Autonomy Levels for Unmanned Systems (ALFUS) Framework

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OUTLINE

1. Introduction on ALFUS Framework
2. Progress/Status
3. Path Forward
4. Conclusion

CONTRIBUTORS

To the ALFUS Framework Effort

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Also referenced: "**Development of Autonomy Levels Through Functional Decomposition and Allocation**", Jeffry Jones (Navigator Development Group) and Mark Ragon (The Boeing Company), approved for public release, distribution unlimited, PM FCS 13 Feb 2007, case 07-04.

ALFUS OBJECTIVES

Framework to facilitate characterizing and evaluating autonomy for unmanned systems:

- Standard terms and definitions
- Metrics, processes, and tools

ALFUS SCOPE

- Generic framework, instantiated for various UMS's
- From remote control through full and intelligent autonomy
- From single UMS low level operational behavior to joint missions

HISTORY AND STATUS
Working Group

- Stage I: Started in 2003 as Cross-Government Ad Hoc Workgroup. Published Terminology.
- Stage II: Ongoing collaboration with FCS. Published Framework.
- Stage III: January 2008, Established SAE AS-4D Unmanned Systems Committee Performance Measures Subcommittee (alongside JAUS)

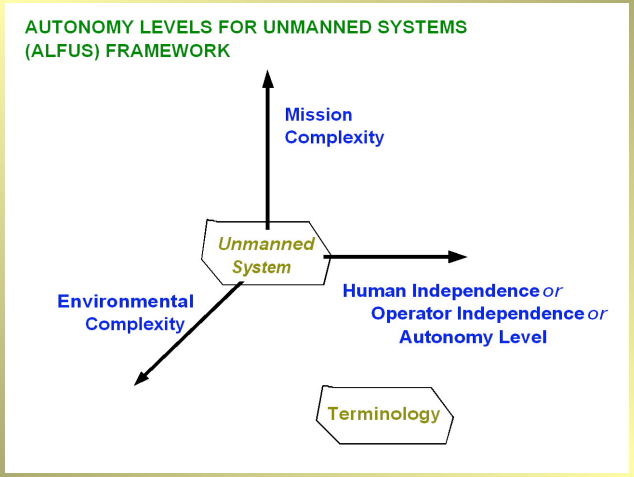
ALFUS FRAMEWORK

Contextual Autonomous Capability:

- Levels of Autonomy
- Levels of Mission Complexity
- Levels of Environmental Complexity
- Metrics Framework

Robot Terminology/Taxonomy/Ontology

ALFUS FRAMEWORK



ALFUS: LEVEL OF AUTONOMY

Degrees of participation by UMS

AUTONOMY

A UMS's own ability of sensing, perceiving, analyzing, communicating, planning, decision-making, and acting/executing, to achieve its goals as assigned by its human operator(s) through designed HRI.

ALFUS: AUTONOMY GUIDANCE

Autonomy

Reference levels:

- Fully autonomous
- UMS lead
- Human-UMS shared
- Human lead
- Teleoperation
- Remote control

Participation Metrics:

- Time spent
- Decision level
- Robotic initiation
- Workload

FCS's 5 LEVELS OF AUTONOMY

Level 5 (Autonomous) The operational case with an unmanned system afforded the maximum degree of independence and self-determination within the context of the system's capabilities and limitations; the case of minimum human influence over unmanned performance; an unmanned system performing out of the direct observation of the human controller; requiring the unmanned system to sense its environment and report its state to the human; all perceiving and acting are done by the machine, most analyzing, planning and decision-making are conducted by the unmanned system; negotiation and collaboration may be performed by the human.

Level 4 (Human Aided) The operational case with an unmanned system performing out of the direct observation of the human controller requiring the unmanned system to sense its environment and report its state to the human; analyzing, planning, and decision-making are shared between the human and the machine; most perceiving and acting is done by the unmanned system.

Level 3 (Human Directed) The operational case with an unmanned system performing out of the direct observation of the human controller requiring the unmanned system to sense its environment and report its state to the human; most analyzing, planning, and decision-making are done by the human; perceiving and acting are shared between the human and the unmanned system.

Level 2 (Tele-operation) The operational case with an unmanned system performing out of the direct observation of the human controller requiring the unmanned system to sense its environment and report its state to the human; all analyzing, planning and decision-making are done by the human; most perceiving is done by the human; human directs all unmanned system actions from the machine's frame of reference.

Level 1 (Remote Control) The operational case with an unmanned system afforded neither self determination nor independence. All sensing, perceiving, analyzing, planning, and decision-making are done by a human; human directs all unmanned system actions from the human's frame of reference; the case of maximum human influence over unmanned performance.

FUNCTIONAL MIGRATION thru 5 LOA

Increasing Autonomy →

		Sensing	Perceiving		Analyzing			
		Level 0 Fusion	Level 1&2 Fusion	Level 3 Fusion	Planning	Decision-making	Acting	Commun-icating
Level 5 (Autonomous)		All UMS	All UMS	Most UMS	Most UMS	Most UMS	All UMS	Most UMS
Level 4 (Human Aided)	+5	All UMS	+1 Most UMS	+1 Shared	+1 Shared	+1 Shared	+1 Most UMS	Most UMS
Level 3 (Human Directed)	+6	+1 Most UMS	+1 Shared	+1 Most man	+1 Most man	+1 Most man	+1 Shared	Most UMS
Level 2 (Tele-operation)	+6	+1 Shared	+1 Most man	+1 All man	+1 All man	+1 All man	+1 Most man	Most UMS
Level 1 (Remote Control)	+5	+2 All man	+1 All man	All man	All man	All man	Most man	+2 Most Man

Approved for Public Release, Distribution Unlimited, PM FCS/24 APR/2007, case 07-136

STATUS
Levels of Autonomy

Results:

- Method
- Reference levels

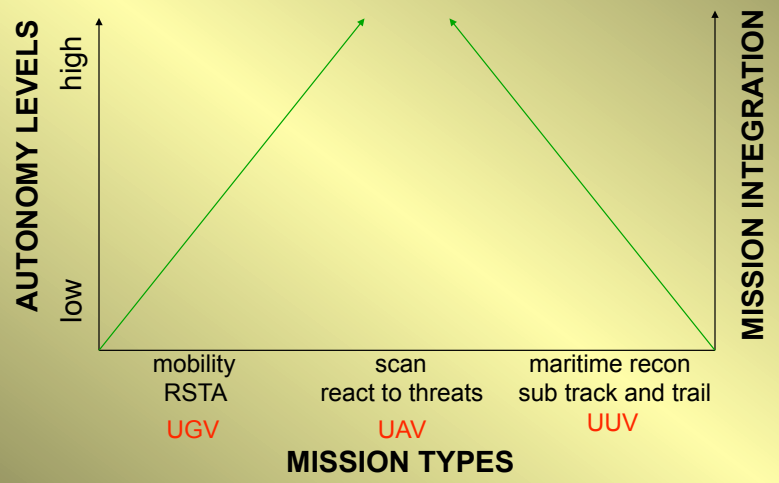
Further development:

- Reference model or specific levels
- Definitions for autonomous functionalities
- Application of metrics

MISSION COMPLEXITY METRICS

- More subtasks, Subsystems, functions
- More decisions (transitions, states), events
- Higher levels of perception
- Comprehensive knowledge base

JOINT MISSIONS

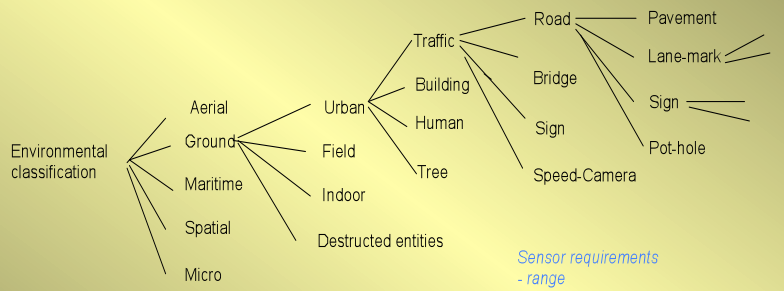


ENVIRONMENTAL COMPLEXITY

How easy is it to plan and execute upon:

- static: terrain, soil, water,
- dynamic: frequency/density/types of objects
- electronic/electromagnetic interferences
- urban: traffic, road, barriers, controlling devices
- rural: vegetation, biologics,
- weather: rain, brightness, temperature,
- operational: threats, decoy,

ENVIRONMENTAL CLASSIFICATION ILLUSTRATION



Sensor requirements
- range
- resolution
...

Robotic requirements
- crawling, sizing, ...
...

STATUS
Contextual Autonomy Capability

Results:

- Three sets of metrics
- NIST Special Publication NIST-SP-1011-II-1.0
- Numerous additional publications

Further development:

- Iterations of metrics
- Application of levels of autonomy, mission complexity, environmental complexity

ROBOT ONTOLOGY

- Terminology
- Taxonomy

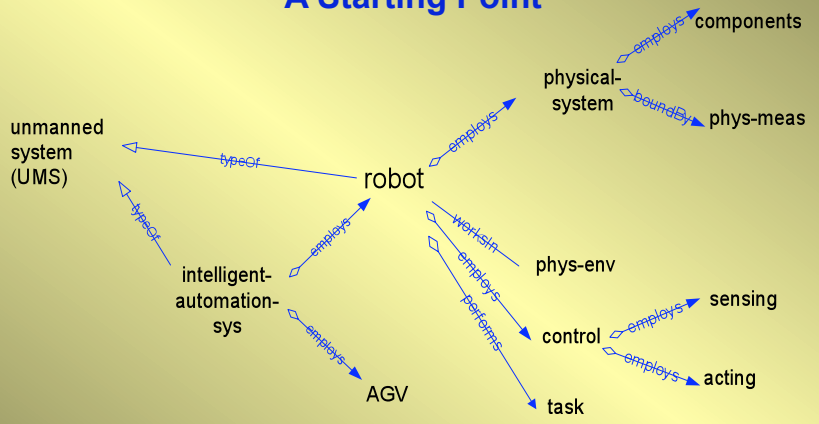
ONTOLOGY OBJECTIVES

Multiple Thread Structures of:

- Robots and components and metrics
- UMS Task Lists and metrics
- Environmental classifications and metrics
- Human interactions and metrics

Community Consensus

ROBOT ONTOLOGY
A Starting Point



Using Protégé capture tool

STATUS
Terminology/Taxonomy/Ontology

Results:

- Version 1.2 Terminology, NIST-SP-1011-I-1.2
- Initial taxonomy

Further development:

- Version 2.0 Terminology
  - Operational/safety critical: Battery, Interoperability related
  - Harmonizing multiple domains
- Comprehensive Robotic Taxonomy/Ontology

PLANNED RESULTS

- Terminology 2.0
- SAE AS-4D UMS Performance Measures
  - Autonomy Measures (LOA, CAC)
  - General Performance Measures
- Robotic Taxonomy/Ontology

SUMMARY

Framework to facilitate characterizing unmanned systems:

- Generic framework covering all UMS's
- Multiple layers of performance metrics
- Standard terms, definitions to facilitate integration and testing (SAE AS-4D)

http://www.isd.mel.nist.gov/projects/autonomy_levels/

Abbreviations

- ALFUS – Autonomy Levels for Unmanned Systems
- HRI – Human Robot Interface
- JAUS – Joint Architecture for Unmanned Systems
- LOA – Levels of Autonomy
- UMS – Unmanned System