Autonomy Levels for Unmanned Systems (ALFUS) Framework

Volume I: Terminology

Version 2.0

Contributed by the Ad Hoc Autonomy Levels for Unmanned Systems Working Group Participants[1]

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October 2008

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We apologize if any contributors have been omitted from the list or misplaced between the two segments. Please inform us, so that we can update the list. Contractors are acknowledged with the organizations or programs that they support. As the development effort continues, the lists are anticipated to be reorganized per the evolution of the Framework.

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Funding support for the ALFUS effort has been provided by:

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National Institute of Standards and Technology
Division Chief: Mr. Albert Wavering
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Department of Homeland Security
Science and Technology Directorate
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Sponsor: Dr. Bert Coursey

The U.S. Army Research Laboratory, under the sponsorship of Charles Shoemaker (retired) and Dr. Jon Bornstein, provided partial funding support at the early stage of the effort.

VERSION HISTORY

- Version 2.0—Added terms, updated definitions, added new domains—Search and Rescue and Manufacturing, added new sections on current robotic terminology standards and rationales for certain term definitions.
- Version 1.2—Updates on terms
- Version 1.1—Document title changed from "Terminology for Specifying the Autonomy Levels for Unmanned Systems" to "Autonomy Levels for Unmanned Systems (ALFUS) Framework, Volume I: Terminology," September 2004.
- Version 1.0—Published in January 2004.
- Draft Version 1.0—Accommodated comments raised in the Workshop #3, distributed on December 11, 2003.
- Draft Version 0.9—Distributed to members and user community on October 25, 2003, redistributed on November 10, 2003.
- Draft Version 0.7—Distributed to members and user community for feedback at the end of September 2003.
- Draft Version 0—Presented and discussed in Workshop #2, September 11, 2003.

EXECUTIVE SUMMARY, VERSION 2.0

This document, Version 2.0 of the Autonomy Levels for Unmanned Systems (ALFUS) Terminology, is based on Version 1.1, published as NIST Special Publication 1011. As stated in the inaugural Workshop, the ALFUS Framework, of which the Terminology is a part, is evolving as the Unmanned Systems (UMS) technology advances. Version 2.0 essentially covers the results of the ALFUS effort up to the end of 2007.

The main objective for this document, as stated in Version 1.1, is to identify and define terms to support the UMS community, particularly from the perspectives of characterizing the autonomy and measuring the autonomous capability of the UMS. Common definitions and terminology facilitates communication and reduces confusion in the UMS community. Version 1.1 has been significantly referenced or adopted in several other UMS standards, proving that ALFUS is achieving this objective. Section 1 provides more detailed descriptions in this regard.

As such, a significant portion of the terms and the format of the documentation remain the same. The main advances in Version 2.0 are:

1. Addition of new terms.
2. Revision of definitions for some of the existing terms.
3. Expansion of Domain Specific Terms section to include multiple Domains, namely, Defense, Urban Search and Rescue, and Manufacturing.
4. Addition of a description of current practices in the area of UMS related terminology.

One of the main objectives of ALFUS, as laid out by the original participants, is to provide common definitions and terminology to facilitate communication of autonomy in the UMS community. Version 1.1 has been significantly referenced or adopted in several other UMS standards, proving that ALFUS is achieving this objective. Section 1 provides more detailed descriptions in this regard.

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EXECUTIVE SUMMARY, VERSION 1.1

This document, produced by the Ad Hoc Autonomy Levels for Unmanned Systems (ALFUS) Working Group (WG), defines and collects the terminology to support the Group's main objective, the definitions of the unmanned system (UMS) autonomy and the metrics for measuring the autonomy.

The WG was sponsored by NIST and with participation from UMS professionals from Government agencies and their supporting contractors[2] on a voluntary basis. The WG output is based on Group consensus. In its first workshop, held on July 18, 2003, the Group decided to launch an effort to produce a framework for autonomy definitions and metrics. In the second workshop, held in September 2003, it was decided that the first volume of the ALFUS framework would be terminology. Also decided was that the first version of the framework should focus on supporting the U.S. Army Future Combat Systems (FCS) program. FCS was selected as the first program that this WG effort collaborate with because, at that time, the program involved the largest U.S. Department of Defense (DOD) collection of robotic systems anticipated to develop increasing levels of autonomy. Also, the program was at a stage of systems engineering requiring the same types of autonomy definitions as the ALFUS group was addressing.

The objective of this terminology effort is to, through a group effort, identify, develop, and document the terms and their definitions so that the results can serve as a common reference for the community. As such, consistency with the general dictionary definitions is assumed. However, for certain terms, we modified the dictionary definitions to better suit the UMS community needs. For some other terms, we repeated the dictionary definitions for referencing purposes.

The overarching guidelines for this terminology effort are:

- Leverage existing work and adopt existing definitions that are publicly available and accepted. This would expedite the WG's effort in proceeding with its core objective, the autonomy level framework. The references are listed at the end of this document. Modifications to the existing definitions may be necessary[3] to fit the objectives of this working group.
- Consider the cultural factor, for example, how people are using the terms, to ensure a seamless transition of the outcome to the users.
- Consolidate similar terms and resolve conflicting ones.
- Some terms may have generic and widely applicable definitions but are further defined for specific domains. We may provide both their generic definitions, in the MULTI-DOMAIN TERMS AND DEFINITIONS section, and their extensions in the DEFENSE ORIENTED TERMS OR EXTENSIONS and/or SEARCH AND RESCUE (SAR) ORIENTED TERMS OR EXTENSIONS sections. It is perceivable that additional sections may be created in future versions to accommodate additional domains. There are also terms that are only applicable to specific domains.

[2] The WG is now open to all the interested professionals.

[3] There are several cases when the definitions contributed by our WG members are similar to those given in the existing references. The descriptions from the existing references were typically adopted as the basis but enhanced by contributions from the WG members.

They are defined, accordingly, in the respective sections. Note that the applicability of the terms could change over time as particular terms may get accepted in more domains while some other terms may become less relevant over time.

- Some of terms are commonly referenced by the acronyms. Those acronyms are a part of this Terminology. Acronyms are collected in a separate section in this document.

Iterations with the WG participants and user communities have been continuing. Version 1 of this document was published in January 2004 to support FCS. This version, Version 2 is planned to be published in late 2008.

Since the WG has adopted a spiral development approach, this document is fully anticipated to evolve alongside the ALFUS framework itself. Readers and user communities have been, and are continuously encouraged to provide feedback.

The web site for the ALFUS effort is: http://www.isd.mel.nist.gov/projects/autonomy_levels/.

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1 INTRODUCTION

Unmanned systems (UMS) have been fielded in several domains in the recent past, ranging from battlefields to Mars and mostly sponsored by the U.S. Government. As the number of programs for developing UMS accelerates, there is a growing need for characterizing the autonomy of these systems. Individual government agencies have begun these efforts. The Department of Defense Joint Program Office, the Air Force Research Laboratory, the U.S. Army Science Board, the Army Maneuver Support Center, and National Institute of Standards and Technology have described levels of autonomy for various programs [2, 28, 29, 30, 31]. NASA has embarked upon a project on defining levels of autonomy for a human space flight vehicle [32]. It is beneficial that these and other agencies leverage each other's efforts to aim at a consistent approach.

This incentive gives rise to the Federal Agencies[4] Ad Hoc Autonomy Levels for Unmanned Systems (ALFUS) Working Group. In its first workshop, held on July 18, 2003 at NIST, the Group determined that its objectives were to define metrics for autonomy and to develop a framework for autonomy levels for unmanned systems (ALFUS). A committee, composed of six participants and representing different application domains, was formed and charged to draft the framework. The Group also determined that a beginning step would be to identify and define a set of terms that may be needed to support the unmanned systems community, to serve as Volume I of the ALFUS framework, and to facilitate the Framework development effort.

The terms should be categorized into a set that is generic and applicable to unmanned vehicles of various domains and a number of additional sets that are domain specific. The domain-specific terms can be instantiations of or extensions from the generic terms. The workshop participants identified the terms based on these premises.

This document defines terms from the perspective of UMS. Therefore, some of the definitions might not be as generic as applicable to domains beyond the UMS domain. Some definitions may include descriptions on how particular communities might use the terms.

It may be inevitable for certain acronyms, or even terms, to be used for different purposes by different communities. For example, ERT refers to Emergency Response Team in the DHS US&R robotics domain, but is also used to refer to Evidence Recovery Team by FBI. In a situation like this, we either list both or select a definition that may be used by a wider audience. In the case of ERT, we regard emergency responses as concerning a much larger citizen population than evidence recovery.

Version 0 of the document was presented and discussed in the Second workshop, held on July 18, 2003 at Baltimore-Washington Airport. Additional terms were identified and were assigned to the participants for definitions. All of the contributions have been incorporated. Numerous further iterations have been conducted with the working group participants and user communities. Version 1.0 of this document was published in January 2004 to support FCS.

The terms and definitions are organized into the following sections:

Section 2: Multi-Domain Terms and Definitions
Section 3: Defense Oriented Terms or Extensions

[4] Including supporting contractors.

Note that the later sections on domain oriented terms are equally important parts of the Terminology. Some of the acronyms in that section are also a part of the Terminology. It is possible that, upon further investigation or iterations, some of the terms currently identified as generic might be reassigned to the domain specific sections, or vice versa. Some other terms might even be considered beyond the scope of the autonomy level definitions at later stages and removed. The applicability of the terms could change over time as some terms may gain wider acceptance while some other terms may become less relevant over time. Additional terms will be included as part of the on-going WG efforts. Additional sections may also be added to accommodate additional application domains.

We plan to continue updating this document and addressing these issues in the future versions.

The style and structural guidelines for this document are:

1. Terms are defined in alphabetical order. Terms that share the same roots are grouped together to facilitate consistent definitions. In these situations, a root term is defined, followed by a collection of associated terms. We also list these associated terms according to their original alphabetical order, but only provide pointers to where they are defined.
2. Boldface is used to indicate the terms defined in this document.
3. We differentiate the following types of references:
   - braces, { }, to indicate that the definition is adopted from the cited reference,
   - brackets, [ ], to relate the stated definitions to the cited reference(s),
   - footnotes to point to extensions in domain specific sections given in later in the document.
   - angular brackets, < >, to point to section 6 RATIONALES FOR TERM DEFINITIONS or APPENDIX A ONGOING DISCUSSIONS OR UNRESOLVED ISSUES.

   Note that some DOD documents that serve as references are only cited by particular numbers. Readers are to use the contact information as stated in the Executive Summary for specific document titles.
4. Multiple definitions, obtained either from multiple references or through members consensus, may be given to a term when necessary. They are indicated with (A), (B), (C) ... .

Since the WG has adopted a spiral development approach, this document is fully anticipated to evolve, in line with the ALFUS Framework.

1.1 Current Practices

There are some UMS terminology publications that have limited scopes and other standards or practices with terminology relevant to UMS. These are listed below. The first three either adopted or referenced this document to a significant extent.

ASTM E 2521 – 07a,
Standard Terminology for Urban Search and Rescue Robotic Operation

ASTM F2395-05,
Standard Terminology for Unmanned Aircraft Systems

ASTM F 2541 – 06,
Standard Guide for Unmanned Undersea Vehicles (UUV) Autonomy and Control

ASTM E 2544
Standard Terminology for Three-Dimensional (3-D) Imaging Systems

R-103-2004
AIAA Recommended Practice: Terminology for Unmanned Aerial Vehicles and Remotely Operated Aircraft

AIAA S-066,
Standard Vocabulary for Space Automation and Robotics (1995)

ISO's robotic terminology standards focus on industrial robotics. ISO TC 184/SC 2 has the following standards:

ISO 14539:2000
Manipulating industrial robots -- Object handling with grasp-type grippers -- Vocabulary and presentation of characteristics

ISO 9787:1999
Manipulating industrial robots -- Coordinate systems and motion nomenclatures

ISO 9946:1999
Manipulating industrial robots -- Presentation of characteristics

ISO 11593:1996
Manipulating industrial robots -- Automatic end effector exchange systems -- Vocabulary and presentation of characteristics

ISO 8373:1994
Manipulating industrial robots - Vocabulary
Note: An amendment ISO 8373:1994/Amd 1:1996 and a Corrigendum ISO 8373/Cor.1:1996 followed.

ISO TC 184/SC 2 also has a list of other robotic standards [39, 40, 41, 42, 43, 44, 45] which might be of interest to some readers.

IEEE has the following standard which provides a very limited amount of terms in robotics:

IEEE 100-2000
The Authoritative Dictionary of IEEE Standards Terms (Seventh Edition, 2000)

1.2 Scope

This document covers engineering UMS and robots that operate in physical environments, but including simulation.

The document covers terms that facilitate the autonomy characterization. Additional robotic terms can be found in other publications, including the NIST 4D/RCS reference architecture [3].

This document does not address the UMS terms from the perspectives of taxonomy or ontology, although this document does provide a basis for them and future versions of this document may cover them.

2 MULTI-DOMAIN TERMS AND DEFINITIONS

Act

See **Execute**.

Adapt to Conditions

A UMS experiencing changes in the operational or environmental conditions that prevent it from continuing w its original mission will react within the confines of its capabilities. Adaptation may involve onboard replanning for alternatives. Applicable capabilities such as hover or stop may be performed until further instructed by operator or superior. System constraints or mission requirements may also mandate that the unmanned system continue to perform the mission in a degraded condition.

This term can be extended for Adapt to Failures, Adapt to Terrain, Adapt to Errors, etc.

Assembly Point (AP)

Location or facility where participating members initially report after receiving activation orders from the sponsoring organization [36].

Autonomous

Operations of a **UMS** wherein the **UMS** receives its **mission** from either the operator who is off the **UMS** or another system that the **UMS** interacts with and accomplishes that **mission** with or without further **human-robot interaction (HRI**).

Associated terms:

Fully autonomous

See **Mode of UMS Operation** - Associated terms.

Semi-autonomous

See **Mode of UMS Operation** - Associated terms.

Autonomy[5]

A **UMS**'s own ability of integrated sensing, perceiving, analyzing, communicating, planning, decision-making, and acting/executing <A.4>, to achieve its **goals** as assigned by its human operator(s) through designed **Human-Robot Interface** (**HRI)** or by another system that the **UMS** communicates with. **UMS**'s **Autonomy** is characterized into levels from the perspective of **Human Independence** (**HI**), the inverse of **HRI**. **Autonomy** is further characterized in terms of **Contextual Autonomous Capability (CAC)**.

[5] Houghton Mifflin Company, The American Heritage Dictionary: "Autonomy: the condition or quality of being self governing"

Associated terms:

Root Autonomous Capabilities (RAC)

The collective sensing, perceiving, analyzing, communicating, planning, decision-making, and acting/executing capabilities as specified in the **Autonomy** definition.

Autonomy Levels for Unmanned Systems (ALFUS) Framework or ALFUS

The overall structure for ALFUS, including the Terms and Definitions, the Metric Model, the Executive model, and the associated autonomy evaluation guidelines and processes, with the Contextual Autonomous Capability (CAC) model as a central concept.

Associated terms:

ALFUS Levels

A general term referring to the Framework levels, namely **Level of Autonomy** (**LOA**) or levels of **Human Independence** (**HI**), levels of **Mission Complexity** (**MC**), levels of **Environmental Complexity** (**EC**), or other types of indices that are derived within ALFUS <6.1>. These levels provide high level, summary perspectives of autonomy and complement the detailed, metric perspectives.

Executive/Summary Model for ALFUS

Equivalent to **ALFUS Levels** <6.1>.

Level of Autonomy (LOA) or Autonomy Level

A set of progressive indices, represented by alphanumeric characters, used to identify a UMS's capability of performing assigned autonomous missions independent of **HRI**. Equivalent to the **HI** aspect of the **Executive/Summary Model for ALFUS**.

Built-in Test

Equipment or software embedded in the operational components or systems, as opposed to external support units, which perform a test or sequence of tests to verify mechanical or electrical continuity of hardware, or the proper automatic sequencing, data processing, and readout of hardware or software systems.

Contextual Autonomous Capability (CAC) Model for Unmanned Systems (UMS)

A UMS's CAC is characterized by the missions that the system is capable of performing, the environments within which the missions are performed, and human independence that can be allowed in the performance of the missions.

Each of the aspects, or axes, namely, **mission complexity (MC), environmental complexity (EC),** and **human independence (HI)** is further attributed with a set of metrics, or capabilities in the complementary perspective, to facilitate the specification, analysis, evaluation, and measurement of the CAC of particular UMSs.

This CAC model facilitates the characterization of UMSs from the perspectives of requirements, capability, and levels of difficulty, complexity, or sophistication. The model also provides ways to characterize UMS's autonomous operating modes. The three axes can also be applied independently to assess the levels of MC, EC, and autonomy for a UMS.

Collaboration or **Cooperation**

The process by which multiple manned and/or **unmanned systems** perform a common **mission** or task synergistically by sharing data, such as coordinates of their maneuver(s) and local Common Relative Operational Picture (CROP) and/or by controlling actions together <A.1>.

Associated term:

Coordination

The ability for **UMS**'s or manned systems to work together harmoniously. Common data such as mission or task plans, coordinates of maneuver(s), local CROP, etc., can be shared. A superior can **coordinate** the task execution of the subordinates to accomplish the missions [3]. Two unrelated UMSs can **coordinate** to negotiate crossing a narrow bridge.

Control Method

See **Method of Control**

Cooperation

See **Collaboration**.

Coordination

See **Collaboration -** Associated term.

Data Fusion

See **Fusion**.

Dynamic mission planning.

See **mission planning**.

E-Stop or **Emergency Stop**

A control action commanded by an operator that removes power to all the moving functions and to any other function that, by design, may cause safety hazards. The procedure of the E-Stop is executed immediately once the command is received. The execution cannot be altered and overrides all the other UMS controls. A reset by the operator is required for further operations of an E-Stop'ped UMS. E-Stop may not be applicable to all UMSs at all times. For example, a UAV may employ an E-stop function only when the UAV is on the ground. Explicitly designed procedures are to be executed, instead, upon the occurrence of in-flight emergency situations. <A.9>, [46].

Environment
The surroundings of a UMS. The environment can be aerial, ground, or maritime. It includes generic and natural features, conditions, or entities such as weather, climate, ocean, terrain, and vegetation as well as man-made objects such as buildings, buoys, and vehicles. It can be static or dynamic, can be further attributed in terms of its complexity, and can be described as friendly/hostile/benign, safe/dangerous, easy/difficult, etc. The significant aspects of the environment are those that the UMS and the operator are interested in or aware of.

Execute

To **Act**. To carry out a plan, a task command, or another instruction [3].

Executive/Summary Model for ALFUS

See **Autonomy Levels for Unmanned Systems (ALFUS) Framework or ALFUS -** Associated terms.

Fault Tolerance

The ability of a system or component to continue normal operation despite the presence of hardware or software faults {14}.

Fully Autonomous

See **Mode of UMS Operation-** Associated terms**.**

Fusion or **Information Fusion** or **Data Fusion**

Information processing that deals with the acquisition, filtering, correlation, comparison, association, and combination/integration of data and information from single and multiple sources to support UMS objectives of recognition, tracking, situation assessment, sensor management, system control, identity estimation, as well as complete and timely assessments of situations and threats and their significance in the context of mission operation. The processes can involve UMS onboard computing resources, externally provided information, and human input. The process is characterized by continuous refinement of its estimates and assessments, and by the evaluation of the need for additional sources, or modification of the process itself, to achieve improved results [7, 8, 13].

Fusion Levels or **Levels of Fusion**

Each of the following six levels of fusion progressively adds meaning at higher levels of abstraction and involves more analysis [5, 9]:

- Level 0 - organize. This is the initial processing accomplished at or near the sensor that organizes the collected data into a usable form for the system or person who will receive it.
- Level 1 - identify/correlate. This level takes new input and normalizes its data; correlates it into an existing entity database, and updates that database. Level 1 Fusion tells you what is there and can result in actionable information.
- Level 2 - aggregate/resolve. This level aggregates the individual entities or elements, analyzes those aggregations, and resolves conflicts. This level captures or derives events or actions from the information and interprets them in context with other information. Level 2 Fusion tells you how they are working together and what they are doing.

- Level 3 - interpret/determine/predict. Interprets enemy events and actions, determines enemy objectives and how enemy elements operate, and predicts enemy future actions and their effects on friendly forces. This is a threat refinement process that projects current situations (friendly and enemy) into the future. Level 3 Fusion tells you what it means and how it affects your plans.
- Level 4 - assess. This level consists of assessing the entire process and related activities to improve the timeliness, relevance, and accuracy of information and/or intelligence. It reviews the performance of sensors and collectors, as well as analysts, information management systems, and staffs involved in the fusion process. This process tells you what you need to do to improve the products from Fusion Levels 0-3.
- Level 5 - visualize. This process connects the user to the rest of the fusion process so that the user can visualize the fusion products and generate feedback/control to enhance/improve these products.

Goal

(A) A result or state to be achieved or maintained [3].

(B) The purpose toward which an endeavor is directed {37}.

Hazard Avoidance

UMS's function of avoiding any physical objects or other adversarial situations, as either assessed by the **UMS**'s perception functions or provided through the **HRI**, that may oppose or deter passage or progress, impede the UMS's mobility in any other way, or cause any form of harm.

Human/Operator Intervention

The need for **Human Interaction** in a normally **fully autonomous** behavior due to some extenuating circumstances. An unanticipated action or input by a human required to complete a task.

Human Independence (HI)

Complementary to **HRI**, a situation in which a UMS is performing a mission without **HRI**. It is one aspect of the three-aspect **ALFUS Metric Model**.

Human Robot Interaction/Interface (HRI) or Human Interaction, Operator Interaction

(A) The activity by which human operators engage with **UMS**s to achieve the **mission goals**.

(B) The architecture for interaction between the robot and the human. It includes the specification of the interaction language: what tasks the user can ask of the robot and the corresponding actions, what tasks the robot can ask of the user and the corresponding actions. It is independent of a particular display or interaction modality. It is the planned and anticipated interactions between the robot and the user.

(C) The physical realization of the method of **Human Robot Interaction** or **Intervention**.

The following are the different roles of interaction possible for the human in **HRI**. Note that one person could possibly assume a number of roles or numerous people could take individual roles or even share roles. The user interface should be based on the types of roles the user will assume. In addition to specific information needed for each role, the user will need some awareness of other roles simultaneously interacting with the robot.

Supervisor

The supervisor monitors one or more robots with respect to progress on the mission, can task the robot(s) at the mission level, monitors mission progress, provides mission level directions, coordinates missions, and can assign an operator to assist a robot if needed.

A commander would be an example of a person who performs the supervisor-only role.

Teammate/Wingman

This is considered to be a human team member. **UMS** and its **teammate** each performs part of the overall mission and coordinate when needed. The teammate may command the **UMS** at the levels of detail of tasks or task plans.

Operator

This is the role assumed by the person performing **remote control** or **teleoperation**, **semi-autonomous** operations, or other man-in-the-loop types of operations. The operator input is expected at certain states during normal operations. During error conditions, the operator determines the problem that a robot is experiencing in interacting with the physical world, interacts with the robot to solve this if possible and returns control to the supervisor with an outcome, successful or not. If the operator cannot overcome the problem, it may be necessary to pass the robot control to the mechanic.

Mechanic or Developer

This role determines the problem with the hardware or software that the robot is having, solves this if possible, may interact with the robot to test out the proposed solution, and returns control of the robot to the supervisor with a determination.

Bystander

The role coexists in the same environment as the **UMS** but with an unknown intent. The bystander role could be neutral, friendly, or adversarial, or include various combinations. The bystander and the **UMS** need to build some expectation of what the counterpart will do in order to react accordingly. For example, the driver, a bystander, of a car may have to interact at a four way stop with a **UMS**. They both need some indication as to whether the other vehicle knows the rules of the road.

Pedestrians and traffic police would be examples of bystanders who would have limited interaction with autonomous driving vehicles. The **UMS** needs to be able to protect itself from possible harm from adversarial **bystander**.

The following list the associated terms with **HRI**:

Human-Operated

The type of **HRI** that refers to **remote control** or **teleoperation**.

Human-Assisted

The type of **HRI** that that refers to situations during which human interactions are needed at the level of detail of **task** plans, i.e., during the execution of a task.

Human-Delegated

The type of **HRI** that refers to situations during which human interactions are mainly at the **task** level.

Human-Supervised

The type of **HRI** that refers to situations during which humans play the monitoring role and human interactions are mainly at the mission level.

Information Fusion

See **Fusion**.

Intelligence in Unmanned Systems (UMSs)

Possession of and the ability to exercise **CAC** in the **UMS**.

Interoperability

The ability of software or hardware systems or components to operate together successfully with minimal effort by end user. Further attributed with functional, behavioral, lifecycle, and architectural scopes, and, therefore, can be delineated in terms of control and can be categorized into levels, types, or degrees in application programs. Facilitated by common or standard interfaces [12, 24].

Leader Follower

See **Robotic Follower** – Associated term.

Level

Relative position or rank on a scale.

Level of Autonomy

See **Autonomy Levels for Unmanned Systems (ALFUS) Framework** - Associated terms.

Level of Control

See Section 3, **Levels of Control (UMS). Levels of Control (UMS/Remotely Operated Systems).**

Marker

An aid used to mark a designated point for such operational purposes as route following, determination of bearings, courses, or location, and identification of key items or points of interest, including landmine markers and area Chemical, Biological, Radiological, or Nuclear (CBRN) decontamination markers. Traffic signs and signals are additional examples of **Markers**. The aid can be visual, electronic, or of other types.

Metric

An identified characteristic used to measure a particular attribute of a subject, such as how a defined goal fits a user's needs and whether the system generates required results; a metric can be subjective or objective.

Method of Control

The interface, either software or hardware, such as a joystick, waypoint selection via a map interface, natural language, hand signals, etc., that operators use to control a **UMS**.

Mission

The highest-level **task** assigned to a **UMS** {3}.

Mission Module

A self-contained subsystem installed on a **UMS** that enables the **UMS** to perform designed **missions**. It can be easily installed and replaced by another type of mission module [2].

Mission Planning

The process of generating tactical goals, a route (general or specific), commanding structure, coordination, and timing for a **UMS** or a team of **UMS**s. The mission plans can be generated either in advance or in real-time. They can be generated by operators on **OCUs** or by the onboard software systems in either centralized or distributed ways. The term **dynamic mission planning** [2, 3] can also be used to refer to onboard, real-time mission planning.

Mobility

The capability of a **UMS** to move from place to place, under its own power and under any mode or method of control. The characteristics of **Mobility** include the **UMS**'s speed, targeted location, and fuel availability [2]. Refueling could be performed either as a part of the **HRI** or autonomously by a fuel management autonomy task at a higher level.

Mode

A particular form or manner.

Mode of Operation for Unmanned Systems, Mode of Unmanned System Operations, or Unmanned System Operational Mode <A.8>

Human operator's ability to interact with a **UMS** to perform the operator assigned **missions**. The following are the defined modes: **fully autonomous, semi-autonomous, teleoperation,** and **remote control.**

Associated terms:

Fully Autonomous

A **mode of UMS operation** wherein the **UMS** accomplishes its assigned **mission**, within a defined scope, without human intervention while adapting to operational and environmental conditions.

Semi-Autonomous

A **mode of UMS operation** wherein the human operator and/or the **UMS** plan(s) and conduct(s) a **mission** and requires various levels of **HRI** [2] <A.3>. The **UMS** is capable of autonomous operation in between the human interactions.

Teleoperation

A **mode of UMS operation** wherein the human operator, using sensory feedback, either directly controls the actuators or assigns incremental goals on a continuous basis, from a location off the **UMS** [2].

Remote Control

A **mode of UMS operation** wherein the human operator controls the **UMS** on a continuous basis, from a location off the **UMS** via only her/his direct observation {2}. In this mode, the UMS takes no initiative and relies on continuous or nearly continuous input from the human operator.

Observation[6]

Detection or measurement of the environment and production of analyzable information.

Obstacle[7]

Any physical entity, physical phenomenon, or marked physical area that opposes or deters passage or progress, or impedes mobility of a **UMS** in any way <6.3>.

Operator Control Unit (OCU)

Also referred to as **operator control interface (OCI)** or **human interaction control unit**. The computer(s), accessories, and data link equipment that an operator uses to control, communicate with, receive data and information from, and plan **missions** for one or more **UMS**s {2}.

Orientation[6]

Analysis and comprehension of observed data and generation of prediction and other information to support decision-making process.

Perception

A **UMS**'s capability to sense and build an internal model of the environment within which it is operating, and to assign entities, events, and situations perceived in the environment to classes. The classification (or recognition) process involves comparing what it observed with the system's a priori knowledge[8] [3].

Associated term:

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[6] A stage in the OODA loop (Observation, Orientation, Decision, Action), conceived by Col. John R. Boyd in the 1970s as an air-to-air combat strategy for military fighter pilots.
[7] See section 3 for Defense extension.
[8] Similar to the combination of Observation and Orientation as used in ACL.

Local perception

When the perception process has occurred locally onboard the **UMS** and is regarding the **UMS's** local environment and within the **UMS**'s mission context.

Perception Levels or Levels of Perception [3]

The progressive results of sensory information after multiple levels of **sensory processing**:

- Level 1 – point or pixel, a point of concern that has physical properties which, in turns, can quantitatively be either measured with the systems' sensor(s) in a one-to-one correspondence or computed over time and space.
- Level 2 – line or list. Formed by groupings of sets of points according to certain criteria, such as continuity in position and direction over space and/or time.
- Level 3 – surface or boundary. Formed by groupings of sets of contiguous lines or lists according to certain criteria, such as continuity in orientation or curvature over space and/or time.
- Level 4 – object. Formed by groupings of sets of contiguous surfaces and boundaries according to certain criteria, such as rigid body mechanics, over space and/or time.
- Level 5 – unit of objects. Formed by groupings of sets of objects according to certain criteria, such as density, distribution, and relative positions, motions, and interactions, over space and/or time.

Point Man or Unmanned Point Man, Robotic Point Man

(A) A human (soldier in the military domain) assigned some distance ahead of a patrol as a lookout.

(B) The capability of a **UMS** to perform tasks analogous to a human **point man**.

Prognostic Health Management

System using artificial intelligence or other intelligent algorithms and a combination of sensors and models of systems to autonomously react to environmental changes and monitor the operational and maintenance characteristics of the system(s) under consideration [16].

Remote Control

See **Mode of UMS Operation** - Associated terms.

Remotely Guided

See **Remote Control**.

Robot[9]

A powered physical system designed to be able to control its sensing and action for the purpose of accomplishing assigned tasks in the physical environment. A robot includes its associated **HRI** [4] <6.2>.

[9] See section 6.2 for rationale.

Robotic Follower

The capability of a UGV to traverse a safe, tactically relevant route previously traversed by another vehicle (leader) <A.5>. The follower vehicle traverses the route automatically (i.e., under computer control using onboard sensors) with potentially significant physical or temporal separation from the leader. This capability takes advantage of human sensing and reasoning in the lead vehicle to reduce the perception and intelligence requirements for the follower vehicle. The follower vehicle may incorporate some limited perceptual capabilities to detect and avoid new obstacles that appear after the lead vehicle has passed {10}.

Associated term:

Leader Follower

The UGV team that operates as described in **Robotic Follower**.

Root Autonomous Capabilities (RAC)

See **Autonomy** - Associated terms.

Self-Diagnosis

Ability to adequately take measurement information from sensors, validate the data, and communicate the processes and results to other devices {18}.

Self-Healing

Automated or semi-automated capability of system repair, covering the infrastructure, hardware, and software aspects [17].

Semi-Autonomous

See **Mode of UMS Operation** - Associated terms.

Sense

Use of a **sensor** to acquire information about an object or a physical phenomenon.

Sensor

Equipment that detects, measures, and/or records signals, stimuli, or any other physical phenomena by means of energy or particles emitted, reflected, or modified by certain objects and activities [19].

Sensor Fusion

(A) Same as **fusion** except limiting data source to sensors.

(B) A process in which data, generated by multiple sensory sources, is integrated and/or correlated to create information, knowledge, and/or intelligence that may be displayed for user or be actionable to accomplish the tasks. The fusion capabilities include Detection, Classification, Recognition, and Identification [9].

Sensory Processing

Function or set of **UMS** software processes that operate on sensor signals to compute the characteristics of the world, to detect, identify, and classify entities, events, and situations, and to derive other useful information about the world. These processes can be hierarchically laid out to produce a series of intermediate outputs with different levels of abstraction and different spatial and temporal resolutions. The output of one process provides input for the process's adjacent, downstream process. Sensory Processing can also include processes that are horizontally laid out with assigned focuses. All the intermediate output may be useful to the UMS operations [3].

The following are ways to organize the progressive sensory processes, to perceive the resulting information, and to structure the knowledge and intelligence:

- Levels of Fusion - see **Fusion Levels**
- Levels of Perception see **Perception Levels**

Situational Awareness

The perception of **UMS**s in the environment within a desirable volume of time and space, the comprehension of perceived situations, and the projection of the **UMS**s' status in the future. In generic terms, the three levels of **situational awareness** are level 1 - perception, level 2 - comprehension, and level 3 - projection. There is both individual and group or team **situational awareness** [25].

Summary/Executive Model for Autonomy Levels

See **Autonomy** - Associated terms.

System of Systems or Team of Teams

Grouping(s) of unmanned and/or manned systems or teams for a particular mission where a team or system is a collection of organized vehicles performing the particular **tasks** or subtasks.

Tactical Behavior

The limited, near-term planning, maneuvers, and reactive procedures and actions used to adapt the execution of higher level, long term mission goals to both the corresponding environmental and the operational conditions.

See section 3 DEFENSE ORIENTED TERMS OR EXTENSIONS.

Task

A named activity performed to achieve or maintain a goal. **Mission** plans are typically represented by tasks. Task performance may, further, result in subtasking. Tasks may be assigned to operational units via task commands [3].

Associated Term:

Skill

The lowest level task.

Task Decomposition

A method for analyzing **missions** and **tasks** and decomposing them into hierarchical subtask structures according to the criteria of command/authority chain, control stability, computational efficiency, and management effectiveness [3].

Teaming

(A) The linking together of platforms, forces, or systems to complete a **mission** or **task** collectively that would be more difficult to do if the units acted separately. The process is characterized by distributed operations and quick maneuvers, which demands rapid synchronization, swift adaptation of plans and control measures, flexible groupings of distributed staff elements, and direct exchanges between commanders across hierarchies. For example, manned and unmanned platforms can be teamed to emphasize their complementary strengths. The unmanned systems have the further requirements of being able to easily and quickly communicate their intentions, goals, present state in the accomplishment of these goals, intended next action, and current problem areas. Additionally, they have to be re-tasked easily to participate in the current overall goal and to fit into their new position in the organizational structure. The above is critical if they are to perform effectively in team activities [19].

(B) A method of operation where a system uses the combined sensing, information exchange, decision-making, and acting capabilities of humans and robots function together to carry out missions within the planned scope.

In the situations of manned – unmanned **Teaming,** air-to-ground teaming means that the manned system is in the air with **UMS** on the ground. Similarly, there could be air-to-air, ground-to-ground, and ground-to-air types of teaming.

Teleoperation. See **Mode of UMS Operation -** Associated terms.

Telepresence

The capability of a **UMS** to provide the human operator with some amount of sensory feedback similar to that which the operator would receive if she/he were in the vehicle {2}.

Terrain

The physical features of the ground surface, including both natural features, such as valleys and hills and manmade features, such as roads and fences. Includes subsurface, such as tunnels, underground structures, and the bottom of the streams. Major terrain types are delineated based upon local relief, or changes in elevation, and include: flat, rolling, hilly, and mountainous. Additional characteristics include: hydrologic features, such as swamps; vegetation characteristics, such as forests; and cultural features, such as cities. The trafficability of the terrain is classified as: unrestricted, restricted, and severely restricted [26, 38].

Terrain Visualization

A component of battlefield visualization that provides a detailed understanding of the background upon which enemy and friendly forces and actions are displayed. Terrain visualization provides common terrain background for all users and all applications.

Additionally, terrain visualization allows interactive planning and mission rehearsal. Terrain visualization includes both natural and man-made features to include impacts of terrain on vehicle speed, maintenance, river-crossing operations, cross-country trafficability, and maneuverability. Terrain visualization includes the subordinate elements of data acquisition, analysis, database management, display, and dissemination. Derived from [22, 27].

Tether

A physical communications cable, fiber optic or other that connects a **UMS** and its **OCU** and restricts the range of operation of the **UMS** to the length of the cable. Some **tethers** include power [2].

Threat Avoidance

Ability to detect/degrade/defeat threats. The continual process of compiling and examining all available information concerning threats in order to avoid encounter <6.3>.

Unattended Ground Sensors (UGS)

Small, low cost, robust sensors, capable of operating in the field for extended periods of time (30 days or more). They consist of modular groups of sensors utilizing configurable ground sensing technologies, such as seismic, magnetic, infrared, acoustic, radio frequency, and Chemical, Biological, Radiological, Nuclear, or Explosive (CBRNE) detection, and other advanced sensing capabilities. **UGS**s may self-organize into a networked sensor array (sensor web) by locating the most efficient gateways for transmission of information. The resulting network may be self-healing, able to quickly bypass a neutralized gateway and locate a functional one within the sensor web.

Unattended System

Any manned/unmanned, mobile/stationary, or active/passive system, with or without power that is designed to not be watched, or lacks accompaniment by a guard, escort, or caretaker.

Unmanned System (UMS)

A powered physical system, with no human operator aboard the principal components, which acts in the physical world to accomplish assigned tasks. It may be mobile or stationary. It can include any and all associated supporting components such as **OCU**s. Examples include unmanned ground vehicles (UGV), unmanned aerial vehicles/systems (UAV/UAS), unmanned maritime vehicles (UMV)--unmanned underwater vehicles (UUV) or unmanned water surface borne vehicles (USV)--unattended munitions (UM), and unattended ground sensors (UGS). Missiles, rockets, and their submunitions, and artillery are not considered the principal components of UMSs [2] <6.2>.

Associated Term:

Logical UMS (LUMS)

(A) A software or otherwise conceptual model of a **UMS**, as in simulation or in other design or analysis tools.

(B) Inherently non-physical, i.e., software entities that either operate as independent entities and interact with their associated **UMS**s or are integral parts of a **UMS** in an inclusive context. Includes high-level computer control and management software systems that command and coordinate the low-level **UMS**s, for example, a shop floor control node in a flexible manufacturing system.

Unmanned Wingman, Robotic Wingman

(A) A **UMS** subordinate to and in support of the designated team leader [13].

(B) The wingman concept assists the leader in the command and control of the system. During operations, the robotic wingman orients itself on the section leader and, in the absence of orders, moves, stops, and shoots when his leader does. Anytime the wingman of a section is engaged or begins an engagement, the section leader supports the wingman's effort {23}.

Waypoint

An intermediate location through which a **UMS** must pass, within a given tolerance, en route to a given goal location {2}.

World Model (WM)

The subject system's internal representation of the portions of the environment that the system is aware of or that are of interest to the system and the operator from the goal perspective. The WM includes models for the system itself and entities in the environment, such as maps, images, situations, relationships, task knowledge, and other categories of knowledge. The WM may be static or dynamic, may be complete or incomplete but its contents are associated with various levels of confidence, may be related to and interact with each other in certain ways, and may contain certain attributes to either positively or negatively affect the system tasks. At lower **LOA**s, the **UMS**'s operations are enabled to lesser extents by the **UMS**'s **WM** and to greater extents by the operator's [3].

Associated term:

World Modeling

Function or process of constructing and maintaining a world model, using a series of software processes that can be hierarchically laid out to produce a series of intermediate outputs with different levels of abstraction and different spatial and temporal resolutions. The output of one process provides input for the process's adjacent, downstream process. **World Modeling** can also include processes that are horizontally laid out with assigned focuses. All the intermediate output may be useful to the **UMS** operations [3].

3 DEFENSE ORIENTED TERMS OR EXTENSIONS

Classes of UGVs

The DOD Joint Robotics Program (JRP) postulates several classes of UGVs, based on weight {2}, <A.2>:

- Micro: < 8 pounds (3.6 kg)[10]
- Miniature: 8 lb to 30 lb (3.6 kg to 13.6 kg)
- Small (light): 31 lb to 400 lb (14.1 kg to 181.8 kg)
- Small (medium): 401 lb to 2 500 lb (182.3 kg to 1136.4 kg)
- Small (heavy): 2 501 to 20 000 lb (1136.8 kg to 9090.9 kg)
- Medium: 20 001 to 30 000 lb (9091.4 kg to 13636.4 kg)
- Large: >30 000 lb (13636.4 kg)

Common Operational Picture (COP)

A single identical display of relevant information shared by more than one command; to facilitate collaborative planning and assist all echelons to achieve situational awareness [13].

Cooperative Engagement

A method of engagement for destroying enemy forces, employing sensors and shooters not resident on the same platform [25].

Levels of Control (UMS). Levels of Control (UMS/Remotely Operated Systems)

Control of **UMS** or remotely operated systems is the authority granted to an entity (operator) to exercise commands to such a system, its subsystems, and subordinate systems to accomplish a given mission. Although based on the Tactical Control System (TCS) ORD, which defines UAV control levels, and the Levels of Interoperability within NATO Standardization Agreement (STANAG) 4586 (UAV Control), it is broadened to address all UMS and the Remote operations of Manned Ground Vehicles (MGV). These authorities will be assigned in five levels:

(a) Level One is the indirect receipt and direct retransmission of imagery and/or data from a remote system.

(b) Level Two is the receipt of imagery and/or data directly from the **UMS**/remotely operated system and the functionality of previous level.

(c) Level Three is the control of the **UMS**/remotely operated system's mission equipment packages, sensors or payloads and the functionality of previous levels.

(d) Level Four is full functionality and control of the **UMS**/remotely operated system, including mobility and the functionality of previous levels, less program specific special authorization, such as safety and security related (e.g. Launch and recovery of UMS where special training or equipment is required).

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[10] NIST endorses SI units. However, since the definition is adopted, in its entirety, from the cited reference, the usage of British units is retained.

(e) Level Five is all inclusive, full functionality and control of an **UMS** from start through completion (including launch and recovery).

Note: The delineation of a given level of control does not preclude the withholding of certain elements of that level for safety, procedural or training purposes.

Point and Shoot

A subset of **cooperative engagement** that allows a soldier or platform to designate a target for lethal engagement by another platform. The information is immediately displayed on the **COP**. Point and Shoot implies the immediacy of effects and generally occurs within the same echelon.

Obstacle

Any obstruction designed or employed to disrupt, fix, turn, or block the movement of an opposing force, and to impose additional losses in personnel, time, and equipment on the opposing force [13].

Scout

Also referred to as **unmanned scout** or **robotic scout**:

1. A person, aircraft, or ship sent out to obtain information, especially in preparation for military action {13}.
2. The capability of an unmanned system to perform tasks analogous to a human scout.

Sensor to Shooter

(A) The information link from a target acquisition capability to the weapons platform(s) that engage(s) the target [19].

(B) Movement of appropriately formatted information from the reconnaissance platform to the attacking weapon system [21].

Tactical Behavior

The limited, near-term planning, maneuvers, and reactive procedures and actions used to adapt the execution of higher level, long term mission goals to the corresponding environment and the force situation while providing own unit (single or multiple elements) security and concealing mission intent from opposing forces.

Threat Levels

The relative ability of an enemy, or potential enemy, to limit, neutralize, or destroy the effectiveness of the current or projected **mission**, organization, or equipment.

Unmanned Rear Guard or Robotic Rear Guard

(A) The rearmost elements, humans or **UMS**s, of an advancing or a withdrawing force. It has the following functions: to protect the rear of a column from hostile forces; during the withdrawal, to delay the enemy; during the advance, to keep supply routes open.

(B) Security detachment that a moving ground force details to the rear to keep it informed and covered {13}.

4 SEARCH AND RESCUE (SAR) ORIENTED TERMS OR EXTENSIONS

Advisory

(A) Formal notification by DHS/FEMA to all task forces that an event is imminent or has occurred but does not require action at this time [36].

(B) Lowest level of notification, used to provide information only. An advisory is issued when conditions have the potential to develop into a disaster. No action is expected of the task force. Advisories provide a means for sharing information concerning incidents, events, or response activities being conducted by other Federal departments and agencies that may or may not result in broader Federal support [33].

Cache

An approved complement of tools, equipment, and supplies stored in a designated location, available for emergency use [36].

Collapse Hazard Zone

The area established by the Government responding team for the purpose of controlling all access to the immediate area of a collapse or a suspected collapse [36].

Designated Area

The area identified in the major disaster declaration which is eligible to receive disaster assistance in accordance with the provisions of Public Law 93-288. Also referred to as the affected area [33].

Mobilization Time Frame

The time in which a task force is expected to assemble at the point of departure (POD). Six hours is the identified time frame [33].

Urban Search and Rescue (US&R, USAR)

(A) The strategy, tactics, and operations for locating, providing medical treatment to, and extricating entrapped victims of structural collapses or any other types of disasters [33].

(B) A FEMA task force equipped with necessary tools and equipment and the required skills and techniques for the search, rescue, and medical care of victims of structural collapse [34].

5 PROPOSED MANUFACTURING ORIENTED TERMS OR EXTENSIONS

It is anticipated that the generic aspects of the **ALFUS** Framework would be applicable to the manufacturing area. Given the size, rich history, and ongoing research and development efforts of the manufacturing industry, there is an abundant amount of vocabulary that is either existent or evolving. Examples include **Agile Manufacturing**, **Computer-Aided Manufacturing (CAM),** and **Autonomously Guided Vehicles (AGVs)**. Nevertheless, there are terms that can be explored from the **UMS** perspective as the industry is more and more moving toward autonomous operations and intelligent manufacturing for improved safety and productivity. Terms that might correspond to industrial practices include **Unmanned Manufacturing System (UMMS)**, **Unmanned Flexible Manufacturing System (UFMS)**, and **Unmanned Workstation (UWS)**. Practitioners are using the term **Next Generation Robots**, although with different meanings such as higher payloads or inherent safety design. **Dynamic Perception** is required for **Autonomous Parts Assembly** on the shop floor.

These conceptual systems are anticipated to involve the same **ALFUS** issues in mission/operational complexity, environment complexity, and human independence and should be worthy of further exploration within the **ALFUS** framework.

6 RATIONALES FOR TERM DEFINITIONS

6.1 Executive Model for Autonomy Level

It is not defined as linear from one level to the next. In ALFUS, the summaries of the metrics dictate these levels. However, the scales for the metrics are not necessarily linear. A suggested guideline could be that, at low levels where technology is ready, the sizes of the requirements/functionality gaps between the consecutive levels should be reasonably close. However, significant leaps could show at high levels where technologies are not ready. The scale can be 0 through 10, 1 through 10, or other ranges. A higher level may or may not include the requirements and the functionality of the lower levels.

6.2 Unmanned System (UMS)

a. UMS to differentiate from robot in that UMS is not required to have moving components.
b. powered physical system to exclude passive mechanisms; system can cover any physical configuration. A UMS can be an individual UGV as well as a team of vehicles and supporting components; however, for the definition of robot, "to be able to control" implies powered;
c. assigned tasks to exclude undesirable or uncontrollable behaviors;
d. physical environments to exclude a desktop computer running software that is irrelevant to UMS operations;
e. may be mobile or stationary;
f. currently, commonly seen groupings for robots include service robots—helping human tasks at home or work, industrial robots—for manufacturing, military robots, etc. As robots are continuously to be applied to new types of tasks, this grouping method could change.

6.3 Obstacle

Obstacles can be natural, manmade, or a combination of both [13]. They can be positive, negative (e.g., ditches), or groupings (e.g., an occupied city), can be moving or still, and can have various types of intentions, such as adversarial (enemy force), natural hazard (a hungry bear, a tornado), or benign (tree). Except for the benign type, obstacles and threats are equivalent.

6.4 World Model (WM)

WM is referenced per **UMS** entity, be it a system, subsystem, or component. An operator could be a part of a system in this regard. A **remote control** only **UMS** may have no **WM** but the operator does. The vehicle's **WM** and the operator's might not always be consistent. **LOAs** and the degrees of complexity of the **WM** may or may not correlate.

7 ACRONYMS

Acronym	Meaning	Reference
4D/RCS	NIST 4D/Real-time Control System Reference Model Architecture	http://www.isd.mel.nist.gov/projects/rcs/
AATD	Aviation Applied Technology Directorate, U.S. Army	
ACL	Autonomous Control Levels	
ACTD	Advanced Concept Technology Demonstration	
AFRL	Air Force Research Laboratory	http://www.afrl.af.mil/
ALFUS	Autonomy Levels for Unmanned Systems	
AMRDEC	(Army) Aviation and Missile Research, Development and Engineering Center	http://www.redstone.army.mil/amrdec/
ARL	Army Research Laboratory	http://www.arl.mil/main/Main/default.cfm
ATD	Advanced Technology Demonstrator	
ATR	Automatic Target Recognition	
BG	Behavior Generation	http://www.isd.mel.nist.gov/projects/rcs/
C3	Command, Control, and Communications	
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance	http://www.fas.org/irp/doddir/dod/c4isr/es.htm
CAC	Contextual Autonomous Capability	
CBRNE	Chemical, Biological, Radiological, Nuclear, and Explosive	
CCI	Command and Control Interface	STANAG 4586
CERDEC	Communication-Electronics Research Development & Engineering Center	
CAT	Crew integration & Automation Testbed	http://www.tacom.army.mil/tardec/
COP	Common Operational Picture	

CROP	Common Relative Operational Picture	
DARPA	Defense Advanced Research Projects Agency	http://www.darpa.mil/
DCD	(Army) Directorate for Combat Development	
DHS	Department of Homeland Security	
DLI	Data Link Interface	STANAG 4586
DoC	Department of Commerce	
DOD	Department of Defense	
DoE	Department of Energy	
DoT	Department of Transportation	
EmCon	Emission Condition	
EOB	Electronic Order of Battle	
EOD	Explosive Ordnance Disposal	
ERT	Emergency Response Team	FEMA US&R-2-FG "Urban Search and Rescue Response System Field Operations Guide," Latest Version (September 2003 or later)
ERT	Evidence Response Team	http://www.fbi.gov/hq/lab/ert/ertmain.htm
FCS	Future Combat Systems	http://www.boeing.com/fcs
FHWA	(DOT) Federal Highway Administration	
FM	Field Manual (US Army)	
FOUO	For official use only	
FWV	Fixed Wing Vehicle	
GCS	Ground Control Station	STANAG 4586
HCI	Human-Computer Interface	
HMI	Human-Machine Interface	
HMMWV	High Mobility Multipurpose Wheeled Vehicle	
HRI	Human-Robot Interface/Interaction	
h	hour	
ICAO	International Civil Aviation Organization	
IED	Improvised Explosive Devices	
INL	Idaho National Laboratory	http://www.inel.gov/
IPT	Integrated Product (Project) Team	

ISD	NIST Intelligent Systems Division	http://www.isd.mel.nist.gov/
ISR	Intelligence Surveillance, and Reconnaissance	
JAUS	Joint Architecture for Unmanned Systems	http://www.jauswg.org
JPO	Joint Project Office	http://www.redstone.army.mil/ugvsjpo/
JRP	Joint Robotics Program	
JTA	Joint Technical Architecture	http://www-jta.itsi.disa.mil/
JTA-A	Joint Technical Architecture - Army	
LADAR	Laser detection and ranging	
LOS	Line of Sight	
LSI	Lead Systems Integrator	http://www.boeing.com/fcs
m	meter	http://physics.nist.gov/cuu/Units/
MANCEN	Maneuver Support Center	
METT-TC	Mission, enemy, terrain, time - troops, civilians	
min	minute	
MOE	Measure of Effectiveness	
ms	millisecond	
NAVAIR	Naval Air System Command	
NAVSEA	Naval Sea System Command	
NBC	Nuclear, Biological, and Chemical	
NIST	National Institute of Standards and Technology	http://www.nist.gov/
NLOS	Non-Line of Sight	
NRL	Naval Research Laboratory	http://www.nrl.navy.mil/
OODA	Observation, Orientation, Decision, Action	
OPSEC	Operations Security	
ORD	Operational Requirement Document	
OSD	The Office of the Secretary of Defense	
PCD	Procurement Control Drawing	essentially a specification
POD	Point of Departure	

RAC	Root Autonomous Capability	
ROE	Rules of Engagement	
RSTA	Reconnaissance, Surveillance, and Target Acquisition	
RDECOM	(Army) Research, Development, and Engineering Command	
s	second	
SA	Situational Awareness	
SDO	Standards Development Organization	
SED	Software Engineering Directorate	http://www.redstone.army.mil/amrdec/directorates/sed/index.htm#main
SI	International System of Units	http://physics.nist.gov/cuu/Units/
SoS	System of Systems	
SP	Sensory Processing	http://www.isd.mel.nist.gov/projects/rcs/
SSEI	System of Systems Engineering and Integration	
STANAG	NATO Standardization Agreement	
T&E	Test and Evaluation	
TACOM	U.S. Army Tank-Automotive and Armaments Command	http://www.tacom.army.mil/
TARDEC	U.S. Army Tank Automotive Research, Development and Engineering Center	http://www.tacom.army.mil/tardec/
TCS	Tactical Control System	
TLX	Task Load Index	NASA
TRADOC	U.S. Army Training and Doctrine Command	
TRL	Technology Ready Level	NASA
TSM	TRADOC Systems Manager	
TTP	Tactics, Techniques and Procedures.	
UAMBL	Unit of Action Maneuver Battlelab	
UARV	Unmanned Armed Reconnaissance Vehicle	
UAS	Unmanned Aircraft Systems	
UAV	Unmanned Aerial Vehicle	

UCAR	Unmanned Combat Armed Rotorcraft	http://www.boeing.com/defense-space/military/unmanned/ucar.html
UCAV	Unmanned Combat Air Vehicle	http://www.darpa.mil/ucav/index.htm
UGS	Unattended Ground Sensors	
UGV	Unmanned Ground Vehicle	
UML	Unified Modeling Language	
UMS	Unmanned System	
US&R, USAR	Urban Search And Rescue	
USV	Unmanned Surface Vehicles	
UUV	Unmanned Undersea Vehicles	http://www.onr.navy.mil/fncs/auto_ops/default.asp
UVA	Unmanned Vehicle Architecture	
UXO	Unexploded Ordnance	
VJ	Value Judgment	http://www.isd.mel.nist.gov/projects/rcs/
VRA	Vehicle Electronics (Vetronics) Reference Architecture	
WM	World Model or World Modeling	http://www.isd.mel.nist.gov/projects/rcs/
WSTAWG	Weapon System Technical Architecture Working Group	http://wstawg.army.mil/
XUV	eXperimental Unmanned Vehicles	

Additional acronyms can be found in http://www.dacs.dtic.mil/topics/acronym/acronyms.shtml.

APPENDIX A ONGOING DISCUSSIONS OR UNRESOLVED ISSUES

A.1. Another school of thought argues that, relatively, **coordination** involves low-level interactions, including inform each other's tasks and avoid conflict. On the other hand, **cooperation** may require, in addition, for the **UMS**s to work toward a common goal. **Collaboration** may require the highest level of interaction, including intellectual efforts. In other words, **Cooperation** may occur at the **task** level and **Collaboration** at the **mission** level. However, the majority of the comments within the group favor not distinguishing **Cooperation** and **Collaboration.**

A.2. Other forums may have looked at other class criteria, loosely based on how much damage they could do if they run amok (such as kinetic energy for UAVs). It depends on the purposes of the class definitions (the aforementioned one for safety concerns).

A.3. Subdivisions of **Semi-Autonomous – By Exception** and **Semi-Autonomous – By Permission** were proposed. While there might have been too much detail in terms of categorizing **modes of control**, these could be very useful in categorizing **HRI** effects on the **autonomy levels**.

A.4. In the definition for Autonomy, a suggestion is to define "sensing, perceiving, analyzing, communicating, planning, decision-making, and acting/executing" as **autonomy enabling functions**.

A.5. Robotic Follower: The current implementations focus on the soldier, as opposed to another **UMS**, to be the lead to provide the intelligence to develop the safe and tactically relevant path for the **UMS** to follow. This reduces the sensing, processing, and reasoning requirements for the unmanned follower vehicle. Since a soldier has developed the path, it should be valid. The only obstacles that the **UMS** are susceptible to are those that appear after the lead vehicle has passed, in which case the follower vehicle has some limited obstacle detection and avoidance capabilities. The key is to have the follower traverse the exact same path (within a very small lateral deviation) as the lead vehicle.

As an example, consider open and rolling terrain with tall grass and some trees. A manned vehicle is able to maneuver through the terrain relatively easily at tactical cross-country speeds. A **UMS** without a path sees the tall grass and trees as obstacles. It can be traversed, but at a much slower speed than a manned vehicle because it cannot easily determine that this is a type of obstacle it can drive through. But now given the proven path of the lead vehicle and other information (such as speed), the **UMS** has confidence that the terrain is traversable and can exploit this knowledge to increase its speed. This is the concept behind the **robotic follower**, using human intelligence to provide a safe path to increase performance.

A.6. Should review and possibly include the terms used in the 10 levels in the Army Science Board Ad Hoc Study.

A.7. Mobility class (see **environment**) needs to be defined?

A.8. Should **Scripted Operation, Automation** be defined as another mode of UMS operation? Defined as:

The machine executes a preloaded or preprogrammed sequence of actions. Does not adapt to changes. May have sensors or interlocks for safety reasons. Is not considered a mode of UMS operations.

A.9. **E-Stop**:

There are different philosophies on how much concern the safety issue should be given with the command, i.e., to fully stop immediately, or to stop as safely as possible. Not applicable to UAV, which may employ a variety of emergency routines. There may also be no universal definition on whether to shut off power to the entire UMS. In factory robots, power is shut off to the drive train and the robots are equipped with mechanical interlocks to hold the links and the grippers in position. For vehicles, breaks may be actively held in a disengaged position, or else power may need to be provided for braking and/or steering if safety is a significant factor. Should the power be shut off once the UMS completely stops? Would different types of brakes, antilock or not, require different power levels for best E-Stop performance?

E-Stop performance may be unique in different situations, for example, **UMS** traversing in ice/rain/snow or going up/down a hill. These should be specified in the applications.

A.10. Addition thoughts on **Levels of Control**

The American Heritage Dictionary [37] defines Control as:

- to exercise authority or dominating influence over; direct; regulate;
- authority or ability to regulate, direct, or dominate.

In the area of UMS, Control is defined for the following two perspectives[11]:

1. authority given to an outside entity, typically operator [35], to exercise commands to the UMS
2. authority given to a UMS, including any capability built in the UMS to act on the environment

The control can be assigned in terms of levels. The levels can signify and can be differentiated by the following factors:

A. Commanding or organizational level. For example, platoon control is at a higher control level than vehicle control; vehicle control is higher than mobility functional control.
B. Portion/extent of a full control loop to which the control is granted. Examples for a full control loop are an Observe, Orient, Decide, and Act (OODA) loop or complete 4D/RCS node function including sensory processing, world modeling, value judgment, and behavioral generation. The control of only the sensing function is at a lower level than a full control loop for mobility tasks.
C. Degree of complexity of the control function.
D. Special concerns over such factors as safety, regulations, or equipment requirements. For example, special equipment and software may be required to perform the takeoff and landing operations of UAVs. This may warrant an elevated control level to conduct those operations.

The following is a series of reference control levels, from low to high:

[11] In addition, authority may be given to system developers or maintainers of a UMS to modify, reconfigure, or upgrade of a UMS, either software or hardware. However, this perspective is beyond the scope of this Control Level definition.

1. for the UMS to receive authorized data only
2. for the UMS to receive and retransmit authorized data to authorized receivers
3. for the UMS to receive and retransmit all data to authorized receivers
4. for the UMS to exercise full control loop on authorized functions of the UMS
5. for the UMS to exercise full control loop on all functions of the UMS
6. for the system of systems to exercise full control loop on all functions

The reference control levels can be further divided, combined, or repeated depending on their complexities. For example, # 4 and #5 could be combined for a single-function vehicle. The reference control levels can be applied to UMSs with any configuration. For example, #5 may be applied to a vehicle and #6 to a section. In this case, there might be a need to insert additional intermediate levels between the two levels to account for the partial functional authorization situations similar to those defined in #1 through #4.

Levels of Control do not necessarily directly correspond to Levels of Autonomy.

The reference control levels are used to define Level of Control for both perspectives of Control:

Level of Control (1), Level of Operator Control, Level of Operator Authority

Control of a UMS or a remotely operated system is defined as the authority granted to an entity (operator) to exercise commands to the UMS or remotely operated system, its subsystems and/or subordinate systems to accomplish a given mission. The authority includes the accessibility to the required equipment and software. These authorities are assigned in five levels:

(a) Level One is the indirect receipt and direct retransmission of imagery and/or other sensory data from a UMS/remotely operated system.

(b) Level Two is the receipt of imagery and/or other sensory data directly from the UMS/remotely operated system and the functionality of the previous level.

(c) Level Three is the control of the UMS/remotely operated system's mission equipment packages, sensors or payloads and the functionality of the previous levels.

(d) Level Four is the full functionality and control of the UMS/remotely operated system, including mobility, less takeoff and landing for UAV, and the functionality of the previous levels.

(e) Level Five is the full functionality and control of a UAV from takeoff to landing.

Rationale: Although based on the Tactical Control System (TCS) ORD which defines UAV control levels, the definition is broadened to address all UMS and the remote operations of MGV. At Level Two, "direct" covers the reception of the UMS data through a relay device that has direct line-of-sight with the UMS. Level Five is for UAV only due to the fact that special concerns, equipment, software, or otherwise are required to perform the takeoff and landing operations. Refer also to NATO STANAG 4586 for the correspondences to the definitions of Levels of Interoperability.

Level of Control (2), Level of Systems Control, Hierarchical Systems Control Level

Is defined by either the hierarchical commanding levels or the logical control structure inside of a UMS:

Level One: Servo control or actuator control
Level Two: Primitive control or dynamic control
Level Three: UMS single-functional task control or elementary move control [3]
Level Four: UMS multi-functional task control or UMS control

Level Five: UMS collaborative task control
Level Six: UMS collaborative mission control

There could be multiple levels of UMS collaborative task control depending the unmanned system of systems structure and, in such cases, UMS collaborative mission control will be higher than Level Six.

Rationale: This corresponds to the 4D/RCS levels, but only addresses autonomy indirectly.

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