “capability of computer systems to perform tasks that normally require human intelligence (e.g., perception, conversation, decision-making.” – Defense Science Board 2016
- **AI** encompasses **many technologies** and **many applications**: deep learning, predictive analytics, translation, classification & clustering, information extraction, speech to text, text to speech, natural language processing (NLP), expert systems, planning, scheduling & optimization, robotics, image recognition, machine vision, machine learning.
• Automation is the automatically-controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human labor – *Merriam-Webster*

• Automation is not “self-directed”, but instead requires command and control (e.g., a pre-planned set of instructions)

• A system can be automated without being autonomous

The “Afternoon Train” (A-Train) is a coordinated group of Earth observing satellites that follows the same orbital “track”.

Autonomous Systems
Autonomy

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

- A system is the combination of elements that function together to produce the capability required to meet a need. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose. – 2016 NASA Sys. Eng. Handbook

The Curiosity rover can autonomously drive from point to point using stereo vision and on-board path planning.
Autonomy involves many functions …

… that can be performed by humans or software
What is NOT autonomy?

**Autonomy is NOT artificial intelligence, but may use AI**
- Machine learning (deep learning, reinforcement learning, etc.)
- Perception (object recognition, speech recognition, vision, etc.)
- Search, probabilistic methods, classification, neural networks, etc.

**Autonomy is NOT automation, but often relies on automation**
- Most robotic space missions rely on automation
- Command sequencing (event, order, time triggered)

**Autonomy is NOT only about making systems “adaptive”, “intelligent”, “smart”, or “unmanned / uncrewed”**
- Autonomy is about making systems self-directed & self-sufficient
- Systems can include humans as an integral element (human-system integration / interaction, human-autonomy teaming, etc.)
- Software (e.g., decision support) can make humans more autonomous of other humans (air traffic control, mission control, etc.)
Why autonomy?

Autonomy is needed …

• When the cadence of decision making exceeds communication constraints (delays, bandwidth, and communication windows)

• When time-critical decisions (control, health, life-support, etc) must be made on-board the system, vehicle, etc.

• When decisions can be better made using rich on-board data compared to limited downlinked data (e.g., adaptive science)

• When local decisions improve robustness and reduces complexity of system architecture

• When autonomous decision making can reduce system cost or improve performance

• When variability in training, proficiency, etc. associated with manual control is unacceptable
Where can NASA use Autonomy?

**EARTH LAUNCH AND LANDING SYSTEMS**
- Launch Vehicles
- Launch Abort Systems
- Entry, Descent and Landing

**EARTH ATMOSPHERIC SYSTEMS**
- Unmanned Aerial Systems
- Vehicle Mission Safety
- Vehicle Performance Enhance
- Human-machine teaming
- National Airspace Management
- Distributed Large-scale Collaborative Systems

**GROUND SYSTEMS**
- Mission Operations
- Visualization and Interaction
- Robotic Inspection and Repair
- Propellant/Commodity Loading

**ROBOTIC EARTH-ORBITING SYSTEMS**
- Formation Flying
- Constellations and Swarms
- Rendezvous and Docking
- On-Orbit Servicing
- In-Space Assembly
- In-Space Manufacturing
- Instrument Data Analysis
- Sensor Web

**ROBOTIC SPACE SYSTEMS**
- Planetary Ascent Vehicles
- Rendezvous and Docking
- Entry, Descent & Landing
- In Situ Access
- Sample Collection
- Orbital Navigation
- Instrument Data Analysis
- In Situ Resource Utilization

**HUMAN EARTH-ORBITING SYSTEMS**
- Life Support
- Rendezvous and Docking
- On-Orbit Servicing
- Visualization and Interaction
- Robotic Assistants
- Mission and Data Analysis
- In-space Manufacturing
- In-space Assembly

**HUMAN SPACE SYSTEMS**
- Planetary Ascent Vehicles
- Life Support
- Rendezvous and Docking
- Entry, Descent & Landing
- Surface Transport
- Robotic Assistants
- Mission and Data Analysis
- In Situ Resource Utilization
Aeronautics
Transforming civil aviation

Autonomy-Pilot Teaming for Complex Ops

Urban Air Mobility (UAM)

UAS Traffic Management (UTM)

Autonomy-Enabled ATM
Human Exploration

From Earth to the Moon and Mars

Earth
- Notional Commercial Platform
- ISS
- Commercial launch Vehicles

Moon
- Orion
- SLS
- Commercial Lunar Lander
- Robotic Surface Missions
- Gateway
  - PPE - Habitat - Airlock - Logistics

Mars
- Mars robotic exploration, technology development

In LEO
Commercial & International partnerships

In Cislunar Space
A return to the moon for long-term exploration

On Mars
Research to inform future crewed missions
Science Missions

Discovering the secrets of the Universe
Space Technology

Technology drives innovation

Early Stage Innovation
- NASA Innovative Advanced Concepts
- Space Tech Research Grants
- Center Innovation Fund/Early Career Initiative

Technology Maturation
- Game Changing Development

Partnerships & Technology Transfer
- Technology Transfer
- Prizes and Challenges
- iTech

Technology Demonstrations
- Technology Demonstration Missions
- Small Spacecraft Technology
- Flight Opportunities

SBIR/STTR

Low TRL
Mid TRL
High TRL

TECHNOLOGY PIPELINE
NASA Programs with Autonomy R&D

New algorithms (TRL 1-3)
- **ARMD**: Transformative Aero Concepts
- **SMD**: Planetary Science and Technology from Analog Research, COLDTech
- **STMD**: Space Tech Research Grants

Scaling the technology (TRL 4-7)
- **ARMD**: Airspace Operations & Safety
- **HEOMD**: Adv. Exploration Systems
- **STMD**: Game Changing Development

Flight systems (TRL 8-9)
- **HEOMD**: Adv. Exploration Systems
- **STMD**: Small Satellite Technology
UAS Air Traffic Management (ARMD)

Overview

- The UTM architecture addresses mission planning and execution strategies for UAS operations
- Provide cooperative, interoperable, digital ability to plan and schedule airspace resources; track vehicles; and assist with contingencies
- Support autonomous and remotely piloted vehicle operations

Research Focus

- Capability for operators to interact with each other through predefined data exchanges and application protocol interfaces
- Provide complete situation awareness of airspace use and constraints
- Urban environments and high density operations
Autonomous Systems & Ops (HEOMD)

Objectives

• Advance autonomy technology for human spaceflight (crew and vehicle)
• Planning and scheduling, fault detection, isolation and impact reasoning, plan execution, and crew decision support

Current activities

• Demonstrate crew decision support system on-board the ISS
• Demonstrate advanced caution and warning for infusion into Orion (for EM-2)
• Demonstrate vehicle systems automation in the iPAS simulation facility (JSC)
Astrobee (STMD)

Free-flying robot for ISS IVA
- 3 robots + docking station
- Open-source software
- Autonomous / telerobotic operations

IVA tasks in human spacecraft
- Mobile surveys (inventory + IVA environment monitoring)
- Mobile camera for mission control

Successor to SPHERES
- Multiple ports for new payloads
- Perform experiments without crew
- 7 guest science projects in devel.

Tech development for Gateway
- Support IVA robotics engineering
- Autonomous caretaking during uncrewed periods
- In-flight maintenance

Launch: NG-11 in April 2019
Distributed Spacecraft Autonomy (STMD)

Scaleable autonomy for multi-spacecraft
- Comm: resilient data distribution
- Fault management: distributed diagnostics engine
- Distributed planning, scheduling, and task execution
- Ops: scaleable ground data system and human-system interaction

Flight demonstration
- Integrated to Starling / Shiver mission
- Reusable core software stack
- Dynamic inter-spacecraft coordination for monitoring variable RF signals

Note: project is completing formulation for FY19 start
Integrated System for Autonomous and Adaptive Caretaking (STMD)

Caretaking of exploration spacecraft
- Autonomous robots + spacecraft infrastructure (avionics, sensors, networking) + ground control
- Develop and test on ISS for future infusion to Gateway

Crewed periods
- Off-load routine work from astronauts
- Tech: safe human-robot interaction, robust navigation

Uncrewed ("dormant") periods
- Monitor and maintain systems in the absence of astronauts
- Tech: sw architecture, diagnostics/prognostics, smart downlink
Future Autonomy R&D?

Perception for Extreme Environments

- Autonomous nav or target selection for icy worlds, interior oceans, caves, pits, etc.
- Requires new 3D sensors (lidar, time-of-flight cameras, etc.) & high-performance computing

Reactive Science

- Observe and/or sample dynamic & transient phenomena (plumes, seeps, weather, etc)
- Requires autonomous on-board decision making (planning, scheduling & execution)
- Must manage risk and uncertainty on-board

Collective Operations

- Enable a spacecraft swarm (10-100+) to collectively perform distributed activities
- Requires a distributed autonomy architecture (including coordination and collaboration)
- Must perform planning, scheduling, health management, etc. at a “collective” level
Autonomous Systems SCLT Activities

**ARMD**
- TACP TTT: “Autonomous Systems” subproject planning

**HEOMD**
- Deep Space Gateway Technology Utilization Working Group
- Exploration Capabilities Coordination Group (ExCCG)

**SMD**
- 2018 “Autonomy for Future Science Missions” workshop

**STMD**
- “Autonomous Operations” R&D planning (focus on STRG and GCD)
- STRG ESI 2018: "Smart and Autonomous Systems for Space” solicitation
- STRG STRI 2018: "Smart Deep Space Habitats” solicitation
- NSTRF TA04 topic chair
- GCD: advice/feedback to current and proposed projects
- Partnerships: review proposed agreement abstracts
Autonomous Systems SCLT Activities

**OCE**
- Autonomous Systems taxonomy development and infusion (to OCT, MDs, etc)
- Baseline assessment: state of capability in NASA

**OCT**
- Interagency Space Science & Technology Partnership Forum

**External engagement**
- DoD: Autonomy Community of Interest (CoI)
- DARPA: Robotic Servicing of Geosynchronous Satellites *(SME support)*
- NSF: Joint solicitation for the “Smart and Autonomous Systems” *(ESI 2018 topic is a pilot for larger NASA collaboration in FY19+)*
- Briefings from AFRL, ONR, etc.
Autonomous Systems Taxonomy

1.0 Situation and Self Awareness
- 1.1 Sensing and Perception
- 1.2 State Estimation and Monitoring
- 1.3 Knowledge and Model Building
- 1.4 Hazard Assessment
- 1.5 Event and Trend Identification
- 1.6 Anomaly Detection

2.0 Reasoning and Acting
- 2.1 Mission Planning
- 2.2 Activity and Resource Planning and Scheduling
- 2.3 Motion Planning
- 2.4 Execution and Control
- 2.5 Fault Diagnosis and Prognosis
- 2.6 Fault Response
- 2.7 Learning and Adapting

3.0 Collaboration and Interaction
- 3.1 Joint Knowledge and Understanding
- 3.2 Behavior and Intent Prediction
- 3.3 Goal and Task Negotiation
- 3.4 Operational Trust Building

4.0 Engineering and Integrity
- 4.1 Verification and Validation
- 4.2 Test and Evaluation
- 4.3 Operational Assurance
- 4.4 Modeling and Simulation
- 4.5 Architecture and Design

2018-04-26
Top Technical Challenges

**Situation and Self Awareness**
- The availability of qualified sensors (e.g., lidar for planetary rovers) and difficulty assuring data directly impacts perception performance.

**Reasoning and Acting**
- Scaling to handle more complex problems (number of constraints, etc.) with uncertainty (dynamic environments, etc.) is an unsolved problem.
- Performance is limited by mission computing (CPU, storage, comm).

**Collaboration and Interaction**
- Humans are complex, but they are a part of any autonomous system. What works for one person may not work for all.
- Human-system integration is a key challenge for NASA (HRP “Risk of Inadequate Design of Human and Automation/Robotic Integration”).

**Engineering and Integrity**
- Autonomous systems are difficult to V&V and to assure.
- Autonomy capability cannot simply be “added” as an afterthought.
Questions?