2010 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
VEHICLE ELECTRONICS AND ARCHITECTURE (VEA) MINI-SYMPOSIUM
AUGUST 17-19 DEARBORN, MICHIGAN

Toward a Common Architecture for the Advanced Explosive Ordnance Disposal Robotic Systems (AEODRS) Family of Unmanned Ground Vehicles

Matthew V. Kozlowski, Ph.D.
The Johns Hopkins University
Applied Physics Laboratory
Laurel, MD

Mark Hinton
The Johns Hopkins University
Applied Physics Laboratory
Laurel, MD

Matthew Johannes, Ph.D
The Johns Hopkins University
Applied Physics Laboratory
Laurel, MD

ABSTRACT

The Advanced Explosive Ordnance Disposal Robotic System (AEODRS) is a Navy-sponsored acquisition program developing a new generation of open, modular EOD Robotic Systems. This paper describes a common architecture for a family of EOD Robotic Systems including the rationale, development, and decomposition into common physical, electrical, and logical interfaces. The paper further describes the role of an open standard for the interchange of information within unmanned ground vehicle systems. The Joint Architecture for Unmanned Systems (JAUS) has enabled the development of the architecture's standards-based interfaces, both at the extra-vehicle controller-interface level, and for the interface and integration of vehicle payloads and subsystems. Finally, the paper explores the contribution of the architecture's common topology, protocols, services and infrastructure to the development of common controllers, payloads and subsystems. Additionally, the effects of the achieved commonality is discussed in terms of reduced field logistics footprint, increased mission flexibility, reduced deployment time for fielding new capabilities, and extended useful design life.

INTRODUCTION

The lack of interoperability between Unmanned Ground Vehicle (UGV) systems imposes limitations on development and deployment, complicating the integration of advanced technologies and control schemes. The Advanced Explosive Ordnance Disposal Robotic System (AEODRS) is a Joint Service Explosive Ordnance Disposal (JSEOD) program, executed through the Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV) via the Navy Program Management Office for Explosive Ordnance Disposal/Counter Remote Controlled Improvised Explosive Device Electronic Warfare (PMS 408). The primary goal is to develop a common architecture at the physical, electrical, and logical interfacial levels for a family of UGV systems to enable interoperability at a level that has never before been executed.

AEODRS Program Description

The AEODRS Program seeks to break down the classical UGV development paradigm by unlocking the prevalent lack of interoperability, which resides at the interfacial level. AEODRS partitions each variant in the family of systems into capability modules (CMs) that serve a specific function within the vehicle architecture. This partitioning results in CMs that are task and function specific and can exist as standalone systems across the platforms. By careful choice of partition and interface, the architecture enables development of capability specific modules that perform specific functions within an overarching system, rather than having these capabilities built into to a standalone revision of a system. This enables the integration of both future technological developments as well as legacy systems within the framework of the UGV. The next generation EOD platform embraces interoperability to enable the integration of advanced CMs. Not only does this increase the effectiveness of the system in operational scenarios, it also reduces system down time as the modular design enables simpler identification and replacement of inoperable or malfunctioning modules. A relevant analogy used to describe this approach is the USB architecture of the modern day personal computer. USB fully defines the interface of a peripheral device to its workstation in terms of the physical, electrical and logical layers. This enables a host of different devices performing specialized function (printing, gaming input, video, etc.) to plug and play using the same interface connection. Similarly, the AEODRS architecture seeks to structure the next generation EOD platform in a similar manner, with individual CMs performing specific functions across standardized interfaces.

The Family of Systems (FoS) Approach to Mission Scenarios

Current use of UGVs in EOD mission scenarios varies depending on the type of mission involved. These mission classifications typically span three operational scenarios. The AEODRS Program consists of a Family of Systems (FoS) to accommodate the various mission needs of the EOD technician. The AEODRS FoS comprises three system variants that are planned to be fielded in an incremental evolutionary approach in order to leverage lessons learned from previous iterations while still addressing immediate needs in the field today. The development of the FoS in achievable increments will also enable further development and refinement of the FoS architecture while allowing management of the risks at each developmental stage.

Current plans are to field the Dismounted Operations system first (Increment 1) and then field the Tactical Operations system (Increment 2) and Base/Infrastructure Operations system (Increment 3) in parallel thereafter. Each system will use a common Operator Control Unit (OCU), with a handheld controller being employed for the dismounted operations system. These systems and relevant mission environments are as follows:

- The Dismounted Operations system (Increment 1) is the smallest variant and must be small enough to be transported via a backpack. The primary mission focus of this system is on dismounted reconnaissance but may also be used to support counter-charge placement.

- The Tactical Operations variant (Increment 2) is a medium sized system that must be able to be transported in an EOD response vehicle, but be capable of being carried by two technicians over a moderate distance. The primary mission focus of this variant is on in-depth reconnaissance and wide-range item prosecution.

- The Base/Infrastructure Operations system (Increment 3) is the largest variant and requires transportation via a large response vehicle/trailer. The primary mission focus of this variant is on maximum load/lift capabilities and the widest-range of EOD neutralization, render-safe, and other special capabilities required.

The three vehicle classifications effectively address the needs of the EOD technicians in a variety of frequently encountered operational scenarios. Use of the common architecture enables use of some capability modules across platforms of all three system variants. Other capability modules can be developed in an incremental fashion built upon the foundations of units developed for earlier increments. Additionally, as will be explained later, all vehicles within the Family will be able to be controlled by a common OCU.

AEODRS Common Architecture Goals

All interfacing elements between two functional components on a UGV system can be defined in terms of their physical, electrical, and logical interfaces. EOD UGV systems may be implemented as a networked system in which subsystem elements (components) are able to communicate with each other or a master processor. The physical, electrical, and logical architecture layers are described in Figure 1, and it is through their careful interface definition and publication that truly interoperable systems may be realized.

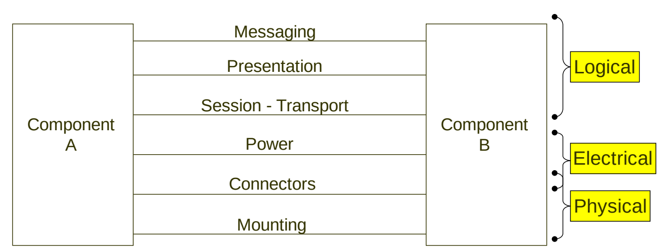

Figure 1 - Physical, Electrical, and Logical Architecture Layers

The AEODRS Family is characterized by the *interoperability* of its capability modules (subsystems) via Government defined and controlled logical, electrical, and physical interfaces and the commonality of its OCU. The Family is also characterized by the *interchangeability* of its capability modules with future capability modules that can be integrated in a plug and play fashion without proprietary issues. The definitions of *interoperability* and *interchangeability* are as follows[1]:

> Interoperability – The ability of systems . . . to provide data, information, materiel, and services and accept the same from other systems . . . and to use the data, information, materiel, and services so exchanged to enable them to operate effectively together . . .

This definition refers primarily to logical layer interfacing.

> Interchangeability – A condition that exists when two or more items possess such functional and physical characteristics as to be equivalent in performance and durability, are capable of being exchanged one for the other without alteration on the items themselves or of adjoining items, except for adjustment, and without selection for fit and performance.

This definition refers primarily to electrical and physical layer interfacing.

A successful common architecture definition and execution based on the above characteristics has as its goals to:

- Reduce the overall logistical footprint of the FoS
- Develop and adopt a common controller module to be used across the FoS
- Segregate and develop mission specific payloads
- Increase mission flexibility through the adoption of new capability modules as part of a continual technical development cycle

These four goals are achieved through the following system characteristics:

Modularity - The ability to provide control system capabilities tailored to a given EOD application without requiring modification of control system hardware or software. At its core, modularity provides the ability to configure rather than develop an AEODRS system for a given EOD application.

Scalability - The ability to add new capabilities or provide higher performance (scaling up) according to mission requirements, or remove capabilities or reduce performance (scaling down) to achieve weight, power consumption, or footprint savings as required by mission environment.

Upgradeability - the ability to introduce new capabilities, improvements in performance, or avoid system obsolescence without requiring extensive reengineering.

AEODRS Common Architecture Solution

Through careful decomposition of the robotic system about the nodes depicted in Figure 2, the architecture concept becomes simplified.

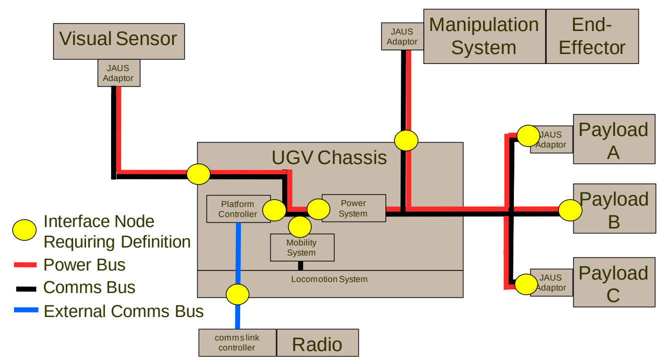

Figure 2 - Notional UGV Block Diagram Depicting Common Architecture Interfaces Requiring Definition

The Common Architecture discussed herein has at its root the definition of the following critical system interfaces:

1) OCU to UGV radio link (Logical)
2) Power bus (Physical, Electrical, Logical)
3) Communications bus (vehicle backbone network) and messaging (Physical, Electrical, Logical)
4) Physical interfaces to each component (Physical, Electrical)
    - Manipulator to UGV
    - Power to UGV
    - Payloads to UGV
    - Etc.

Through careful definition of these core interfaces and by breaking the system about these lines of subsystem demarcation, a common architecture becomes realizable. The following sections describe the philosophy of the change from the way that EOD (and other UGV) systems and solutions have been realized in the past and contrasted with the way that the AEODRS is being executed.

Historical Background

Past EOD systems have been provided by a single vendor who has integrated internally developed or off-the-shelf subsystems under proprietary architectures, typically employing proprietary communication link protocols and

1 DAU Glossary of Defense Acquisition Acronyms and Terms, 12th edition, July 2005

messages. Interoperability, even within a given vendor's product lines, has been difficult to achieve. Each platform, each controller, and each sensor and actuator has utilized its own, generally proprietary, interface. As discussed in earlier sections, the result is a lack of interoperability and concomitant failure to realize interchangeability; this failure increases the logistics footprint of fielded systems. The following figure illustrates the problem presented:

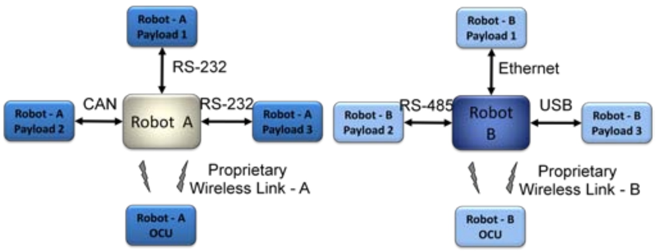

Figure 3 – Historical Architecture Paradigm

The use of dissimilar physical interfaces complicates physical integration of a new device or capability with the platform; the use of dissimilar electrical interfaces complicates providing power for that capability, and excludes electrical means of control; the use of dissimilar messaging standards precludes direct control of the capability by the system unless system software is modified or enhanced to accommodate the capability's messages and protocols.

The AEODRS Common Architecture addresses this problem through modularity by capability, and by the use of standard interfaces (physical, electrical and logical) between defined Capability Modules. Further, the AEODRS Common Architecture provides an approach by which existing "legacy" payloads and subsystems may be integrated with an AEODRS platform, and to provide means by which new payloads and subsystems may be used within existing AEODRS systems.

Adapter Paradigm for Legacy Subsystems

An immediate resolution to the problem of proprietary, non-interoperable interfaces may be found in the introduction of well-specified system interfaces. This is accompanied by the development of adaptors that support the system interface, and provision of mapping of system-level operations to the interfaces and operations required by the supported payload, device or subsystem. This approach isolates proprietary and dissimilar interfaces from the overall system. The following notional figure depicts the use of an adaptor paradigm to encapsulate the dissimilar interfaces of several sensors and actuators, providing a standard "AEODRS interface" to the system:

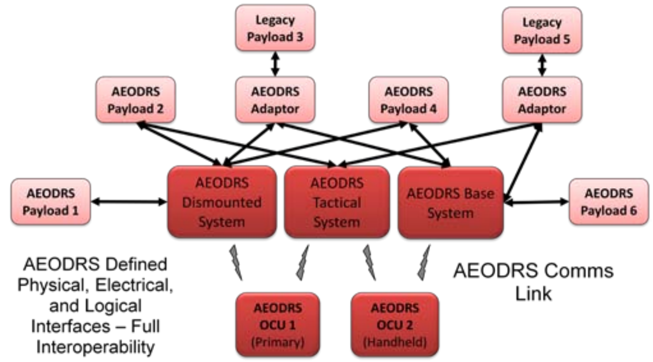

Figure 4 - Current AEODRS Architecture Paradigm for Legacy and AEODRS-Native Capability Modules

This simplistic example shown in Figure 4 of the "adaptor paradigm" introduces a notion that will be built on herein for the remainder of the architectural discussion. That is the notion of providing interoperability by implementation of a standards-compliant façade for elements requiring interface into the system. Simply put, prescription of

- The electrical and physical connectivity of the subsystem to the power bus (via specified connector and connection characteristics),
- The electrical and physical connectivity of the subsystem to the communications bus (via specified connector and connection characteristics)
- The messaging, timing and presentation of the subsystem commands to the communications bus (via logical layer protocols and messaging),
- The mechanical attachment of the subsystem to the host or other subsystem

fully define the interface for a subsystem component.

Capability Module Concept

The term "Capability Module" is AEODRS program specific, and denotes an AEODRS vehicle module consisting of any mechanical, electrical, and logical elements necessary to achieve a set of clearly delineated system capabilities. As an example, a Manipulator Capability Module would consist of a Manipulator, means of actuation, feedback and control of that Manipulator, and implementation of the standard AEODRS Manipulator interface. Thus, an AEODRS Capability Module encapsulates a fundamental capability and presents a standard set of interfaces (logical, electrical, and physical) to the robot platform while preserving the native interfaces to each sensor, actuator, or other device on which it relies.

Capability Modules and Distributed Architecture

A key characteristic for the AEODRS Family of Systems (FoS) is the interoperability of its Capability Modules, achieved through Government defined and controlled logical, electrical and physical interfaces and commonality of OCUs. The AEODRS FoS is also characterized by the interchangeability of capability modules between family members, and extensibility of system capabilities with future capability modules that can be integrated in a near plug and play manner without proprietary issues.

The desire for interoperability and interchangeability, and for system extensibility, drives the partitioning of system capabilities into implementable, intercommunicating Capability Modules; this, in turn, strongly suggests a distributed architecture for the Vehicle Control System. Interoperability is maintained through the use of a message-passing distributed architecture with well-specified messages and messaging interfaces. Interchangeability is facilitated through the definition and use of standard electrical and physical module interfaces.

The following conceptual diagram depicts the partitioning of a notional EOD UGV Vehicle Control System into multiple Capability Modules, and illustrates some Capability Module boundaries and interfaces:

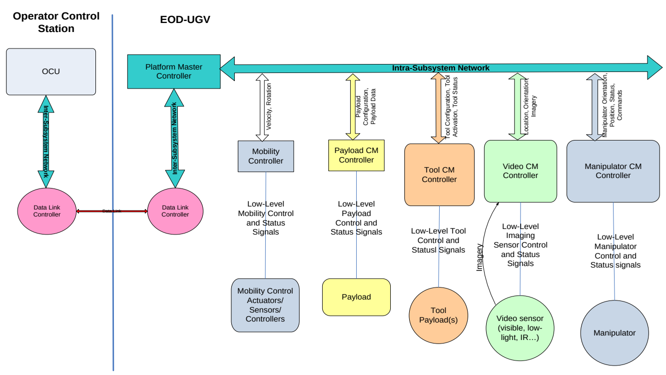

Figure 5 - Capability Module Concept as Illustrated on the Intra-Subsystem Network

The Mobility Controller, in Figure 5, receives commands and requests for information (for example, a request for current platform linear and rotational velocities) over the standard AEODRS interface, by means of AEODRS messages. These commands and requests are processed by the Mobility Controller, and the Controller appropriately commands actuators, monitors sensors, and possibly communicates with subordinate controls (such as a drive controller) to implement commands and respond to requests. Each AEODRS Capability Module Controller receives its commands and requests and returns responses via an Intra-Subsystem Network, which serves as the inter-module communications backbone of the AEODRS vehicle's distributed control topology.

Logical Layer System Overview

The AEODRS Common Architecture prescribes a system consisting of two primary subsystems: An OCU, and a UGV. The UGV is itself a distributed system, consisting of a set of intercommunicating Capability Modules, connected by a single network. This network, termed the Intra-Subsystem Network, is separate and distinct from the Inter-Subsystem Network, which links the OCU Subsystem and the UGV Subsystem. The routing of messages between the two networks is one of the primary tasks of the Platform Master Module ("Master CM" in the figure below).

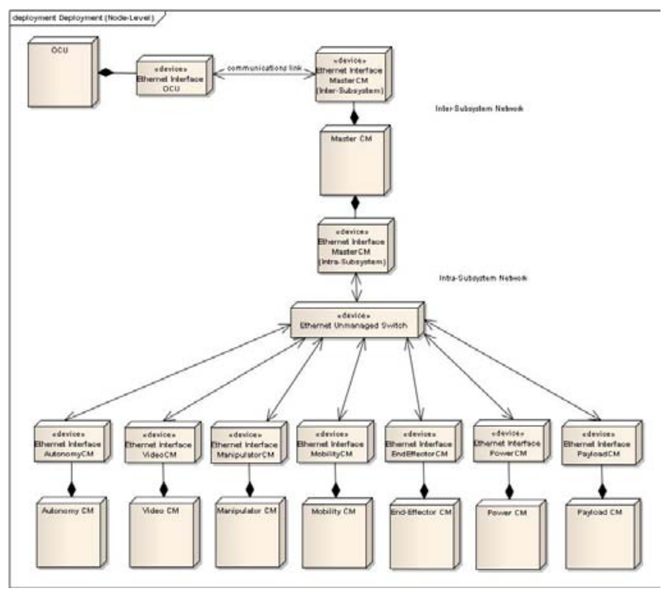

Figure 6 - Logical Layer System Topology

The Intra-Subsystem network is implemented as a Gigabit-capable Ethernet, relying on an unmanaged, speed-sensing switch to enable the connection of Capability Modules supporting 100BASE-T as well as 1000BASE-T interfaces. This provides adequate bandwidth to support present and future telemetry and video requirements. Thus, the platform Master Controller would route an OCU request for Manipulator information to the Manipulator CM, and the Platform Master Controller would route the Manipulator CM response to the OCU.

Protocols, Services, and Standards

The AEODRS program has adopted the Joint Architecture for Unmanned Systems (JAUS) protocols, services and messages as the core of its inter-module communications architecture. We believe that the JAUS standard, tested in numerous demonstrations and field experiences, has reached adequate maturity to support systems architecture and design; we also find that the JAUS standard provides a comprehensive architecture element for construction of an interoperable system.

Initially envisioned as a component architecture standard for the development of unmanned ground systems, and initially called the Joint Architecture for Unmanned Ground Systems (JAUGS), the standard has evolved into a more broadly scoped service-oriented architecture for use throughout the unmanned systems community. As a message-based architecture, JAUS is well suited to the distributed, message-passing architecture we envisioned for AEODRS; as a service-oriented architecture, JAUS is readily tailorable for use in ground robotics.

The migration of the JAUS standards development effort and standards publication to SAE, an international standards body for mobility engineering, has resulted in increased availability of the JAUS standard; the resulting international availability of the standard make it more appealing to potential AEODRS vendors with overseas operations or customers.

Core services defined in the JAUS standard include message transport services, safety services (such as the heartbeat messages of the Liveness Service), event generation and handling, authority-based arbitration of component control, and a Discovery service providing for the automatic detection, registration, and publication of Services provided by components and nodes within a distributed system.

Discovery and Routing

The routing services provided by the Platform Master Controller, by which messages from the OCU subsystem are routed to the appropriate Capability Module and vice verse, clearly rely on some form of addressing information. The required routing information is acquired during the Discovery process provided by the JAUS Discovery Service.

The Discovery process consists of two fundamental phases:

- Detection and Identification
- Publication

In these two phases, Discovery can be used to "discover" the Components and their constituent Services resident on any Node or Module within a Subsystem, and can also be used to "discover" the Subsystems and constituent Nodes present within a System.

The sequence of operations in the Discovery process is straightforward:

- On startup, a Component in the Vehicle subsystem announces its presence by broadcast of a node-level QueryIdentification message on the Intra-Subsystem network.
- In response to this message, the Discovery Server component within the Subsystem scope (in this case, the Vehicle subsystem, as seen on the Intra-Subsystem Network) responds with the appropriate node-level ReportIdentification message, as a unicast message.
- The received ReportIdentification message bears the SubsystemIdentifier of the sender; thus, this mechanism provides the SubsystemIdentifier of the vehicle to the requesting Component and its parent CM. On receipt of the ReportIdentification message, the new Component also knows the identification of the Discovery Component, and registers its Services with the Discovery Server by constructing and sending a RegisterServices message.
- The Discovery Server typically sends a CreateEvent message to the registering Component, so that it will be automatically notified in any change to the Component's available Services.
- At this time, the Component and its Services are registered with the Discovery Server; any other Component may now query the Discovery Server to find Services registered in the Subsystem.

An external subsystem may, over its Inter-subsystem Network connection, query the Vehicle subsystem's Discovery Server and "discover" the services provided by the Vehicle subsystem.

Capability Module Example: Video CM

Having discussed the concept of the Capability Module, and the control topology of a modular UGV system taking advantage of that concept, we'll next examine an example AEODRS Capability Module that employs the Adaptor Paradigm.

Simply put, an AEODRS logical adaptor can be thought of as consisting of three basic blocks: a JAUS front end; the logic and algorithms necessary for control; and a backend responsible for sensor and actuator interface, or for native interfaces to lower-level controls:

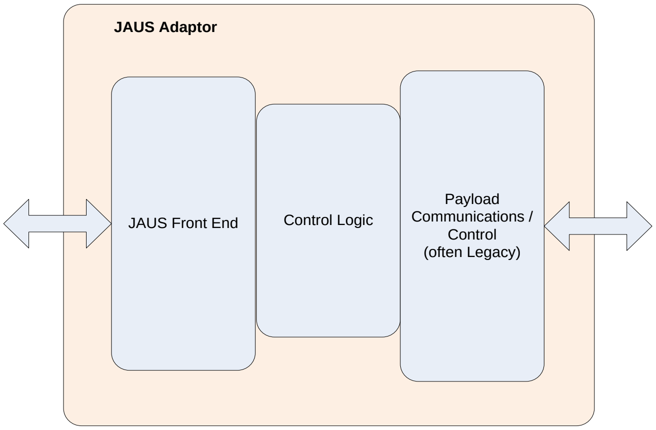

Figure 7 - JAUS Adapter

For our example, consider a Capability Module supporting one or more video sensors. This Video Capability Module can provide flexible control of the video sensor, the digitization and encoding of its stream of video frames, and associated equipment. We'll take the simplest case of a module supporting exactly one video source, which provides a stream of JPEG frames to the module:

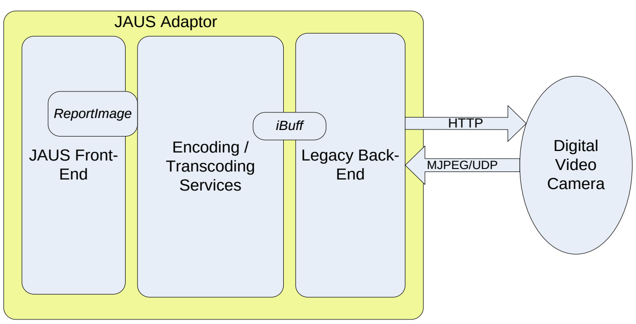

Figure 8 - Video Data Feed

In this case, the module's JAUS Front-End receives commands via the Intra-Subsystem Network. The commands may configure the encoding services provided by the middle or "control logic" layer, or may pass through that layer to the Back-End, which builds configuration and control messages to be sent to the camera (in this illustration, the camera control messages are passed via an http connection to the camera). The camera's video stream is received by the Back-End, and each frame is placed in a framebuffer for handling by the control logic layer's encoding services if necessary. The resultant frame could then be encapsulated in JAUS ReportImage messages, and conveyed in that form to the component that requested the video.

While the use of the three-layer design model shown here is not necessary, it does serve to illustrate some key points of AEODRS Adaptor architecture. First, the Front-End encapsulates the module's JAUS Runtime Engine (including Transport services, message serialization and deserialization, message handlers, message dispatch, and protocol support). Second, the Back-End encapsulates support for what we term "legacy interfaces," including messaging interfaces and message protocols for subordinate controls and direct I/O interfaces for "non-intelligent" devices. This allows the control logic to remain unaffected by changes in the payload (due, for instance, to device replacement resulting from device obsolescence), and affords some isolation from future changes in the JAUS standard itself. This separation of concerns has direct impact in reducing software maintenance and sustainment efforts.

As a further example, consider the impact of accommodating an upgraded camera. It is likely that the modified camera command interface would be accommodated completely within the Back-End, and require no change to the control logic or the front end. Similarly, a change in video encoding might be expected to reside completely within the control logic.

It is important to note, however, that architecture is an enabler: The key to realization of proper separation of concerns is design foresight consistent with architectural intent.

System Example: Dismounted Operations System

The Dismounted Operations System is the smallest member of the AEODRS Family of Systems, and must be small enough to be transported via a backpack. The primary mission focus of this system is on reconnaissance, but it may also be used to support counter-charge placement. This system entails the development of eight capability modules and controllers:

- Platform Master Controller
- Mobility Controller
- Manipulator CM
- End-Effector CM
- Video CM
- Power System CM
- Payload CM

The following paragraphs will summarize the capabilities of each module / controller, then present and briefly discuss the JAUS Components and Services that provide access to those capabilities. But before we discuss the capabilities of each module, there are a few pieces of JAUS terminology to introduce:

- A *service* is a “mechanism to enable access to one or more capabilities, where the access is provided using a prescribed interface and is exercised consistent with constraints and policies specified by the service description.” A JAUS service “facilitates interoperation of unmanned vehicle systems, subsystems and payloads by standardization of the message set and associated protocol.”
- A *service set* is a packaging of documentation of a group of related services.
- A *component* is a software element in a JAUS system , encapsulating a set of services that provide or support a clearly-delineated capability. A component is frequently realized as an independent executable.

Traditionally, JAUS Components have been implemented as independent executables. Implementations built on an operating system platform that supports the classical notion of a process have generally implemented each JAUS Component residing on a node as a separate process on that node. Communication between JAUS Components on a given node has commonly been realized with JAUS compliant messaging via IPC mechanisms.

The AEODRS program does not prescribe or proscribe design below the defined Intra-subsystem interfaces: The preceding discussion of traditional JAUS component implementations is provided for background purposes.

Some clarifications of AEODRS network naming and terminology are also in order:

- The *Inter-Subsystem Network* enables communications between AEODRS Subsystems. Examples of AEODRS Subsystems include AEODRS Unmanned Ground Vehicles and AEODRS Operator Control Units.
- The *Intra-Subsystem Network* enables communications between entities within an AEODRS Subsystem. Examples include communications between AEODRS Capability Modules onboard an AEODRS UGV.

Platform Master Controller

The Platform Master Controller interfaces to both the Inter-Subsystem Network and the Intra-Subsystem Network.

The Platform Master Controller provides vehicle subsystem management support in the form of Intra-Subsystem Network address assignment for Capability Modules, Discovery services to support detection, registration and deregistration of Capability Modules as part of the vehicle subsystem, and message-routing services for communications beyond the Subsystem boundary. Other subsystem management services are also provided.

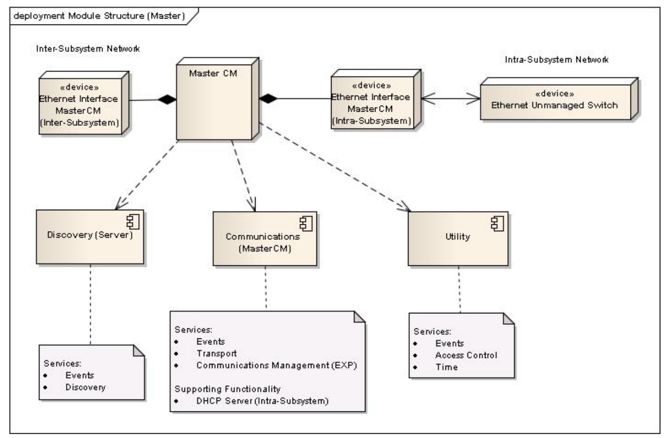

Figure 9 - Master Controller Architecture

Each AEODRS node (whether a Subsystem or a Capability Module) contains a resident Communications Component. The Platform Master Controller’s Communications Component supports the dual-homed configuration of the Platform Master. The Platform Master provides an Intra-Subsystem Network for communications with on-vehicle Capability Modules, and an Inter-Subsystem Network for communications with remote resources (predominantly an operator control station) and appropriate message routing between the two networks. The Communications Component also provides a DHCP server for assignment of IP addresses to CMs and Controllers within the UGV Subsystem

The Discovery Component implements mechanisms for presence detection, identification, registration and publication of capabilities and services provided by Components on multiple Capability Modules. These mechanisms are required to effectively minimize manual system configuration activities.

The Utility Component provides utility services best implemented centrally and useful by components on multiple capability modules. The first such utility service is the Time service, providing a central vehicle-resident time-of-day service for application where synchronized timestamping is needed (such as in the generation of merged system logs).

Mobility Controller

The Platform Mobility Controller interfaces to the Intra-Subsystem Network. The Platform Mobility Controller provides a low-level interface to Mobility capabilities, including basic effort-based drive control and reporting of low-level feedback and status. The Platform Mobility Controller also provides access to and control of several platform-associated capabilities, including control of annunciators, lighting systems, and stabilization devices such as flippers or articulators.

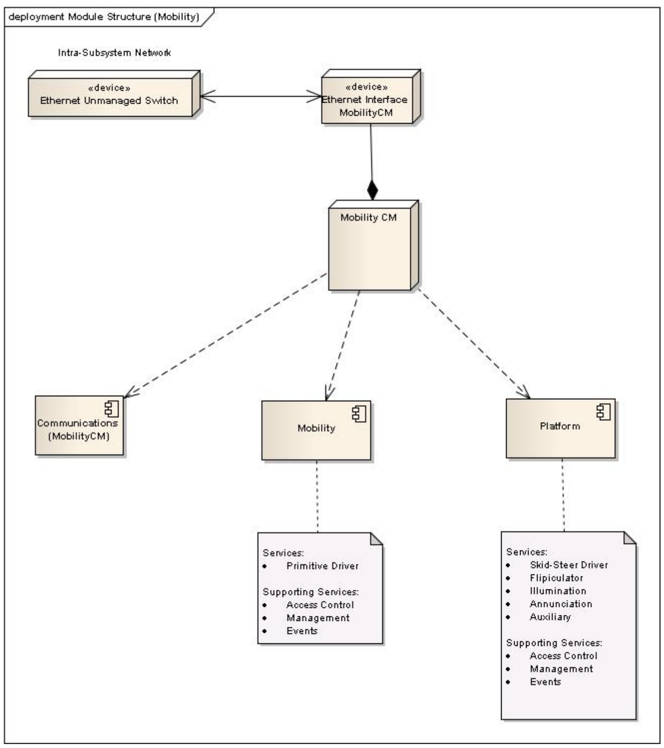

Figure 10 - Mobility Controller Architecture

The Mobility Controller implements three components: Communications, Mobility and Platform. The Communications component supports the single-homed configuration of AEODRS Capability Modules, providing JAUS-compliant communications using JUDP transport for modules residing on the Vehicle over the Intra-Subsystem Network. The Mobility Component implements a low-level interface to control of the AEODRS vehicle mobility platform, including basic effort-based drive control and reporting. The Platform Component implements driving services specific to the steering system geometry of the vehicle; management services for powerplant and drivetrain low-level control (as appropriate to the specific AEODRS platform); platform stabilization services (where applicable); and auxiliary device control services.

Higher-level mobility control modes are provided by the Mobility Support Component residing on the Autonomy Module.

Manipulator CM

The Manipulator Capability Module interfaces to the Intra-Subsystem Network.

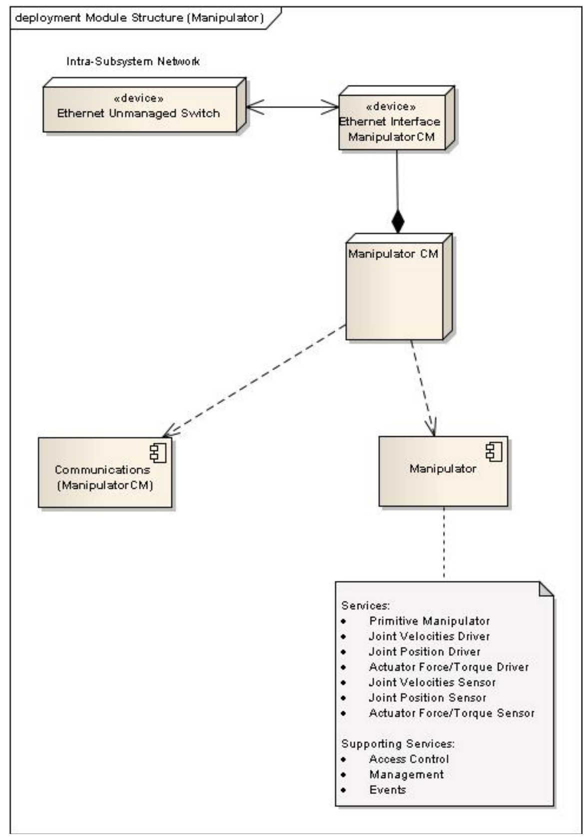

Figure 11 - Manipulator CM Architecture

The Manipulator Capability Module provides joint-based control of the Manipulator. The supported joint-based control modes and reporting capabilities include:

- Joint-Position control and reporting.
- Joint Velocity control and reporting.
- Joint Force (for prismatic joints) and Joint Torque (for revolute joints) control and reporting.
- Primitive effort-based (open-loop) joint control and commanded-effort reporting.

End-Effector CM

The End-Effector Capability Module interfaces to the Intra-Subsystem Network. The End-Effector CM provides a low-level interface to control of simple gripper-type end-effectors for the Dismounted member of the AEODRS FoS.

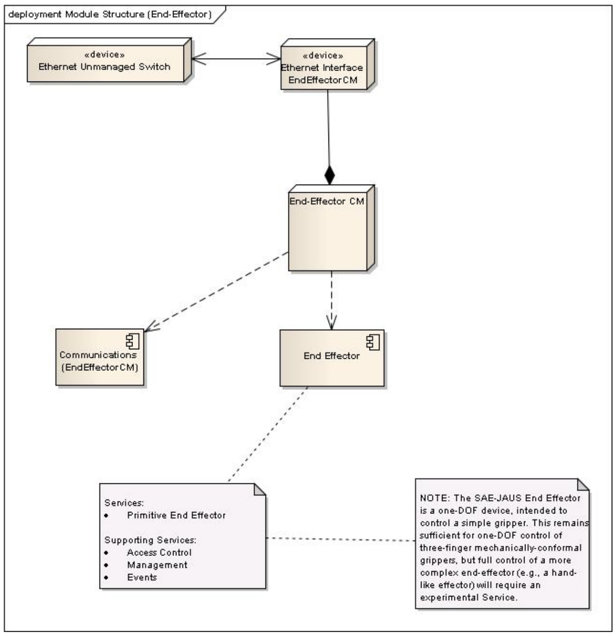

Figure 12 - End-Effector CM Architecture

The low-level interface provides open-loop, effort-based control of the single DoF of a simple End-Effector, as well as simple status reporting.

Higher-level control modes are provided by the Manipulation Support Component residing on the Autonomy Module. The Intra-Subsystem Network provides connectivity

Video CM

The Video Capability Module provides a well-defined message-based interface for the initialization, configuration and control of Video Sensors, and the configuration and control of any video stream or single frame image requested by another AEODRS capability module or subsystem.

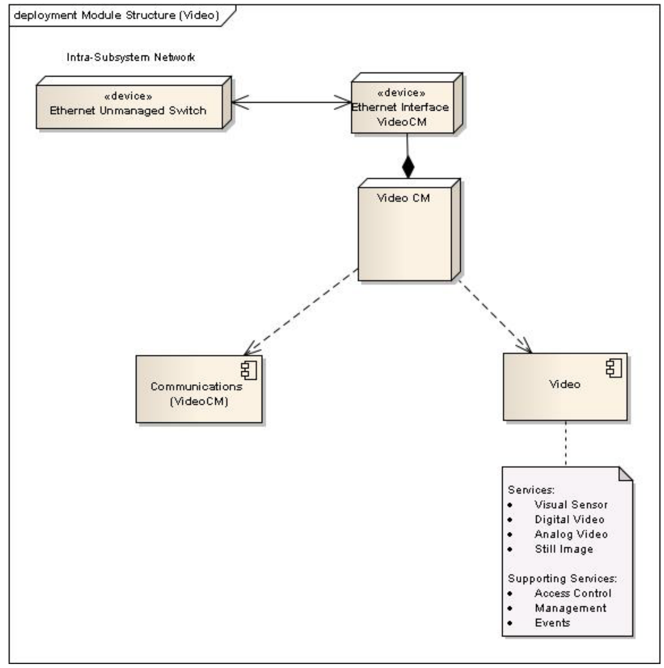

Figure 13 - Video CM Architecture

The Video Capability Module interfaces to the Intra-Subsystem Network.

Power System CM

The Power System Module interfaces to the Intra-Subsystem Network. The Power System Module provides the AEODRS vehicle platform with a multi-source, multi-bus power system, and with management and control services supporting its utilization.

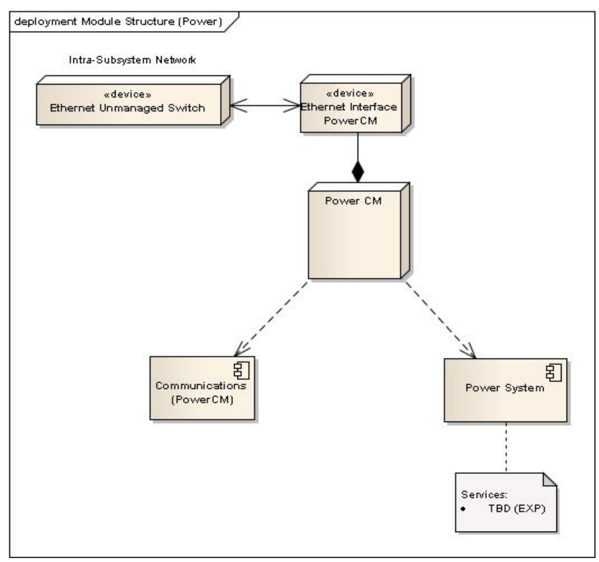

Figure 14 - Power System Controller Architecture

Autonomous Behaviors CM

The Autonomous Behaviors Capability Module (CM-AUTO) interfaces to the Intra-Subsystem Network. CM-AUTO accepts and acts upon mission definitions for autonomous and semi-autonomous operations, and provides aids to the operator for assistive teleoperation of the platform, its manipulator, and its payloads.

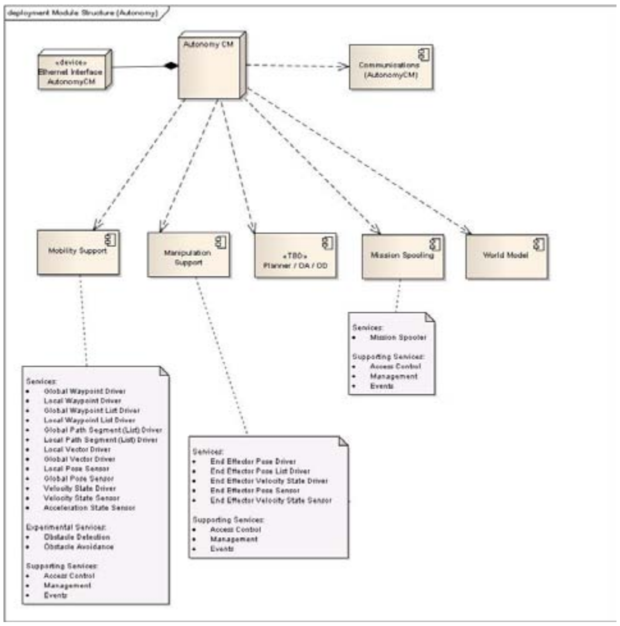

Figure 15 - Autonomous Behaviors CM Structure

CM-AUTO obtains position, orientation, obstacle, and other needed information through sensors integrated with CM-AUTO. CM-AUTO also provides standard service interfaces through which other AEODRS Capability Modules and Controllers may gain access to its sensor data. The CM-AUTO receives high level commands from other capability modules, or from the System Controller (operator control station).

Electrical Layer System Overview

The AEODRS Common Architecture defines an electrical layer for both the system power bus and the system communications bus. The result of trade studies on system bandwidth, power budgeting, and market analysis on available COTS systems has led to the selection of the buses as described below.

Power Bus

A negatively grounded 24V joint payload and platform power bus has been selected for the Increment 1 system. The Increment 2 and Increment 3 systems retain the 24V payload power bus, and add a separate 48V platform power bus. The internal platform power bus is used for high power devices such as platform drive motors and possibly manipulation systems (on Increment 2&3 systems). The external platform accessibility will be minimized due to safety concerns. The secondary bus (payload 24V) primarily drives external payloads, peripherals, and sensors. This bus is more externally accessible for in-the-field interoperability and swap of field configurable capability modules. In addition to maintaining commonality, the standardization of the power bus maximizes efficiency through the avoidance of using multiple DC/DC converters.

Communications Bus

A Gigabit Ethernet (IEEE 802.3ab) communications bus has been selected for the intra-vehicle network. Gigabit Ethernet is adequate for bandwidth needs of the system and allows for future expandability. Many new sensors are being made with Ethernet communications links and the use of a network switch allows various speed peripherals to operate seamlessly on the gigabit bus.

Physical Layer System Overview

The AEODRS Common Architecture defines a physical layer for the connection of the Capability Modules to the power bus and to the communications bus. Additionally, the physical layer defines the mechanical mounting of the capability modules to the base platform or other capability modules where required.

Power/Communications Connectivity

Due to the environmental requirements and availability of military standards as well as a precedent set forth in the UGV and other related fields, the selection of MIL-STD-38999 series connectors has been made. These connectors are used for both the power and communication busses via a single cable arrangement.

Mechanical Mounting

The mechanical mounting of capability modules to the host platform or to other capability modules is specified through the use of a mechanical breadboard approach. This interface system used by optical industry and mechanical vibration and test bench applications uses ¼ - 20 threaded hole pattern on a 1” x 1” grid array. By sizing the requisite grid on a capability module basis for the worst-case torque/force loading, a reliable and simple interface is achieved.

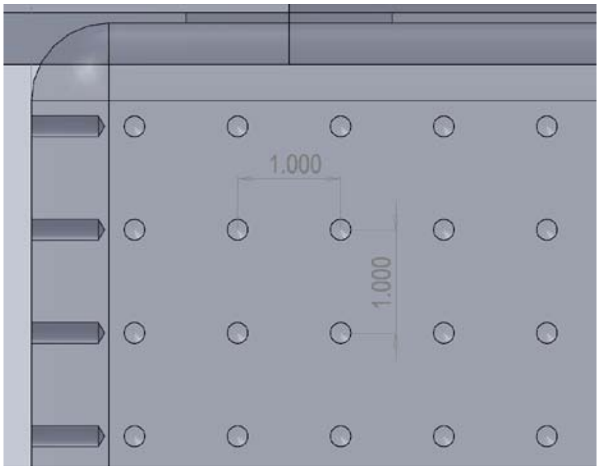

Figure 16 - Mechanical Breadboard Mounting Approach

Conclusion

The Common Architecture described herein allows for the successful interoperability at the system and subsystem levels. The resulting FoS has at its core the ability to severely reduce the logistical footprint of fielded systems and opens the door to unlimited continual improvement programs without the barriers of proprietary vendor interfaces. It is the hope of the AEODRS program and the technical team working to bring it to fruition that the UGV market adopt this and other emerging common architectures to bring standardization to the industry analogous to that which has been seen by the PC, automotive and other modern day industries.

REFERENCES

[1]