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Information capabilities for robots of the future battlefield

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The future battlefield will be inhabited by a growing number and kind of robots (autonomous mobile physical agents). Successful and efficient application of robots will require a continuously increasing level of coordination, and cooperation. For this reason robots should have new, advanced information capabilities. In this paper we summarize the main characteristics of robots of the future battlefield, and demonstrate the necessity of cooperation. Then we analyze the required information capabilities. Finally we discuss the role of semantic interoperability, and the ways to achieve it.

> *"Military robotic systems will proliferate throughout the 21st century force structure, performing dirty, dangerous, and dull tasks, while providing a revolutionary capability across the spectrum of missions and conflicts".*[1]

Introduction

It can be easily foreseen, that the future battlefield will be inhabited by a growing number and kind of robots (autonomous mobile physical agents). Unmanned aerial, ground, etc. vehicles carrying different sensors will be used to gather necessary intelligence and information. Other robots will perform different combat tasks: strike targets, jam electronic systems, or construct obstacles. Finally logistic robots will support maneuver units carrying out transportation tasks on the battlefield.

Successful and efficient application of robots requires a continuously increasing level of coordination, and cooperation. Robots with small "footprint" can cooperate to fulfill tasks far beyond their individual capabilities. It is clear, that not only similar robots, but robots with different functions and capabilities should and will take part in such a cooperation. Successful cooperation requires well-defined information capabilities, e.g. interoperable communication, shared situational awareness, and cooperative planning capabilities.

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[1] *Joint Robotics Program Master Plan 2001* (DoD USA) [p 1]

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Robots with the information capabilities mentioned before, will work in a heterogeneous military information environment. They have to exchange information with other robots (or human beings!) not only in a technically, and syntactically, but in a semantically interoperable way. Semantic interoperability is a mutual capability of different actors to develop a common interpretation of identical things (environmental effects, messages, data), sufficiently identical for successful cooperation.

Robots on the battlefield, their future characteristics, necessity of cooperation

The characteristics of military conflicts and threats have dramatically changed. The requirements for cuts in defence budgets lead to the reduction of personnel in almost all NATO-partner countries, and armies. At the same time casualties in out-of-area missions become even more difficult to be politically justified. So substitution of personnel in hazardous environments and during fatigue activities became an important military requirement.

Robots – in general – are machines or devices that work automatically or operated by remote control. In military application unmanned systems are mobile and stationary military systems without a human operator aboard. Main categories of unmanned systems are: unmanned ground vehicles (UGVs), unmanned aerial vehicles (UAVs), unmanned underwater vehicles (UUVs), unattended munitions (UUVs), and unattended ground sensors (UGSs).[2]

Potential unmanned ground vehicle applications in land combat operations include detection, neutralization, and breaching of minefields and other obstacles; reconnaissance, surveillance and target acquisition; unexploded ordnance clearance; explosive ordnance disposal; force protection; physical security; fire-fighting; urban warfare; weapons employment; and operations in contaminated and other denied areas. Peacetime applications include the use of small, man-portable systems for earthquake search and rescue, and law enforcement operations.[3] Other possible application is transportation on the battlefield.

Different types of UGVs planned to play different role in combat. Soldier UGVs carried by one or more soldiers perform a variety of tasks (reconnaissance, surveillance, door breach, smoke generation, etc.) in support of dismounted soldiers. Transport (mule) UGVs towed to the operational area by a larger vehicle perform transportation missions (dismounted troop material services, or supplies movement). Armed

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[2] *Joint Robotics Program Master Plan 2001*, Terminology for the JRP [p B-3]
Missiles, rockets, and their submunitions, and artillery are not considered unmanned systems.

[3] *Joint Robotics Program Master Plan 2001* [p 2]

reconnaissance vehicle UGVs perform armed RSTA missions and are capable of man-in-the-loop weapon fire via a C4ISR network. Finally unmanned ground combat vehicles (UGCVs) include robotic direct fire, and robotic non-line-of-sight fire weapon systems.

Unmanned air vehicles will have different types too. Existing UAVs are principally used to accomplish RSTA missions. Unmanned combat air vehicles (UCAVs), and unmanned combat armed rotorcrafts (UCARs) will augment a force on high risk, high priority missions. UCAVs, and UCARs will perform: new combat missions that do not currently exist; high-risk missions where the risk to the human life is unwarranted; or current missions where its use is more cost effective than current platforms.

As an example, the US Army's Future Combat Systems (FCS) program seeks to develop concepts of a network-centric, distributed force that includes manned command and control elements (personnel carriers), robotic direct-fire systems, robotic non-line-of-sight (NLOS) weapon systems and all-weather robotic sensor system coupled with other layered sensors.[4]

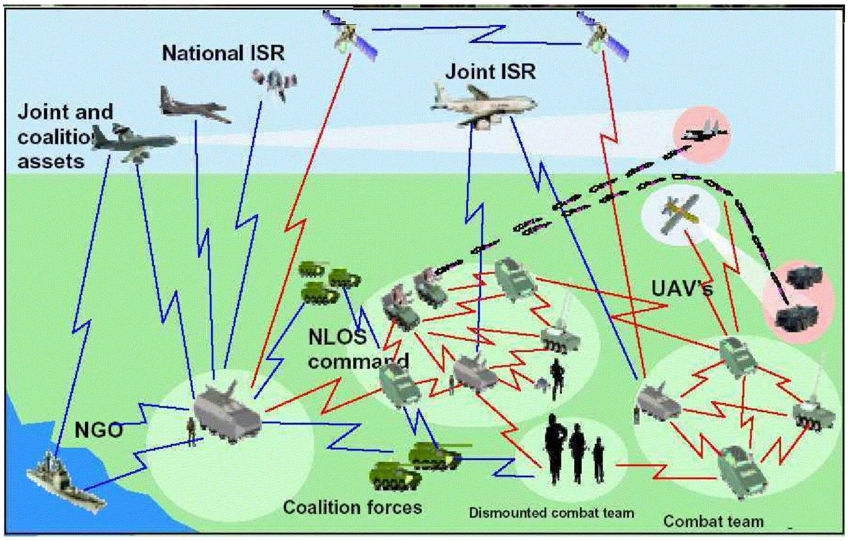

Figure 1: FCS system of systems overview[5]

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[4] *Joint Robotics Program Master Plan 2001* [p 57]

[5] Source: FCS Industry day briefing [p 15]

An FCS unit cell (an ensemble system) will have both manned and unmanned elements, where the robotic elements maneuver together with manned elements in a tactically intelligent manner.

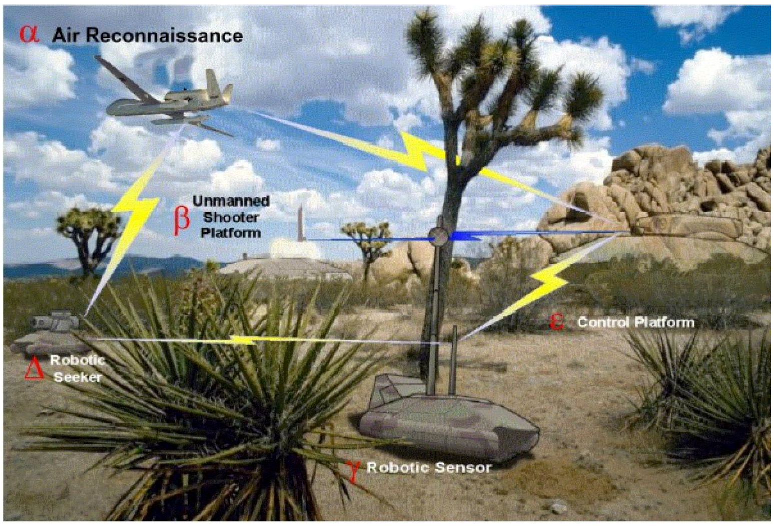

Figure 2: Illustration of a hypothetical FCS “unit cell”[6]

It is almost obvious that future combat will require multiple layers of interactions between warfighters and the autonomous and semi-autonomous systems that will be an indispensable part of the future force, but by all means there will be robots working autonomously on the battlefield. Co-existence, co-working of robots in the same environment is theoretically possible:

- without any knowledge of each other;
- with perception of each other;
- with communication between them;
- and with coordination between them.Teams of robots generally can accomplish tasks more quickly and effectively than a single agent working independently on a task. So effective and reliable coordination, cooperation has been and will continue to be an essential element in the success of combat missions with both unmanned and manned assets. Cooperative operations require the ability of two or more robots (unmanned

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[6] Source: THING-THAYER: *Autonomuos Robots for Military Systems.* [p 49]

systems) to share data, coordinate their maneuver, and perform tasks synergistically.[7] Cooperative robotics is a modern research field, with applications to such areas where a population of cooperative robots can accomplish tasks that would be difficult, if not impossible for a single robot. Cooperative robotics can use a lot of results from multi-agent systems researches (distributed planning, task allocation, communication languages and coordination mechanisms, etc.).

As it is discussed in detail in a research paper prepared for DARPA,[8] there are a variety of methods to approaching the robot coordination problem. Coordination architectures (general forms, by which communication and successive member interactions are performed) are of key importance to robotic workforces, because they considerably influence the synergistic effects of cooperation. The possible architectures include the following:

- centralized coordination ("master-slaves");
- hierarchical coordination ("organizations");
- reactive coordination ("swarms");
- decentralized coordination ("partners").

In case of centralized coordination ("let some 'omniscient' master dictate") a central robot has knowledge of the given requirements, collects all perceived data from the other robots, processes data to find a "solution", then the solution is sent to the robots for execution. In case of hierarchical coordination ("think through the situation fully at various levels, then respond") a planner robot divides an overall task into subtasks, assigns subtasks to other robots, they create (sub)plans, planner resolves conflicts and allows others to proceed. In case of reactive coordination ("directly respond to the stimulus") all robots created equal, they have simple reflex (stimulus-response) rules, that hopefully lead to cooperative behaviour, lack of internal state. Decentralized coordination based also on robots considered equal, but these robots have ability to communicate in some way with their peers, any of them may initiate contact with any other.

Finally the participants of a given (robot-)cooperation can be: homogeneous robots (with identical capabilities); or heterogeneous robots (with specialized capabilities). Analyzing the possible application areas both versions seem to be possible. Ordnance clearance, disposal or physical security (e.g. intrusion detection) are examples for tasks suitable for a homogeneous group of robots, and RSTA or combat missions require cooperation of different kinds of robots.

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[7] See a similar definition in *Joint Robotics Program Master Plan 2001*, Terminology for the JRP [p B-1]

[8] THING-THAYER: *Autonomous Robots for Military Systems*.

From the considerations discussed previously we can expect a likely scenario where dynamically changing groups of heterogeneous robots with changing capabilities cooperate with each other and with human actors to fulfil common goals by coordinated actions.

Required information capabilities, shared situational awareness, cooperative planning

The necessity of information capabilities for robots is based on their definition. To operate autonomously requires at least information storing and processing capabilities, otherwise operation by remote control requires information communication and transformation capabilities. Information capabilities of robots can be grouped into individual, and group/team capabilities.

Individual information capabilities of robots include: information gathering about relevant aspects of the environment, and about the other actors (human beings and robots) in this environment; communication capabilities to transfer and receive descriptive and prescriptive information to and from other actors; and information processing capabilities to be able to convert sensory data to perception, to do forecasts, and to develop plans. Additionally group (team) information capabilities of robots include the following: interoperable communication; shared situational awareness; cooperative planning.

In psychology and cognitive sciences, situational awareness is considered as knowledge created through interaction between an agent and its environment. In this sense, awareness can be simply defined as "knowing what is going on". Basic characteristics of awareness, setting it apart from other kinds of knowing, are the following:

- awareness is knowledge about the state of the same environment bounded in time and space;
- environments change over time, so awareness is knowledge that must be maintained and kept up-to-date: depending on the rate of changes, information has to be continually gathered and updated;
- maintenance of awareness is accomplished through interaction with the environment (gathering information through sensory perception, and actively exploring surroundings based on the information picked up);
- awareness is almost always part of some other activity that is maintaining awareness and is rarely the primary goal of the activity.

Awareness is an everyday phenomenon, and its role becomes more noticeable as situations and environments become more dynamic, complex, information demanding, and with higher workload, or risks.

Creation and maintenance of situational awareness is a three-stage process, with the following components:

- perception of relevant elements of the environment;
- comprehension of those elements;
- prediction of the states of those elements in the near future.

So an agent acting in an environment should first gather perceivable (observable) information; selectively attend to those elements that are most relevant for the task at hand; integrate the incoming perceptual information with existing knowledge and make sense of them in light of the current situation; and finally should be able to anticipate changes in the environment and predict how incoming information will change.

Shared situational awareness is a prerequisite of cooperation, a coordinated, continuously harmonized system of individual situational awarenesses, that in the case of complex groups of actors, can be even multilevel. Situational awareness of individual robots – according to the level and contents of cooperation between them – can overlap each other: to effectively, and successfully accomplish the related activities, they must have identical, or equivalent knowledge of the affected elements of the situation. In addition to these overlaps, naturally any robot's situational awareness can also contain other pieces of knowledge, typical for, and necessary to, the given robot.

To develop a plan for a group of robots it is necessary to know: what robots are available; and what are the actual capabilities of these robots. In case of dynamically changing groups of robots with changing capabilities it is necessary to manage: joining and leaving of groups; and advertisements of actual capabilities. This is also true for such a group of robots where all of them are of the same type (e.g. robotic jammers), because in a real environment some of them may be destroyed, and/or some of their individual capabilities may have been lost. Of course it should be emphasized that solving these problems is not enough alone to build a cooperative planning system.

In a dynamic and heterogeneous environment of robots to enable successful cooperation all of them have to signal their presence, and to advertise (if necessary to withdraw) their actual capabilities. At the same time others – at least robots with planning tasks – have to seek for given, available capabilities. For efficient handling the available robots, and their actual capabilities in the field of multiagent systems a special class of software-agents are used. Brokers, and matchmakers support matchmaking implementing a publish-subscribe architecture.

It is worth to highlight that both shared situational awareness, and capability matchmaking requires exchange of information in a meaningful, semantically interoperable way. So cooperating robots should have a (partially) common model of the "world" (objects, properties, and relations), and a common model of possible capabilities (services), and their attributes.

Exchange of information in a heterogeneous environment, semantic interoperability

Exchange of information is actually exchange of meaning.[9] The concept of meaning originally connected to human beings, but it can, even should be interpreted in case of systems (robots) as intended meaning, planned interpretation. Information exchange has a commonly accepted three-level model. The first is the physical (material) level of media used; the second is the syntactic level of languages, message and data formats used; and the third is the semantic level of content, and meaning to exchange. NATO common interoperability standards system identifies the three levels as technical, procedural, and operational, and groups interoperability standards according to these categories.

In our days interoperability between cooperating systems (e.g. robots) on the two first levels can be realized easily. The degree of heterogeneity at these levels has significantly decreased, and expected to decrease in the future. Both physical transmission means, and message formats have dominated by standardized solutions. Much more difficult to ensure common interpretation (semantic interoperability) of data transmitted in messages, and functions, services provided by different systems.

In case of military robots, unmanned systems the problem of semantic interoperability, therefore the necessity of the appropriate information capabilities haven't yet really arisen. One of the first appearances of a partial solution of this question can be seen in the case of unmanned aerial vehicles. At the end of 2002 started the formal ratification process of STANAG 4586, entitled "Standard Interface of the Unmanned Control System (UCS) for NATO UAV Interoperability".[10] Up to this point, each UAV system has had a different ground control station (GCS), producing systems that use unique elements that employ proprietary protocols and message formats. This hindered interoperability and obstructed widespread dissemination of payload

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[9] See different definitions of information: 'meaning assigned to data by means of known conventions', or 'data in context as understood by an individual' in ADatP-32 Part 1, *The NATO Corporate Data Model. Concept and Description* [p 2-1]

[10] Ratification of STANAG 4586. *AUVSI Online*, October 2002.

data/information. Operation of multiple types of air vehicles from the same GCS has not been possible. Implementation of STANAG 4586 will enable information between different UAVs to be collated and shared via common ground stations.

In case of unmanned combat aerial vehicles (UCAVs) the necessity of information, and semnantical interoperability between military robots is expressed in the format of a technical requirement called network connectivity: a dynamically managed, interoperable, high-capacity connectivity between UCAVs, manned aircrafts, UAVs, off-board sensors, and ground stations. Cooperative engagement capability and development of a single integrated air picture requires cooperative inter-platform operations, meaningful information exchange.[11]

In the development concepts of Future Combat Systems there is an abstraction layer that insulate C4ISR applications from low level details of the C4ISR sensor packages. This layer (C4ISR Sensor Data Management) provides sensor control services, manages the publishing of sensor data within platforms and to the FCS network in an FCS standard sensor data format, and provides a gateway to external sensor data sources from other (unit of employment, joint, national, and coalition) assets.[12]

Summary

Future military forces ("hybrid armies") will have a lot of robot components that will play an essential role in almost all military functions and activities. Military robots will fulfill their tasks mainly in cooperation with other robots and human actors. The cooperative robot-robot, and human-robot groups will be dynamically changing, and heterogeneous in many respect.

Military robots must have appropriate ("value-added", "enabler") information capabilities, and these capabilities will significantly determine their usefulness. One of the most important capabilities will be the capability to support semantic interoperability, a prerequisite of meaningful information exchange in a dynamically changing group of possibly more or less heterogeneous robots.

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[11] BARRY-ZIMET: UCAVs – Technological, Policy, and Operational Challenges. *Defense Horizons*, Number 3.

[12] *Future Combat Systems, Command, Control, Communications, Computers, Intelligence, Surveillance & Reconnaissance (C4ISR) Conference*. South Anaheim, 2002 [p 46]

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