ENABLING INTEROPERABLE SPACE ROBOTS WITH THE JOINT TECHNICAL ARCHITECTURE FOR ROBOTIC SYSTEMS (JTARS)

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ABSTRACT

Robots that operate independently of one another will not be adequate to accomplish the future exploration tasks of long-distance autonomous navigation, habitat construction, resource discovery, and material handling. Such activities will require that systems widely share information, plan and divide complex tasks, share common resources, and physically cooperate to manipulate objects.

Recognizing the need for interoperable robots to accomplish the new exploration initiative, NASA's Office of Exploration Systems Research & Technology recently funded the development of the Joint Technical Architecture for Robotic Systems (JTARS). JTARS charter is to identify the interface standards necessary to achieve interoperability among space robots.

A JTARS working group (JTARS-WG) has been established comprising recognized leaders in the field of space robotics including representatives from seven NASA centers along with academia and private industry. The working group's early accomplishments include addressing key issues required for interoperability, defining which systems are within the project's scope, and framing the JTARS manuals around classes of robotic systems.

1. INTRODUCTION

In January of 2004, NASA was given a presidential directive to "gain a new foothold on the moon and to prepare for new journeys to the worlds beyond our own." As part of this initiative, NASA is focused on returning to the moon by 2020 to serve as the launching point for missions beyond. Robotic probes are expected to be on the lunar surface by 2008, with a human mission as early as 2015, "with the goal of living and working there for increasingly extended periods of time."

To achieve NASA's mandate for creating a sustainable campaign of space exploration, a paradigm shift will have to occur in the space robotics industry. Specifically, robotic systems-of-systems must be realized through a renewed focus towards interoperability, modularity, and reuse. The practice of developing unique mission-specific components communicating through custom user-defined interfaces will have to give way to standardization.

The focus of lunar and Martian expeditions will extend from early exploration, to site preparation, to ultimately long-duration habitation. Given the hostile environmental conditions, each of these activities will require the extensive use of robotic systems. Robots that operate independently of one another, like those seen in the past (e.g. Sojourner, Spirit/Opportunity), will be inadequate to accomplish the complex tasks associated with these challenges. Rather, complex systems-of-systems will be required in which robots work cooperatively by widely exchanging information, planning and dividing complex tasks, sharing common resources, and physically cooperating to manipulate objects. The challenges associated with cooperative robotics are many, including communications, control, autonomy, physical compatibility, sensor processing, and operator control.

The development of the Joint Technical Architecture for Robotic Systems (JTARS) is funded by NASA's Advanced Space Technology Program (ASTP) in the Office of Exploration Systems Research and Technology (ESR&T) [2]. In January of 2005, the JTARS working group was tasked with establishing the technical architecture by which interoperable space robots can be developed. Once established, the JTARS architecture will be used by those involved in the acquisition, development, or management of new or improved robotic systems within NASA. The JTARS working group is scheduled to complete its task in 2008, but the resulting documents will be updated periodically.

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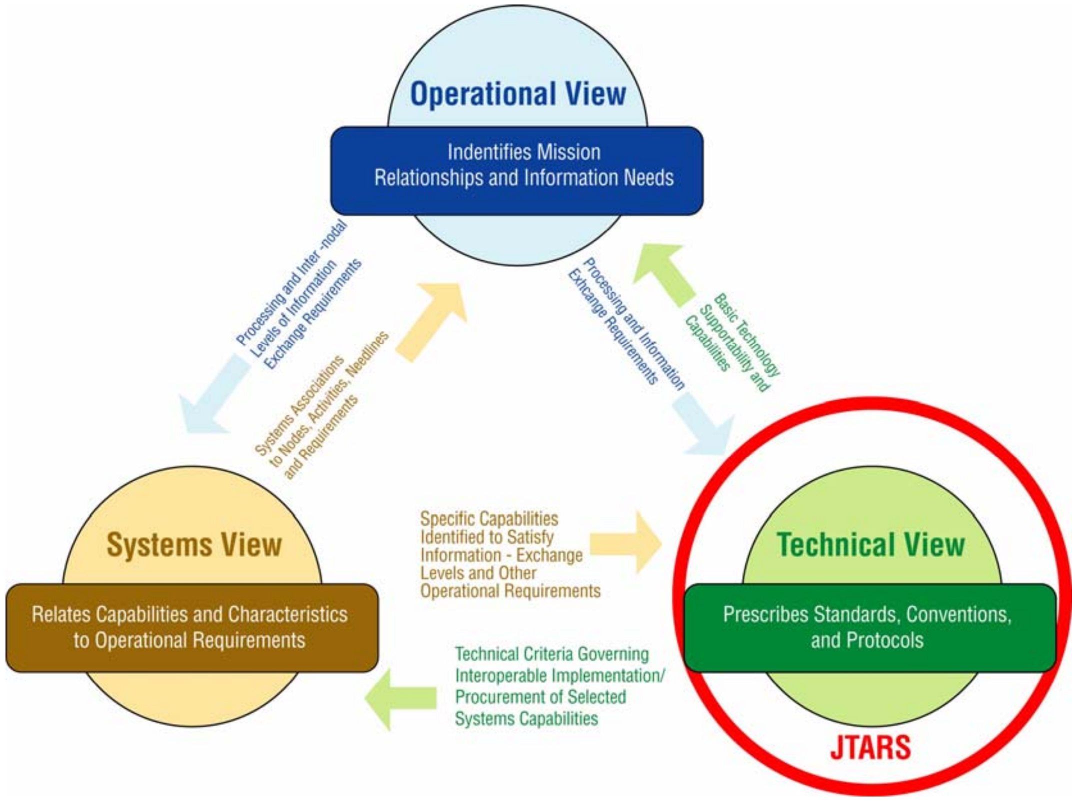

Fig. 1. Interrelated views [1].

A similar theme of standardization, interoperability, and reliable intercommunication was introduced ten years ago in the Department of Defense (DOD). In an effort to achieve those goals, the Asst. Secretary of Defense issued a directive to principals to "reach a consensus of a working set of standards" and "establish a single unifying DoD technical architecture (TA)…" so that "new systems can be born joint and interoperable, and existing systems will have a baseline to move toward interoperability." From that directive, the Joint Technical Architecture (JTA) was created. Though now superseded by DOD's Information Technology Standards Registry (DISR), the JTA was established to mandate the minimum set of standards and guidelines for acquisition of all DOD systems that produce, use, or exchange information. JTARS has a similar charter but with space robotics as its focus.

JTARS is a joint technical architecture that identifies required standards, protocols, and practices to be used for NASA robotics. In this context, the term "joint" refers to the architecture being crosscutting, equally applicable to in-space, aerial, surface, and subsurface robotic systems. Following the concepts put forward in the JTA, the term "architecture" refers to the structure of components, their relationships, and the principles and guidelines governing their design. As shown in Fig. 1, JTARS is part of an interrelated set of views: operational, system, and technical.

The **operational architecture** contains descriptions of the operational elements, their assigned tasks and activities, and the information flow required between them to complete the mission. It also details the nature of information exchanged in sufficient detail to determine specific interoperability requirements.

The **systems architecture** is a description of systems and interconnections supporting mission functions. It shows how the systems interoperate, and details the operations of particular systems within an architecture. The systems view of a single system includes descriptions of the physical connections, location of key nodes, circuits, networks, platforms, etc. It also specifies system and component performance parameters (e.g., total dose, mean time between failures, operating speed, etc.).

The **technical architecture** provides guidelines upon which engineering specifications are based, modular elements defined, and product lines developed. It includes a collection of the technical standards, conventions, and rules with criteria that indicate which are appropriate for a particular product.

JTARS is a technical architecture for space robotics. It identifies the information and physical interface standards necessary for robotic interoperability within complex systems. It enables cooperative robotic networks and enhances modularity, reconfigurability and reusability. JTARS promotes affordability through increased competition leading to sustained exploration and the commercialization of space.

2. GOALS

The four high-level goals associated with JTARS are discussed below.

2.1 Establish a comprehensive working group of senior contributors to NASA robotics

JTARS is being developed by a working group comprising representatives from seven NASA centers as well as experts from industry and academia. Dr. Bradley of NASA LaRC serves as the project's principal investigator and working group chairman. Many recognized experts working in NASA robotics are actively participating in the working group.

The working group openly invites additional participation from industry and academia, as well as from the international space community (e.g. DLR, JAXA, CSA, ESA, JSA, etc.). Working group contacts as well as the meeting schedule can be found at www.jtars.org.

Relationship to Broader ESR&T Goals

The establishment of a comprehensive working group of senior robotics engineers assists ESR&T in advancing the current state of the art in space robots. The group will assist in the identification of standards necessary for creating robots capable of interoperating to accomplish difficult tasks. The group will also work to create an open dialogue between NASA centers, industry, and researchers as they focus on the many challenges facing exploration.

2.2 Identify and document recommended standards and protocols for NASA robotic systems

The JTARS working group is tasked with identifying and documenting the standards, protocols, and practices necessary for creating interoperable space robots.

It is expected that two volumes will be generated, one identifying recommended standards and practices, and a second identifying emerging technologies. The documents will identify both "core" elements common to all systems and application-specific standards organized into corresponding domains and subdomains.

The expectation is that future NASA robotic systems that fall within the scope of JTARS will be developed compliant with the JTARS recommended standards. Provisions will also be provided to accommodate legacy systems. Systems will ultimately be identified as "JTARS-compliant," indicating that they follow the prescribed standards, protocols, and practices.

Relationship to Broader ESR&T Goals

The development of JTARS manuals will provide NASA robot developers with a comprehensive set of guidelines prescribing standards, protocols, and practices. Such uniformity will help to ensure long term product reusability, which will result in cost reduction. Standardization will further enable more complex robotic networks by allowing better intercommunication and cooperation.

2.3 Develop an online JTARS resource

JTARS will be an evolving knowledge base, one that must keep pace with advancing technologies, technical challenges, the marketplace, and the associated standards upon which it's based. The JTARS manuals will therefore be "living documents," updated periodically by a small subset of the working group. As part of the JTARS effort, the working group will set up a NASA website where the most current JTARS documents can be downloaded, minutes from the working group meetings reviewed, and change requests processed.

An online technical database will also be developed to provide developers and integrators information detailing how current robotic systems align with JTARS recommendations – helping to reduce risk, lower cost, and avoid interoperability problems.

Relationship to Broader ESR&T Goals

The online resource will allow engineers to search a technical database of robotic systems, detailing system specifications and their respective alignment with JTARS recommendations. Sharing of compliance information will help to facilitate interoperability, technical exchange, and cost reduction. The manuals and meeting minutes will also be available to disseminate the latest JTARS information. The resource will facilitate interoperability, technical exchange, and cost reduction.

2.4 Ensure End-User Product Adoption

With product adoption in mind, JTARS emphasizes participation by end users, including NASA engineers, industry developers, academic researchers, and international partners. It also leverages the expertise of technical standards programs and synergistic activities both inside and outside the agency (e.g. NASA's Technical Standards Program [3], DOD's JAUS [4], and NIST's ALFUS [5]).

The final year of the proposed 4-year effort will shift the working group from investigating standards and drafting recommendations to ensuring NASA-wide adoption. This will be accomplished though on-site presentations and training throughout NASA as well as within industry and academia. Suggestions and corrections resulting from the outreach activities will be reviewed and implemented prior to the first official release of the manuals.

Once released, system developers will use JTARS to facilitate the development of systems that are capable of cooperative behavior, intersystem interoperability, and long-term reusability. System integrators will use JTARS to foster the integration of legacy and new systems.

Relationship to Broader ESR&T Goals

The widespread adoption of JTARS will ensure standardization, which will result in long-term reusability of NASA space robots as well as significant cost reductions. End-user briefings will serve NASA as a valuable outreach effort and is inline with the philosophy of creating "One NASA."

3. SCOPE

NASA has many systems under development, from satellites to rovers, many of which can be considered "robotic" in nature. An important milestone of the JTARS Working Group was therefore to clearly define the scope of the effort, specifically answering the question, "What systems fall within the charter of JTARS?"

Two broad approaches were considered. One divided systems based on where and how they were used, the other divided systems based on capabilities. Ultimately, the approach based on capabilities was adopted, because it greatly simplifies the identification of what systems are within the scope of JTARS.

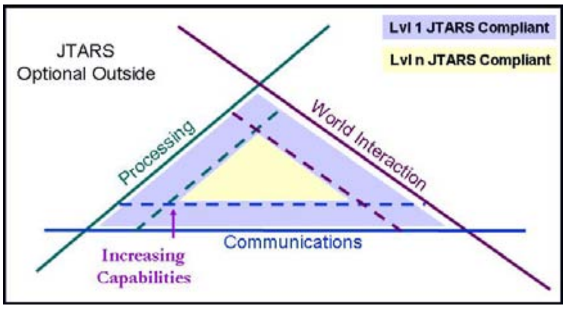

Fig. 2. Metrics to determine scope.

Fig. 2 illustrates how three metrics are used to determine which systems fall within the scope of JTARS. The metrics considered descriptive of robotic systems are processing capability, communications, and the ability to physically interact with the world.

Systems that meet a minimum level of all three metrics fall within the scope of JTARS. Within the "core" bounded region, sub-regions can be identified to indicate systems with advanced capabilities. It is expected that JTARS will levy additional recommendations on more capable systems enabling them to perform advanced cooperative activities. Therefore, there can be different levels of compliance depending on system capabilities. Note that the specific boundaries are not yet defined, and are likely to shift over time as technologies advance.

There are several important implications that result from our definition of what systems fall within the scope of JTARS. Specifically, the definition suggests that JTARS applies to robotic systems independent of their:

- Location (e.g. Mars, Earth, moon, in-space, etc.)
- Function (e.g. rovers, station crawlers, UAVs, etc.)
- Level of autonomy (e.g. teleoperated to fully autonomous)

An important exception is that JTARS requirements should not supersede higher-level system-use requirements. For example, robots used on ISS should follow ISS requirements over JTARS unless approved by ISS authorities. However, this exception will be mitigated as future systems-of-systems directly leverage the standardization offered through JTARS.

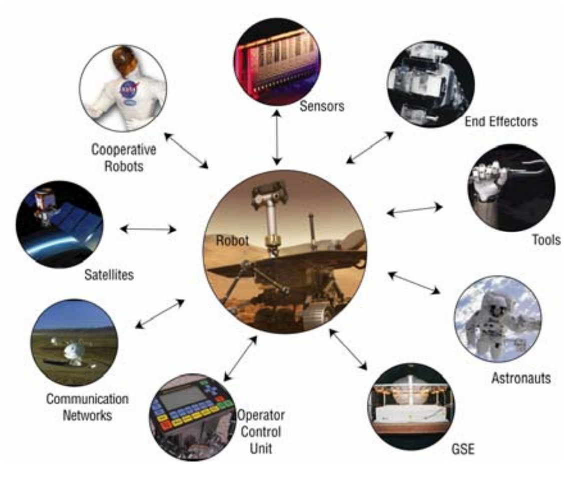

Fig. 3. JTARS robot-centric view.

4. CONTENT

JTARS is robot centric in that it prescribes how a robot should interact with other systems, whether they are additional robots, sensors, payloads, satellites, etc. Fig. 3 illustrates the robot-centric view.

The specific format or technical content of the JTARS manuals has yet to be fully defined. What is known is that two manuals will be developed, one that prescribes existing technologies, and a second that identifies promising future technologies. The documents will identify both "core" elements common to all systems and application-specific standards organized into corresponding domains and subdomains.

4.1 Domains

The JTARS manuals will likely be organized into classes of robotic systems known as "domains." There are many ways to classify robots into domains, including:

- Hierarchical (e.g. component, subsystem, system, system-of-systems)
- Interfaces (e.g. communications, software, hardware)
- Tasks (e.g. exploring, assembly, manufacturing, etc.)
- Operating Environments (e.g. surface, transport, orbital, aerial, etc.)

The specific organization of the JTARS manuals has not yet been decided. However, Fig. 4 illustrates a preliminary concept of possible domains and subdomains.

Given the working group's current understanding, JTARS will likely focus on two broad areas: communications and physical interaction. Domains within communications might include operator control, message sets, and protocols. Subdomains would cover everything necessary for communicating between systems, including such things as data/command format, I/O devices, and timing.

Domains relating to physical interaction might include interfaces, devices for manipulation, mechanical constraints, workspace considerations, and structural requirements. Subdomains would incorporate things necessary for robots to physically cooperate on tasks, including such things as end effectors, hard points, size/weight constraints, and frames of reference.

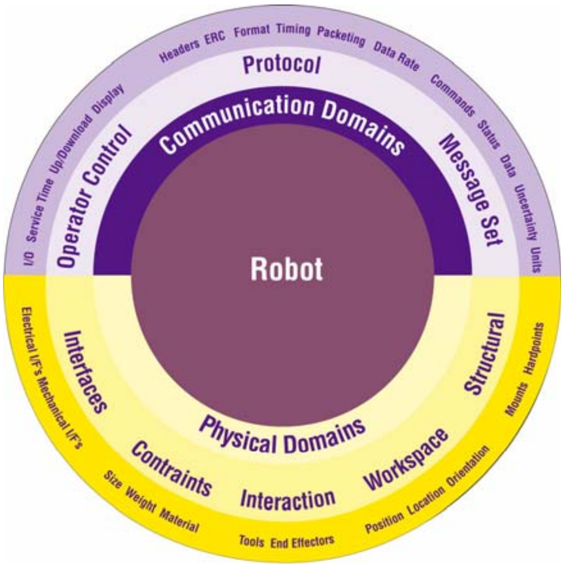

Fig. 4. Initial concept of domains and subdomains.

5. SUMMARY

In January of 2005, JTARS was initiated by NASA's Office of Exploration Systems Research and Technology. The primary goal of the project is to establish the technical architecture by which interoperable space robots can be developed. JTARS will prescribe standards, protocols, and practices to be used for NASA robotics, and has the long-term goal of broadening into an international standard.

When defining the scope of JTARS, an approach was adopted that divided systems based on capabilities rather than function. As a result, JTARS applies to robotic systems ranging from teleoperated to autonomous independent of "where" or "how" they are to be used as long as they meet or exceed three metrics. Those metrics are processing capability, communications, and physical interaction with the world.

The specific format or technical content of the JTARS manuals have yet to be fully defined. What is known is that two manuals will be developed, one that prescribes existing technologies, and a second that identifies promising future technologies. The documents will identify both "core" elements common to all systems and application-specific standards organized into corresponding domains and subdomains.

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6. REFERENCES

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