National Aeronautics and Space Administration

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NASA Langley Research Center 1917-2017

Self-Aware Vehicles for Effective Human-Machine Teaming

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Collaborative Sensing, Learning, and Control in Human-Machine Systems
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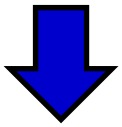
A Storied Legacy, A Soaring Future

Motivation – Why Self-Aware Vehicles?

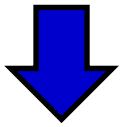
- To realize a future world where aviation has been transformed by autonomy and on-demand air transportation is a reality …
- To enable safe, effective and affordable space exploration and colonization …

New capability is needed beyond the current state of the art



Self-Aware Vehicles

Designed to be part of an integrated system with a human mission manager



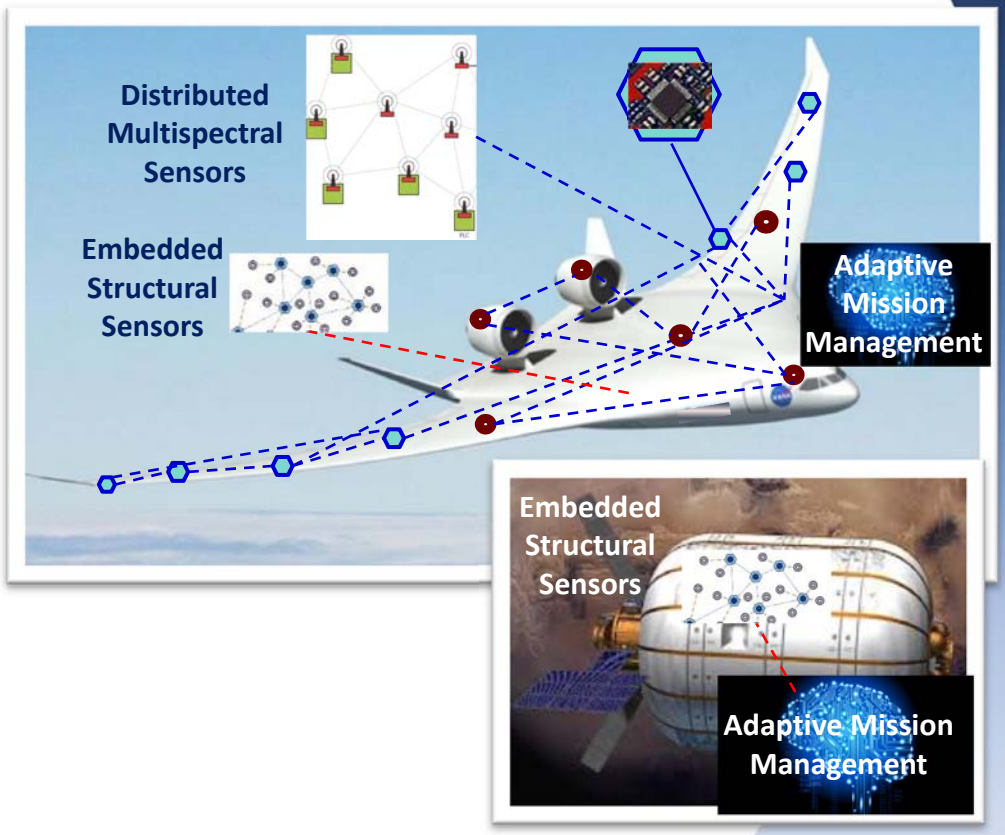
Human-Machine Teaming

Exploit the human to make the machine smarter and use the machine to make the human more effective

What is a Self-Aware Vehicle?

A Self-Aware Vehicle

- **Is aware of its internal state**
- **has situational awareness of its environment**
- **can assess its capabilities currently and project them into the future**
- **understands its mission objectives**
- **can make decisions under uncertainty regarding its ability to achieve its mission objectives**



It is an intelligent system whose self-assessment and projection of its capability over a temporal range in real-time redefines its "nominal" operations.

Self-Aware Aircraft – Technologies

- **Networked Distributed Sensors**
  - Multi-spectral sensor fusion & **information extraction**

- **Internal State Awareness**
  - platform health – structural, dynamic, subsystems
  - capability and constraints
- **External Situational Awareness**
  - external resources – home base, supervisors, or collaborators
  - threats that can affect system performance – weather, congestion, uncooperative agents, criticality of human operator status

- **Adaptive Mission Management**

Self-Aware Vehicles - Technologies

- **Adaptive Mission Management – The "brain" of the self-aware vehicle:**
  - understand mission objectives communicated at high level - **commander's intent** rather than detailed mission plan → paradigm change
  - plan actions to optimize mission performance
  - integrate vehicle state assessment with external situational awareness
  - assess ability to complete current mission
  - if cannot achieve mission objectives, revise mission plan and/or alter execution strategy to remain within current safe operational limits

- **Decision-making under uncertainty – integral for adaptive mission management :**
  - predict and understand self-capability over a variable temporal horizon
  - predict actions of other vehicles and objects
  - certainty, trust and completeness of available information
  - predict, assess, observe/understand consequences of own actions
  - demonstrate decision transparency to contribute to trust between human and machines

Self-Aware Vehicle – Complimentary Technologies

- **Validation & Verification, Test & Evaluation**
  - key V&V research conducted in parallel with self-aware technology development

  → help advance V&V for adaptive, learning autonomous systems
- **Tools for determining autonomy impact on mission effectiveness**
  - properly assess impact of autonomy on all aspects of self-aware aircraft
  - develop appropriate safe, cost-effective, mission efficient architectures and concepts
- **"Big Data" prognostics capability**
  - assist in extracting information from large network of distributed multispectral sensors
  - self-aware vehicles present a good test case for applicability of algorithms developed for big data analysis to engineering databases (magnitudes differences in data volume)
- **Vehicle Flight Prediction framework**
  - used to manage uncertainty leading to low-risk cutting edge vehicles

Self-Aware Vehicle – Langley Contributions

V&V
T&E

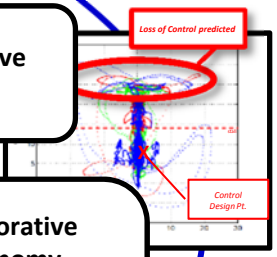
Intelligent
Propulsion
System

Vehicle Flight Prediction

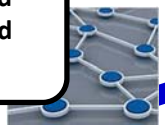
Multimodal
Autonomous
Navigation

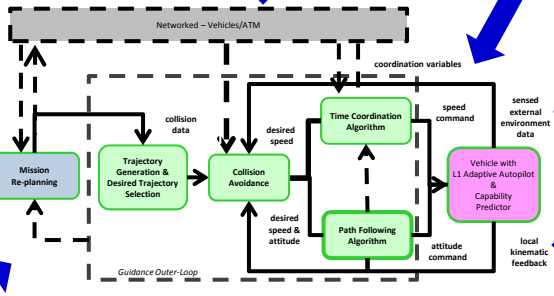
Learn-to-Fly

L1 Adaptive
Control

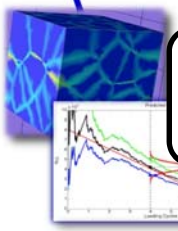


Networked
Distributed
Sensors



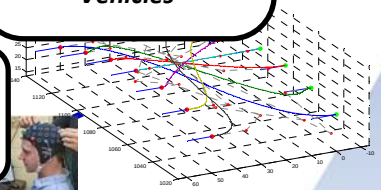


Collaborative
Autonomy
Time-Critical
Coordination
Heterogeneous
Vehicles



Digital
Twin

Adaptive Mission Management
Decision Making
Autonomous GNC



Human-
Machine
Teaming

Tools for Autonomy
Mission
Effectiveness

"Big Data" Prognostics

Unconventional
Configurations

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Systems View

Self-Aware Vehicles

Designed to be part of an integrated system with a human mission manager

&

Human-Machine Teaming

Exploit the human to make the machine smarter and use the machine to make the human more effective

How to Build a Team

- **Communication using "natural language"**
  - Mission definition
  - Intervehicle and intravehicle communication
- **Trust → Machine or "Autonomy" to decide how to achieve goal**
  - Coordinated flight path generation
- **Sacrifice**
  - Obstacle avoidance

Why We Need Natural Interaction

Natural Language:

Common methods humans use to communicate with one another

- **Speech, gestures, pictures, text, etc.**

Develop a natural-language interface which *non-pilot* can quickly and easily use to define and fly trajectories for an autonomous, unmanned vehicle.

- Decreased workload on humans
- Increased system-wide situation awareness
- Increased trust

Allow experts in their field to initiate and control multiple autonomous agents

May increase collaborative teaming

Intravehicle Communication

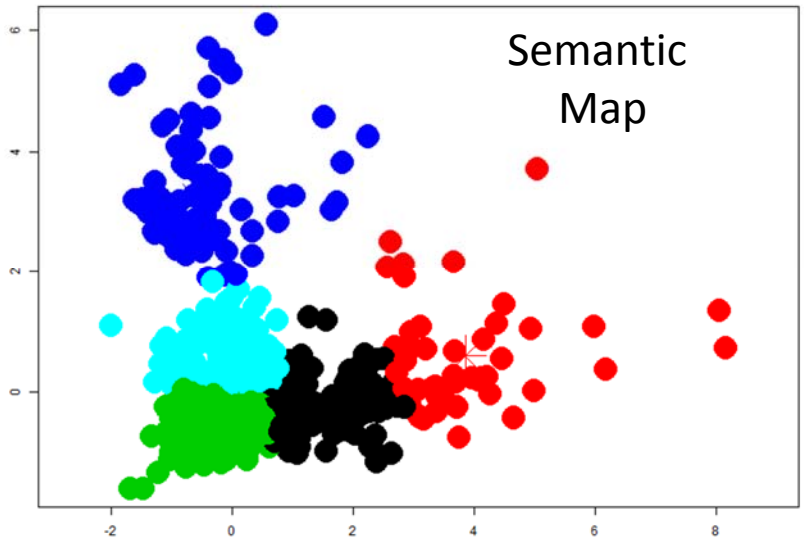
Infer "Commander's Intent"

Autonomous agent able to answer back appropriately to the question

"What are you doing?"

Based on:

- **Mission context**
- **Previous utterances**



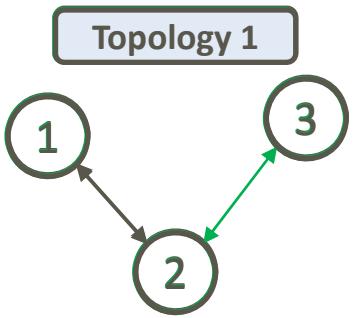
Latent Semantic Analysis (LSA)

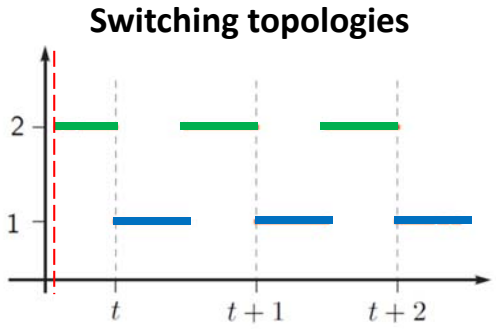
- Observed language used by human operators while working with UAVs
- Analyzed data to produce a semantic map for UAV operation

Resulting map can be continually trained with additional data

Intervehicle Coordination

Vehicles reach consensus to perform coordinated mission





Guaranteed Exponential Stability

$$\frac{1}{n}\frac{1}{T}\int_{t}^{t+T} \boldsymbol{Q}\boldsymbol{L}(\tau)\boldsymbol{Q}^{\top} d\tau \geq \mu \mathbb{I}_{\boldsymbol{n-1}}, \quad \forall\, t \geq 0$$

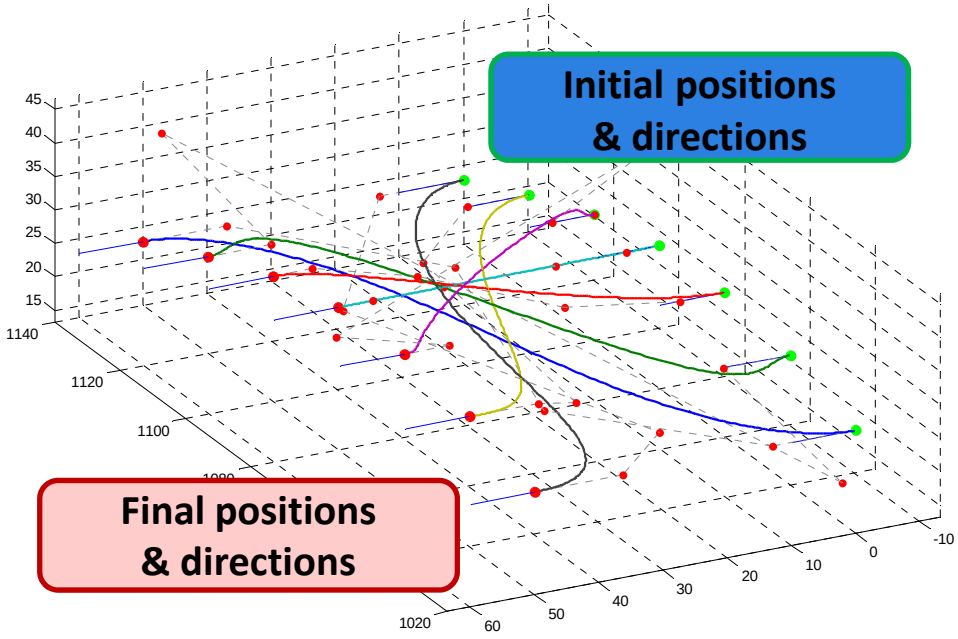
Trust

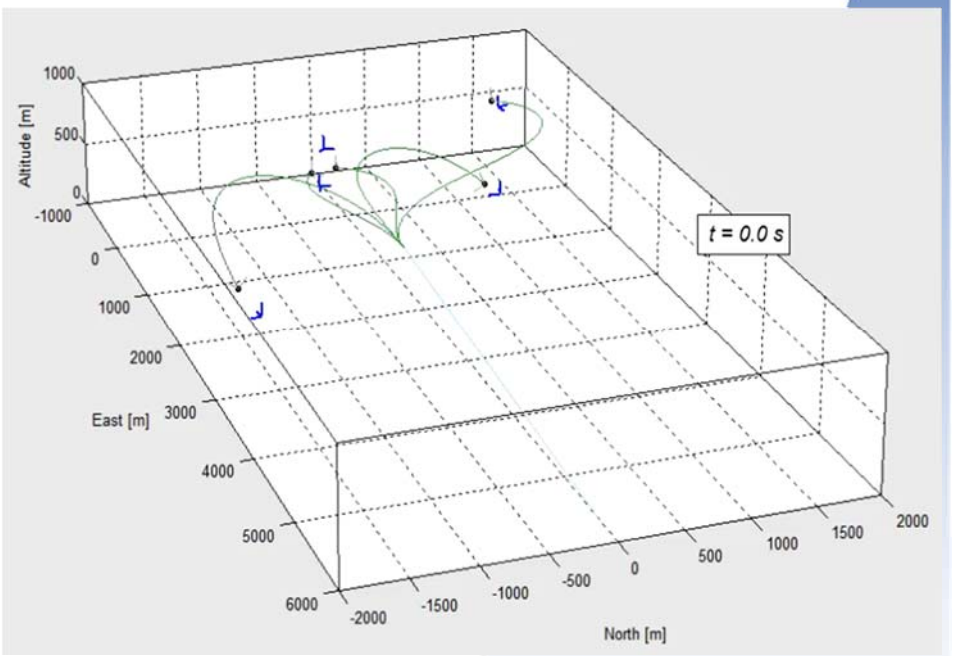
Autonomous Vehicles to Make Decisions:

- **Agent decides *how* to achieve the goal**

➢ Given high level **boundary conditions** defined by the user such as

- Initial and final position and direction

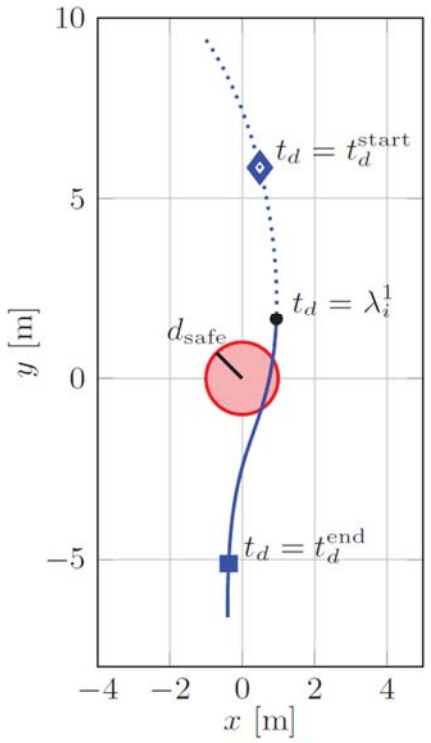


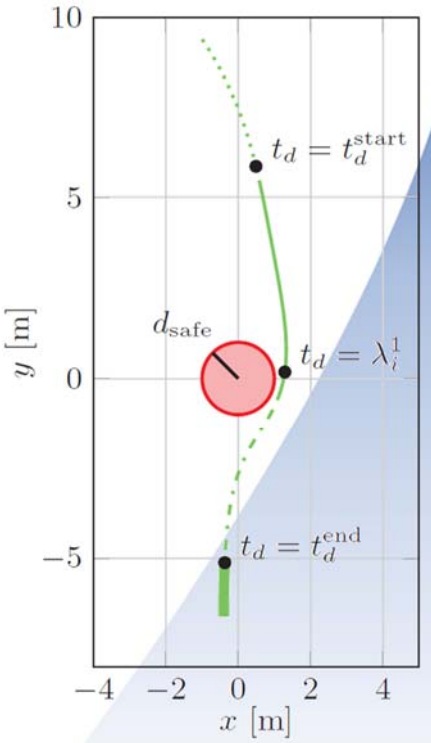


Sacrifice

Willingness to sacrifice *own* goal optimization to allow mission success

- **If an unexpected obstacle appears in the nearby airspace that jeopardizes the execution of the mission → collision avoidance algorithm re-plans trajectory**
  - May not be optimal for *a* vehicle but optimal for mission objectives





How to Build a Team

A self-aware vehicle is critical

Allows mission manager to:

- **Communicate using "natural language"**
- **Trust that all agents will achieve the mission objectives/goals**
- **Have faith that mission objectives/goals are optimized at the sacrifice of a particular agent's own goals**

Increases collaborative teaming

Self-Aware Vehicle - Applications

Self-aware vehicle concept has several immediate applications

- **Applicable to all vehicle classes and missions with initial technology infusion/proving ground into aircraft**
  - UAVs
  - innovative vertical lift concepts
  - performance self-optimization for transport aircraft
- **A building block for teams of self-managed vehicles that enable UAV-based payload (sensor of interest) directed flight for atmospheric measurements and exploration**
- **Self-aware capability provides truly autonomous flight including enabling cargo delivery and low-time or no-time pilot operations**
- **Allows aircraft to interact with cooperative and non-cooperative actors providing safety and increased capacity in the National Airspace System**
- **Space exploration and colonization beyond Low Earth Orbit (LEO) – smart habitats**

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