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POSTPRINT

RESULTS OF JAUS OPC EXPERIMENT 3.0

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14. ABSTRACT
The primary objective of the OCU and Payload Committee (OPC) within the Joint Architecture for Unmanned Systems (JAUS) working group is to assess the JAUS Reference Architecture (RA) specification's ability to address interoperability. The OPC was tasked to evaluate new messages and protocols before accepting them into the RA. To accomplish these objectives, the OPC conducted several experiments for collection of information on current and recommended approaches. The latest experiment, Experiment 3.0, was conducted at Tyndall AFB, FL in April 2006. Organizations from government, industry and academia participated in this experiment. Experiment 3.0's goal was to evaluate recommended approaches for advanced autonomy capabilities including mission execution and world modeling. There were three main conclusions: 1) Extensions to the JAUS standard message set provide a solid foundation for interoperability. 2) Compliance verification is vital prior to mission command and control of unmanned systems 3) Future work is needed for implementation consistency. This paper provides an overview of the OPC experiment development, results, and future plans.

15. SUBJECT TERMS
Compliance Testing, JAUS, Interoperability, Message Sets, Mission Planning, OPC, Perimeter Security, SAE/AS-4, UGV, World Model

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Results of JAUS OPC Experiment 3.0

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Abstract: *The primary objective of the OCU and Payload Committee (OPC) within the Joint Architecture for Unmanned Systems (JAUS) working group is to assess the JAUS Reference Architecture (RA) specification's ability to address interoperability. The OPC was tasked to evaluate new messages and protocols before accepting them into the RA. To accomplish these objectives, the OPC conducted several experiments for collection of information on current and recommended approaches. The latest experiment, Experiment 3.0, was conducted at Tyndall AFB, FL in April 2006. Organizations from government, industry and academia participated in this experiment. Experiment 3.0's goal was to evaluate recommended approaches for advanced autonomy capabilities including mission execution and world modeling. There were three main conclusions: 1) Extensions to the JAUS standard message set provide a solid foundation for interoperability. 2) Compliance verification is vital prior to mission command and control of unmanned systems 3) Future work is needed for implementation consistency. This paper provides an overview of the OPC experiment development, results, and future plans.*

Keywords- Compliance Testing, JAUS, Interoperability, Message Sets, Mission Planning, OPC, Perimeter Security, SAE/AS-4, UGV, World Model

Introduction

The Joint Architecture for Unmanned Systems is sponsored by the Office of the Under Secretary of Defense for the purpose of reducing life cycle costs, shortening development and integration time, providing a framework for technology insertion, and accommodating expansion of existing systems with new capabilities. The OCU and Payload Committee (OPC) within JAUS was created by the JAUS working group with the charter to evaluate extensions to the standard and report recommendations to the JAUS executive committee. The OPC has conducted a series of experiments in order to fulfill this charter. For OPC experiment 3.0 the main focus was on mission execution and world modeling. It was hosted by the Air Force Research Laboratory at Tyndall Air Force Base, FL in late April 2006. Participants included representatives from industry, academia, and government [1]. In 2005, JAUS began migrating to SAE as AS4 "Unmanned Systems". Much of what has been learned from these experiments is being used in the development of unmanned system specifications under SAE. Today both organizations coexist and are marching to a well-defined migration plan.

One area of interest to the unmanned systems community, which is currently not addressed in the latest JAUS Reference Architecture (RA), is the capability to automate command and control of multiple heterogeneous platforms and the ability to store environment information for later use. For OPC experiment 3.0, the JAUS standard message set defined in the JAUS RA version 3.2 was used along with extensions for mission execution and world modeling. For the purpose of testing these new extensions, a perimeter security mission was designed and implemented that required the UGVs to accept roles as detectors and responders.

OPC experiment 3.0's 5 day agenda was:

- Day (1) "Compliance". All platforms to pass tests provided by the compliance tool.
- Day (2) "OCU". All platforms should take commands from the common mission controller.
- Day (3) "Scenarios". Detector UGVs search and when intruder is discovered, the OCU and its mission planner dispatches a responder UGV.
- Day (4) "Swap". UGVs mix to form new alliances.
- Day (5) "Buffer & Lessons Learned". Experiment team looks at results and forms recommendations.

The range of UGVs at OPC 3.0 varied from the 20 pound PackBot to the 3,000 pound NaviGator. The larger UGVs were assigned to be "Responders" and the smaller UGVs had the role of "Detectors". Figure 1 maps two collections called Set 1 and Set 2.

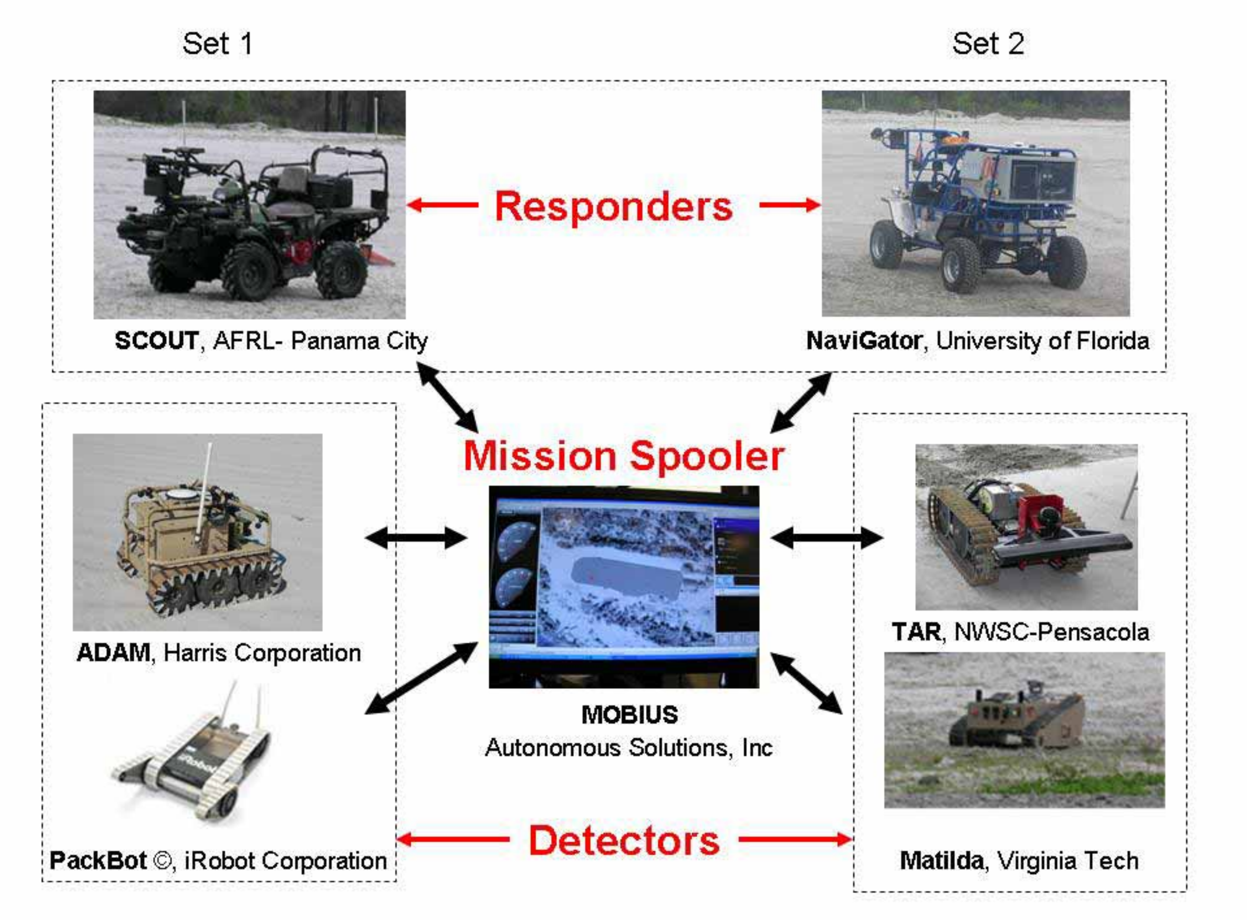


Figure 1 OPC 3.0 UGV Sets

Compliance

Past OPC experiments [2] [3] showed that interoperability exercises need to establish compliance early. This is essential during the early stages of evaluating extensions to the JAUS message set. OPC experiment 3.0 used software to unit-test six UGV's for mission compliance. Figures 1-3 displays a hierarchical tree of the software's functions in three categories: Communications, Tele-operations, and Global Pose. The compliance tool provided by Autonomous Solutions, Inc. [4] was designed to help JAUS implementers prepare for integration with their COTS software [5]. This Windows .NET compliance tool consisted of a suite of test cases which were executed within the NUnit GUI tool [6].

Figure 2 Communications Test

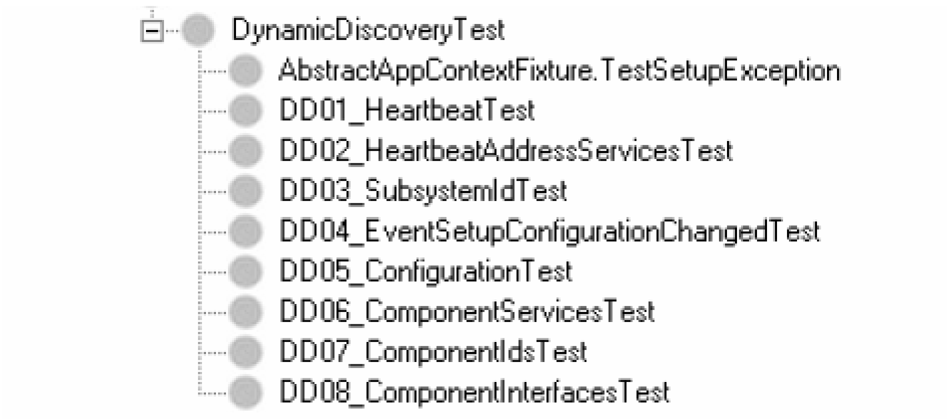


Figure 3 Tele-Operation Test

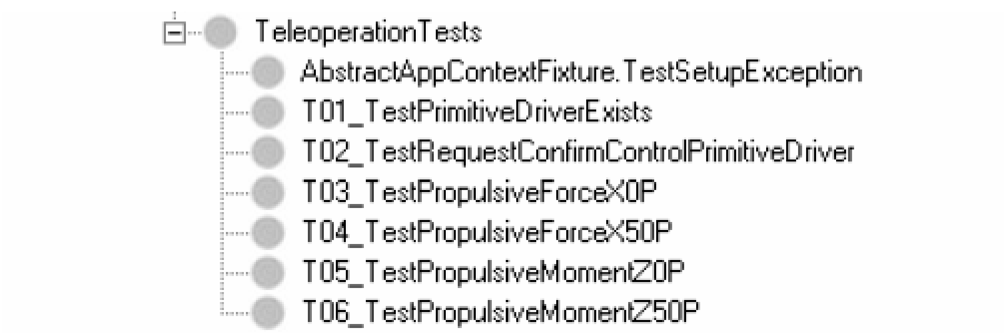
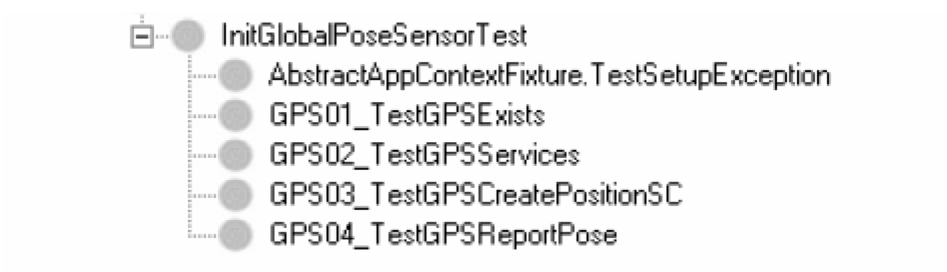


Figure 4 Global POSE Test



These tests were the gateway for UGVs participating in the perimeter security mission. Waypoint compliance tests followed on Day 2. Functions included: Waypoint exists, Command to

Waypoint, and Spool preferences. We show a summary of compliance results in Figure 5.

	A	B	C	D	E	F	G	H
1								
2		Team 1			Team 2			
3	Day One (Monday)		#REF!			#REF!		
4		SCOUT	ADAM	PackBot	NaviGator	TAR-1	TAR-2	Matilda
5		PASSED	PASSED	PASSED	PASSED	PASSED	PASSED	PASSED
6	JAUS Communication							
7	HeartBeat	Y	Y	Y	Y	Y	Y	Y
8	HeartBeatAddressServices	Y	Y	Y	Y	Y	Y	Y
9	SubSystemID	Y	Y	Y	Y	Y	Y	Y
10	EventSetupConfigChanged	Y	Y	Y	Y	Y	Y	Y
11	Config	Y	Y	Y	Y	Y	Y	Y
12	ComponentServices	Y	Y	Y	Y	Y	Y	Y
13	ComponentID		Y	Y	Y	Y	Y	Y
14	ComponentInterfaces	Y	Y	Y	Y	Y	Y	Y
15								
16	Global POSE							
17	TestGPSExists	Y	Y	Y	Y	Y	Y	Y
18	TestGPSServices	Y	Y	Y	Y	Y	Y	Y
19	TestGPSCreatePositionSC	Y	Y	Y	Y	Y	Y	Y
20	TestGPSReport	Y	Y	Y	Y	Y	Y	Y
21								
22	TeleOperation							
23	TestPrimativeDriverExists	Y	Y	Y	Y	Y	Y	Y
24	TestRequestConfirmControlPrimativeDriver	Y	Y	Y	Y	Y	Y	Y
25	TestPropulsiveForceX0P	Y	Y	Y	Y	Y	Y	Y
26	TestPropulsiveForceX50P	Y	Y	Y	Y	Y	Y	Y
27	TestPropulsiveMomentZ0P	Y	Y	Y	Y	Y	Y	Y
28	TestPropulsiveMomentZ50P	Y	Y	Y	Y	Y	Y	Y
29								
30								
31		Team 1			Team 2			
32	Day Two (Tuesday)	SCOUT	ADAM	PackBot	NaviGator	TAR-1	TAR-2	Matilda
33		ALMOST	PASSED	ALMOST	ALMOST	PASSED	PASSED	ALMOST
34	Mission Spooler							
35	WayPoint Exists	Y	Y	Y	Y	Y	Y	Y
36	Command to WayPoint	Y	Y	Y	Y	Y	Y	Y
37	SpoolPreferences	Y	Y	Y	Y	Y	Y	Y
38								
39	Mobius Mission Spooler							
40	Spool Mission		Y			Y	Y	
41								

Figure 5 Compliance Summary

Environments:

OPC 3.0 physical environment consisted of a control building overlooking a field 300 yards long by 75 yards wide of fine sand, as shown in Figure 6. The network environment was parsed into three separate channels. The reason for network separation was UGV performance, diagnostics, and field-safety. Each UGV collection had access to a dedicated 802.11b channel, while a third channel was set-up for testing. Net assignments are shown in Figure 7. The C^2 application (MOBIUS) and the OPC Chairman were members of Nets 1 and 2.

Figure 6 View from Control Building

Org	Team	Robot?	IP	MAC	Person/Function
AFRL	1	Scout	192.168.128.15		
Harris	1	ADAM	192.168.128.50	00:40:53:0A:59:0F	
Harris	1		192.168.128.51	00:0F:F8:55:8F:31	Dennis
Harris	1		192.168.128.52	00:CB:97:31:5A:EF	bridge
Harris	1		192.168.128.53	07:A1:E8:40:B7:2C	Clark
Harris	1		192.168.128.54	00:0D:56:E3:D2:03	Loran
iRobot	1		192.168.128.60	00:12:3F:E3:65:37	Kathy
iRobot	1	PackBot	192.168.128.61	00:0F:F7:5F:6F:56	
NSWC	2	Tar-1	192.168.128.31		
NSWC	2		192.168.128.32	00:12:3F:E3:E5:8C	
NSWC	2	Tar-2	192.168.128.33	00:02:2D-18-0F:F7	
UF	2	World Model	192.168.128.120	00:0F:EA:3C:C9:A1	World Model
UF	2		192.168.128.121	00:0B:DB:A0:39:EA	Danny
UF	2		192.168.128.122	00:90:4B:B1:74:F0	Tom
UF	2		192.168.128.123	00:0B:CD:74:73:6F	Bob
UF	2	Navigator	192.168.128.124	00:0F:90:15:2D:81	
VT	2		192.168.128.2	00:12:F0:A8:A4:DE	Steve
VT	2		192.168.128.3	00:13:CE:2B:11:86	Grant
VT	2		192.168.128.4	00:0E:35:4D:19:4B	Visualization
VT	2		192.168.128.5	00:0E:35:1C:54:87	Ruel
VT	2	Matilda	192.168.128.6	00:02:6F:21:F8:46	
VT	2		192.168.128.7	00:0B:7D:08:2B:E5	Chris
API	Both		192.168.128.55		Parag
ASI	Both		192.168.128.40		Sarah
ASI	Both		192.168.128.41		Extra
ASI	Both	Mission	192.168.128.42		Brian
ASI	Both		192.168.128.43		Carl
SPAWAR			192.168.128.110	00:0F:1F:14:CC:10	

Figure 7 Network Assignments

Scenario:

OPC experiment 3.0 consisted of a simple autonomous perimeter security mission for the purpose of testing the proposed extensions of the JAUS RA. The mission created involved a three-step process, all of which was executed automatically by the mission spooler after the mission was initiated. First, the detector UGV was sent to patrol an area perimeter by means of a set of waypoints. Second, the detector UGV simulated the detection of an intruder and registered the intruder's location into the world model. And third, the responder UGV was automatically sent to intercept the detected intruder, again by means of a waypoint. A picture of this mission is depicted in Figure 8.

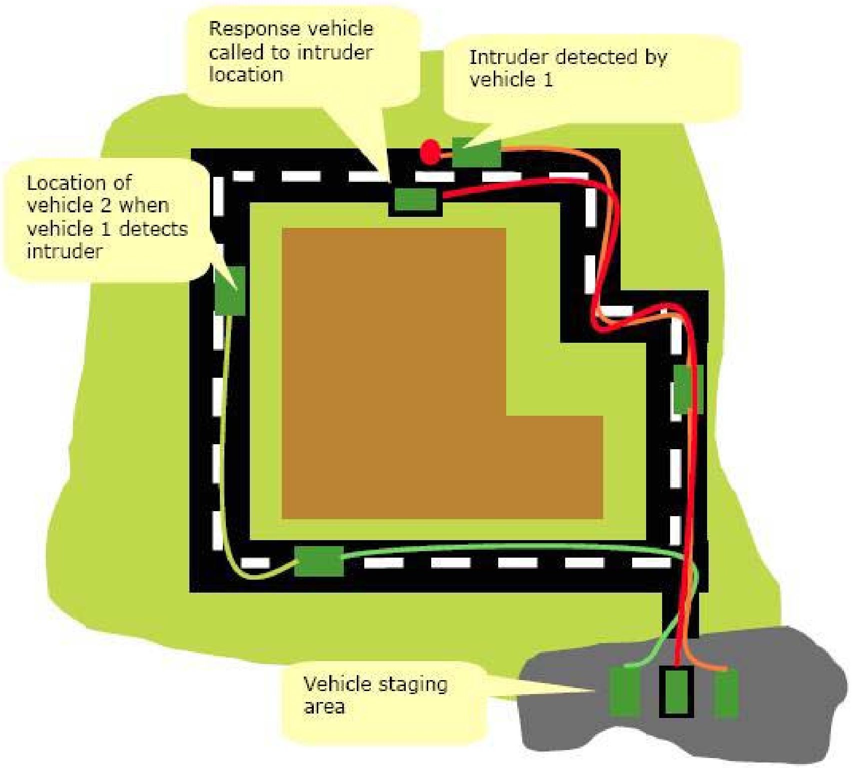


Figure 8 Perimeter Security Scenario

JAUS Extensions:

The core purpose and charter of the OPC is to evaluate extensions to the JAUS architecture. Here, we describe the basic set of extensions which were evaluated.

- Transport: This includes low-level IP and Serial-based communications of JAUS messages between nodes. In particular, we evaluated extensions to the IP Transport Layer to incorporate OS-based port-forwarding, to increase message routing efficiency
- Component Discovery: We continued to evaluate capabilities to enable JAUS components, nodes, and subsystems to be seamlessly integrated into existing JAUS networks through the use of multicast-based discovery protocols.

- Capability Discovery: In keeping with the desire of the JAUS Working Group to move towards a service-based architecture, we have eliminated the semantic link between JAUS component IDs and functionality. Instead, we added a ReportCapabilities message which enables an OCU or other Subsystem to discover what capabilities a JAUS node possesses.
- Mission Planning: We evaluated basic mission spooling capabilities and enabling communication of mission plans and parameters.
- World Modeling: We evaluated methods and messages for transferring raster and vector world knowledge.

Results:

There were three main conclusions: 1) the published JAUS RA message set, combined with proposed extensions for mission execution and world modeling, provide a solid foundation for OCU and UGV interoperability and co-operation, 2) While the message sets are maturing, there is a lack of protocol regarding the consistent usage of these messages, and 3) Compliance testing has value in qualifying platforms prior to a mission. Tailored JAUS prerequisites are one method to establish a common mission protocol. In OPC experiment 3.0, it allowed the team to focus evaluations on JAUS mission spooler extensions.

Future Work:

The lack of consistent protocol must be addressed in future versions of the JAUS RA specification to achieve operational interoperability of unmanned systems. The JAUS committee has developed a comprehensive JAUS Compliance application called JCTS [7]. Future versions of JCTS should consider integrating functions used successfully in [5].

OPC 3.0
April 2006

References

[1] List of participants: (AFRL- Panama City, Applied Perception Inc., Autonomous Solutions Inc., AMRDEC, Coroware Test Labs, Defense Technologies Inc., Harris Corporation, iRobot Corporation, NWSC-Pensacola, SAIC- Huntsville, SPAWAR- San Diego, CIMAR: University of Florida-Gainesville, Virginia Tech- Blacksburg)

[2] OPC 1.0: **JAUS Operator Control Unit (OCU) interoperability experiment: preparation and results:** Gray, Sarah A.; Harrison, Joseph F.; Smith, Brian G. *SPIE, Volume 5422-47*April 12-16 2004.

[3] OPC 2.0: **JAUS Implementation: Robots Gather for Successful Interoperability Experiment:** M.N.Clark, *Robotics & Automation Magazin*e, IEEE, vol 12, Issue: 1 March 2005

[4] Autonomous Solutions Inc. 1946 S 1600 W, Wellsville, UT 84339

[5] MOBIUS: an HMI developed by Autonomous Solutions, Inc. for controlling and monitoring multiple unmanned systems

[6] NUnit: http://www.nunit.org NUnit is a unit-testing framework for all .Net languages.

[7] JCTS: **JAUS Compliance Tool Suite-ver 0.4b(Beta Test):**Wes Brown- *JAUS Working Group Conferenc*e- Salt Lake city, UT January 18, 2005