ROBOTIC MANIPULATION AND HAPTIC FEEDBACK VIA HIGH SPEED MESSAGING WITH THE JOINT ARCHITECTURE FOR UNMANNED SYSTEMS (JAUS)

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Harris Corporation and OpenJAUS have teamed up to retrofit the Harris RedHawk AGS UGV with a modular software interface based on the Joint Architecture for Unmanned Systems (JAUS). This effort, which was funded by Quantum Signal LLC via a SBIR contract with TARDEC, is aimed at advancing RedHawk AGS to meet the latest architectures for modular unmanned systems. The RedHawk™ family is a modular, expandable system comprised of wireless haptic controllers, precision manipulators, advanced ground platforms, and accessories that can be adapted for specific mission profiles. RedHawk AGS consists of a 6-DOF manipulator arm integrated onto a six-wheeled UGV. RedHawk AGS utilizes AEODRS Increment 2 tool changers and force control to enable automated tool-changing. OpenJAUS worked with Harris to develop a JAUS architecture solution using a combination of standard and experimental JAUS services to enhance the existing system. This solution implements capabilities in accordance with the Interoperability Profiles v0 (IOPv0) standards developed by the Robotic Systems Joint Program Office (RSJPO). The software developed was based on the OpenJAUS Software Development Kit (SDK) which provides a robust cross-platform implementation of the SAE JAUS standard. The OpenJAUS SDK provides complete implementation of core JAUS services which are in accordance with the IOPv0 standard. Of special interest to this project was the inclusion of the RedHawk Manipulator. This manipulation system includes real-time haptic feedback between the Manipulator and OCU operator. This required high speed (100+ Hz) JAUS messaging. This requirement challenged an industry misconception of the JAUS architecture; that JAUS is not capable of doing high-speed real-time command and control. This project also required the implementation of an experimental JAUS service to provide the force-feedback values from the Manipulator to the OCU. This paper will show how the team implemented the solution and was able to accomplish project goals using JAUS without negative impact on system performance.

INTRODUCTION

The capabilities and performance of Unmanned Systems is growing at a rapid pace. One area of particular interest in recent years has been in the arena of manipulation. As the mobility capa-

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bilities of Unmanned Ground vehicles have increased, the need for accurate and robust manipulation has been of interest, particularly in the Explosive Ordinance Disposal (EOD) arena. Harris' RedHawk™ family of systems was developed to meet these needs. The RedHawk family is a modular, expandable system comprised of wireless haptic controllers, precision manipulators, advanced ground platforms, and accessories that can be adapted for specific mission profiles. One of the primary goals in the development of the RedHawk systems was to enable mobile robotic platforms to have human-like manipulation capabilities, including dexterity, precision, strength, and a sense of touch (i.e. haptics).

Harris Corporation has partnered with Quantum Signal LLC (QS) to develop advancements for the Harris RedHawk AGS system, including development of an autonomy payload for the system. This work was funded by the United States Air Force Commercialization Pilot Program through a SBIR Phase III contract with QS that was managed by the United States Army Tank Automotive Research, Development and Engineering Center (TARDEC). One of the goals of this contract is to advance the RedHawk AGS system to meet the latest architectures for modular unmanned systems. Towards this end, Harris and OpenJAUS teamed up to retrofit the RedHawk AGS system with a modular software interface based on the Robotic Systems Joint Program Office (RSJPO) Interoperability Profiles (IOP) standard. RedHawk AGS consists of a 6-degree of freedom (DOF) manipulator arm integrated onto a six-wheeled UGV. RedHawk AGS also provides point-and-click autonomous driving and high-precision dexterous manipulation with haptic feedback. OpenJAUS worked with Harris to develop an IOP/JAUS architecture solution using a combination of standard and experimental JAUS services to enhance the existing system.

This paper explores the unique challenges of developing this system and incorporating a number of unique features including haptic force feedback and real-time open-loop control over JAUS. This requirement challenged an industry misconception of the JAUS architecture; that JAUS is not capable of doing high-speed real-time command and control.

HARRIS REDHAWK DEVELOPMENT

Over past several years Harris has developed the RedHawk™ family of systems. The RedHawk family is a modular, expandable system comprised of wireless haptic controllers, precision manipulators, advanced ground platforms, and accessories that can be adapted for specific mission profiles.

One of the primary goals in the development of the RedHawk systems was to enable mobile robotic platforms to have human-like manipulation capabilities, including dexterity, precision, strength, and a sense of touch (i.e. haptics). By providing these capabilities, an operator can perform challenging manipulation tasks from a safe standoff distance – a critical need for EOD (Explosive Ordnance Disposal) technicians, First Responders, and CBRNE (Chemical, Biological, Radiological, Nuclear, and Explosives) personnel. The RedHawk systems were designed using the input from hundreds of active duty operators. Harris has continuously improved and refined the design based input from multiple EOD user groups.

The current RedHawk family, shown in Figure 1**Error! Reference source not found.**, includes RedHawk MPR (Manipulation Payload Retrofit), RedHawk AGS (Advanced Ground System), and the RedHawk OCU (Operator Control Unit). RedHawk MPR is a bolt-on retrofit for existing unmanned ground vehicles (UGVs). It consists of a 6-DOF arm with a 1 DOF gripper. The gripper includes compact, high-strength 6-axis force/torque sensors in each finger, providing crisp multi-axis force feedback for haptic control. RedHawk AGS consists of a 6-DOF manipulator arm integrated onto a six-wheeled UGV. The RedHawk AGS manipulator provides the same high-precision dexterous manipulation with haptic feedback that RedHawk MPR provides, but with the added functionality of automated tool-changing through the integration of AEODRS Increment 2 tool changers. RedHawk AGS also provides “point-and-go” and other semi-autonomous driving behaviors through the integration of an autonomy payload co-developed with QS that incorporates QS’ PointCom semi-autonomous navigation software and DRIVER software infrastructure. The RedHawk OCU is a 6+1 DOF haptic interface. That is, it is able to measure the 6 DOF motion of the hand grip (3-DOF translation, 3-DOF rotation) as well as the 1-DOF displacement of an actuated trigger located on the hand grip. The interface provides haptic (force) feedback to the grip as well as force-feedback through the trigger. Using the RedHawk OCU to control either RedHawk MPR or RedHawk AGS provides an operator with immersive high-fidelity, multi-axis force feedback, even in the presence of degraded communications (i.e. low bandwidth, high/varying latency).

Figure 1. RedHawk MPR (Left), RedHawk AGS (Center), RedHawk OCU (Right)

RedHawk control algorithms, including intuitive spatial motion control, dynamic motion scaling, and camera-frame teleoperation, enable a novice operator to perform complex tasks with minimal training time and reduced cognitive burden. This has been validated through multiple rounds of human-factors testing. For example, testing performed by the US Army compared a RedHawk system to an MTRS QinetiQ Talon for performing a variety of EOD and CBRNE manipulation tasks. Testing results showed a significant reduction in task completion time (20.2% faster) and workload (18.6% workload reduction). Furthermore, testing showed an overwhelming preference for the RedHawk system – 100% of the soldiers said that the use of the RedHawk improved their overall performance[1].

JOINT ARCHITECTURE FOR UNMANNED SYSTEMS (JAUS) AND INTEROPERABILITY PROFILES (IOP)

The Joint Architecture for Unmanned Systems (JAUS) is a commercial standard developed by the AS-4 Unmanned Systems Committee as part of the Society of Automotive Engineers (SAE). JAUS was originally developed in the late 1990’s and early 2000’s as a Department of Defense (DOD) standard to provide a common C2 interface to unmanned ground vehicle (UGV) systems. Over the past decade, the JAUS standard has expanded in scope to cover additional domains and capabilities as well as becoming a more well-defined standard based on a Service Oriented Architecture (SOA)[2]. This formal architecture defines a number of services which provide a common interface through which behavior can be achieved through well-defined protocol based on messaging. Of particular interest to this paper is the work being done by the US Army's Robotic Systems Joint Program Office (RSJPO) in defining Interoperability Profiles (IOP).

While JAUS provides a common language through which systems can be built and interoperability achieved, there remains enough flexibility and options in the various services and messages that interoperability is not guaranteed between two implementers. For example, one user may develop a robot which navigates using the Global Waypoint Driver service. However, another user may develop an Operator Control Unit (OCU) which only supports open-loop navigation using the Primitive Driver service. While both of these systems are indeed JAUS compliant, they are not interoperable. IOP provides additional detail and guidance on the implementation of JAUS within an unmanned system that reduces ambiguity and makes out-of-the-box interoperability achievable.

IOP specifies a set of Interoperability Attributes that may be provided by a system. Some Interoperability Attributes examples include: Platform Management, Core Mobility, Teleoperation, Manipulator Control and a large variety of Payloads (Sensors, Actuators, etc). Interoperability Attributes can be modified using Attribute Options, Parameters and Modifiers. For a given selection of values, the IOP profiling rules specify the exact interfaces that must be implemented for interoperability. These Interoperability Attributes are defined in the *SAE JAUS Profiling Rules* document[3]. To date, RSJPO has completed two revisions of the IOP documentation. Version 0 was released in spring 2011, and version 1 was released in spring 2012. For the effort described herein, the IOPv0 documentation was utilized.

OPENJAUS SOFTWARE DEVELOPMENT KIT

The OpenJAUS Software Development Kit (SDK) is a collection C/C++ software libraries which provide an abstract programming interface (API) to the JAUS standard. OpenJAUS develops the SDK to provide an abstraction of the JAUS services, components and messages to enable developers to quickly and accurately focus on their application-level software without the need to completely understand and implement the low-level JAUS messaging and protocol requirements. Consisting of over 100,000 lines of code, the SDK includes support for all JAUS service sets including Core Services, Mobility Services, Manipulator Services, Environment Sensing Services and more. The OpenJAUS SDK is developed using a Model-Driven Design (MDD) pattern which enables the JAUS Services and Messages to be modeled using a customized high-level language and code to be generated using a set of custom code generation templates[4]. This design approach enables a small team of software engineers to quickly and accurately maintain the robust and large codebase. Using the OpenJAUS SDK enables customers to save an average of 3-6 months of software engineer development time. Of particular interest to the effort described herein, the OpenJAUS SDK also includes experimental libraries to support the custom IOP JAUS services and messages. Through the course of this effort, these libraries were shown to be interoperable with the program's IOP requirements using the TARDEC Interoperability Profile Conformance Verification Tool.

HARRIS REDHAWK JAUS/IOP ARCHITECTURE

The Harris RedHawk AGS system was initially developed without a JAUS capability. Harris and OpenJAUS collaborated to develop an architecture which implements capabilities in accordance with IOPv0 for the RedHawk AGS system. To accomplish this, three JAUS Nodes were developed consisting of a total of 5 JAUS components and over 30 different JAUS services.

To implement this system, Harris and OpenJAUS agreed to develop a customized UDP interface between the legacy RedHawk system software and the necessary JAUS nodes and components to be developed by OpenJAUS to meet the IOP requirements. Figure 2 shows the key software components and connectivity developed for this effort. By encapsulating the JAUS software to a separate software component, parallel development of between the JAUS components and the RedHawk software could be done without impact on program progress.

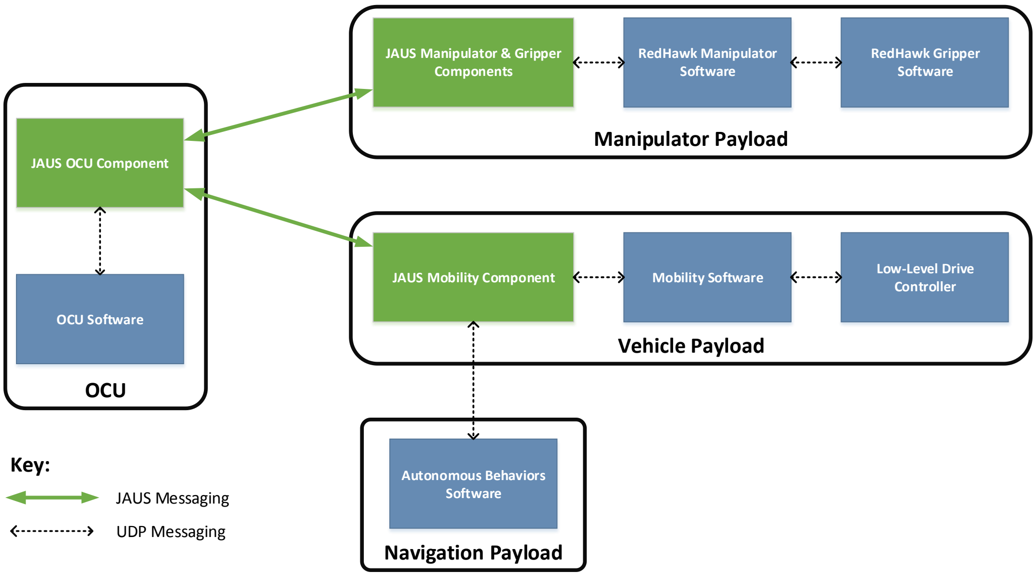

Figure 2. RedHawk Software Components and Connectivity

Two unique challenges presented themselves to implementing the RedHawk system. The first unique challenge was that the JAUS Manipulator Service Set does not currently provide a service which provides the necessary feedback for the haptic (force) aspect of the RedHawk manipulator. The second unique challenge was that this haptic feedback data as well as the open-loop manipulator control data needed to be exchanged between the OCU software and manipulator / gripper software at a relatively high speed (125 Hz).

To overcome the first challenge, OpenJAUS with Harris' assistance, designed and implemented the Gripper Force Sensor service. This experimental JAUS service provides feedback from the Gripper for the 6-DOF force and torque feedback (reported in N and N*m, respectively) from the RedHawk manipulator.

In past experience, OpenJAUS has typically built JAUS systems with a maximum data refresh rate of approximately 50-60 Hz. The need for high-speed, low-latency communication between controller and actuator challenged industry assumptions about JAUS and the overhead it adds on overall system latency. Using the OpenJAUS SDK and running on an embedded Linux platform, Harris and OpenJAUS was able to successfully implement feedback and control of the RedHawk Manipulator and Gripper using JAUS messaging at 125 Hz. This was a significant accomplishment and added minimal latency (less than 30 ms) to overall system performance, even over a wireless communications link.

CONCLUSION

The Harris RedHawk AGS system enables a novice operator to perform complex tasks with minimal training time and reduced cognitive burden. The purpose of this effort was to add an interface to the RedHawk system that implements capabilities in accordance with the JAUS and IOP architectures. In order to accomplish this, a number of unique challenges had to be overcome. These included the design and incorporation of a unique experimental JAUS service for gripper force feedback as well as the real-time open-loop control and feedback functionality required to support the RedHawk haptic OCU. This project has shown that systems based on the IOP and JAUS standards can be built to meet today's most challenging Unmanned Systems problems. Harris and OpenJAUS were able to utilize JAUS and IOP to build a solution with performance on par with the legacy system while providing a more robust and modular interface for use on a variety of future programs and systems by utilizing the IOP / JAUS interface.

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