JAUS Implementation: Robots Gather for Successful Interoperability Experiment

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Approximately 30 industry, research, and military robot specialists met for five days in Alton, Virginia, in August 2004 to test their communication software in the second of three scheduled experiments named OPC. The messaging framework is the Joint Architecture for Unmanned Systems (JAUS). JAUS is sponsored by the Office of the Under Secretary of Defense (OUSD) for Acquisition, Technology, and Logistics.

JAUS is mandated for use by all of the programs in the Joint Robotics Program (JRP). This initiative is to develop an architecture for the domain of unmanned systems. JAUS is an upper-level design for the interfaces within the domain of unmanned ground vehicles (UGVs). It is a component-based, message-passing architecture that specifies data formats and methods of communication among computing nodes. It defines messages and component behaviors that are independent of technology, computer hardware, operator use, and vehicle platforms and isolated from mission.

JAUS uses the Society of Automotive Engineers (SAE) generic open architecture (GOA) framework to classify interfaces. JAUS is prescriptive, as opposed to descriptive, and is sufficiently flexible to accommodate technology advances. Any unmanned system—air, ground, surface, or underwater—can use JAUS, whether it is commercial or military.

EXPERIMENT FRAMEWORK

Figure 1 presents the communication, robot, and payload framework used for Experiment 2. Three 802.11 wireless channels provided control and testing for the subsystems. At the top of Figure 1 are the participants followed by payloads installed on the robots identified in the lower tier. Each channel was assigned an operations control unit (OCU). Applied Research Inc., Virginia Polytechnic Insitute and State University (Virigina Tech), and the U.S. Air Force Research Lab (AFRL) maintained channels 11, 6, and 1, respectively. Each team's goal was to validate that their OCU could talk to all robots and control all payloads. It was a demonstration of interoperability.

JOUSTER

The five-day experiment was the first held at the new Joint Unmanned Systems Test, Experimentation and Research (JOUSTER) site at the Virginia International Raceway (VIR). A large Virginia Tech student team coordinated by Michael Fleming and led by Charles Reinholtz, professor of mechanical engineering, provided documentation, intranet access, and facility liaisons with the raceway staff. The networks, data logging, measurements, safety validations, video recording, loaner tools and components, and support staff were all provided by the JOUSTER organization.

JOUSTER is a partnership between Virginia Tech, the Institute for Advanced Learning and Research, and VIR. None of the raceway's scenic or serpentine racecourses were used to evaluate the culmination of months of effort. Instead, the group of about 30 used an open field, garage space, offices, and a meeting room to collaborate on a robot communication specification. Woody English, the event's leader, set expectations early. Success would be measured by the degree of vehicle, payload, and control interoperability the diverse groups brought to the experiment.

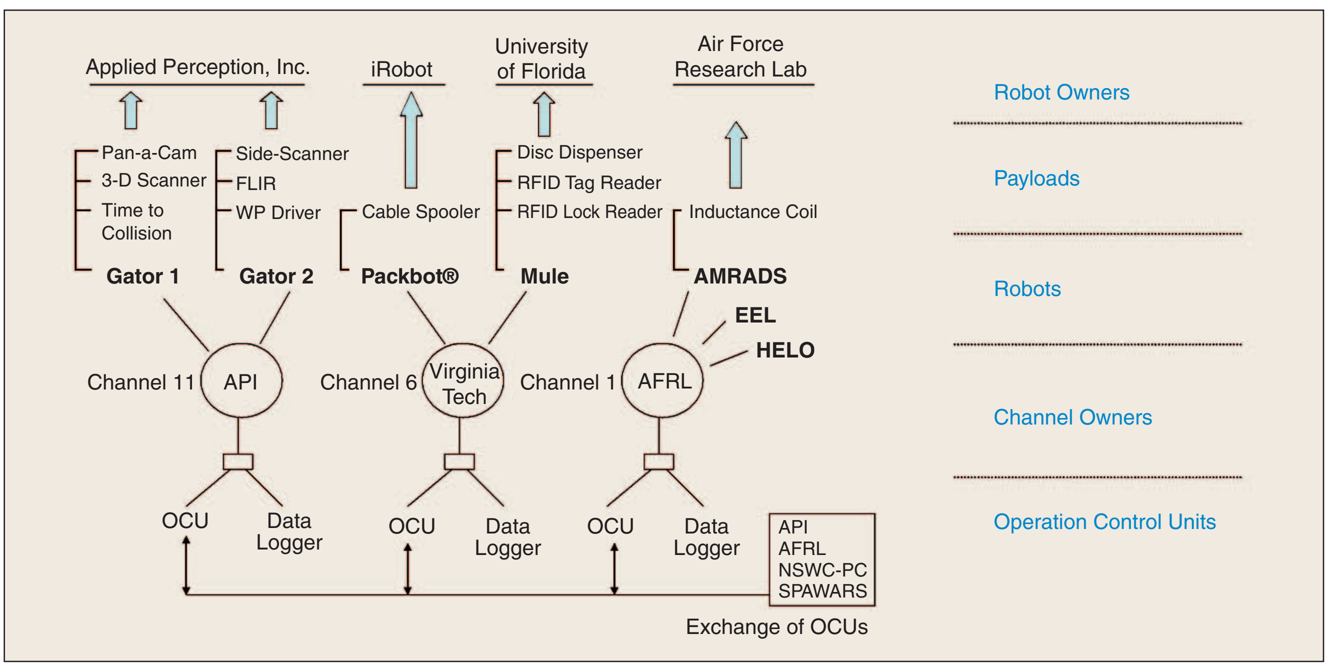

Figure 1. *Framework for payloads, robots, and OCU interoperability.*

DYNAMIC REGISTRATION

Technology independence and scalability are key themes in JAUS. Imagine directing several robots made from different contractors, where the robots have different propulsion mechanisms, sensor gear, and payloads. Add the ability to detect in real time when payloads are installed or removed from these platforms. The JAUS experiment last week in the hills of Virginia demonstrated this ability. The mechanism was dynamic payload registration. As with most robot events, the first few days dealt with infrastructure, such as channel assignments and preparing the hardware. By midweek, different team OCUs were recognizing and driving other team's robots. Some teams, like API, were well advanced in JAUS messaging.

Figure 2. *The U.S. Air Force Research Laboratory's innovative robotic system: the Advanced Mobility Research and Development System (AMRADS).*

Figure 3. *HELO, a Naval Surface Warfare Center robot.*

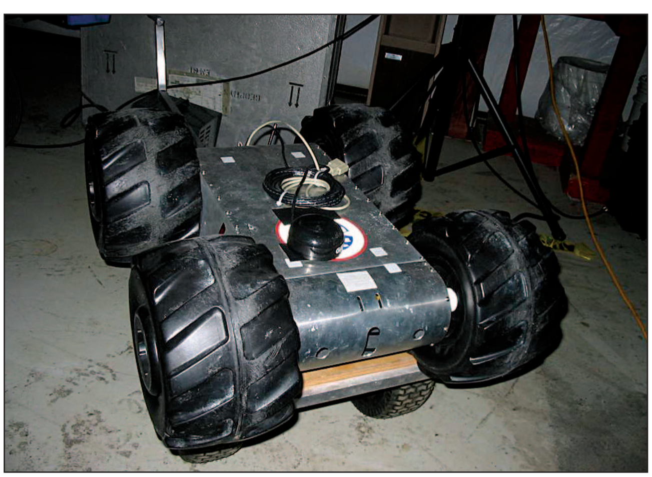

Figure 4. *EEL, a robot from the Naval Surface Warfare Center.*

INTEROPERABLE ROBOTS

The U.S. Air Force Research Laboratory at Tyndall Air Force Base developed an innovative robotic system, called the Advanced Mobility Research and Development System (AMRADS). Their robot (Figure 2) is an all-stainless-steel tracked vehicle equipped with an electromagnetic sensor, the EM 61, which locates buried objects. The diesel-powered track vehicle recently towed this inductance payload in Montana, searching for Lewis and Clark relics.

The Naval Surface Warfare Center, Panama City (NSWC-PC) brought two robots called HELO and EEL (Figures 3 and 4, respectively). These were not demonstrated outside the garage, but JAUS messages were passed to and received from these units. In addition, NSWC-PC software detected API's payloads and drove other robots.

The University of Florida's Center for Intelligent Machines and Robotics (CIMAR) brought Mule, a utility vehicle (Figure 5). Its payload was a disk-dispensing device. Space and Naval Warfare Command (SPAWAR) supplied RFID (radio frequency identification) tag and lockout readers, which were then successfully controlled by OCUs from API and NSWC-PC.

API brought two robots that use John Deere utility carts for mobility. One was gasoline and the other electric powered. The payloads, seen in Figure 6, are a three-dimensional (3-D) laser scanner, a demorphing camera (Pan-a-Cam), and time to collision (TTC), a simple but innovative use of lidar.

INTEROPERABILITY

According to Woody English, "We are moving closer to the day when the design engineer can choose a product (payload) from Vendor A, place it on Vendor B's robot, and control the subsystem and other robots with Vendor C's software. By giving the designer a choice of similar products from different companies, an open marketplace will drive better products at a lower cost."

Today's UGVs are custom entities, and directing them must be performed through the contractor's software. This means that for each subsystem deployed, a separate technology platform must be supported. This is costly in both personnel and material resources. In the realm of collaborative robotics, a standard communication framework is essential for complex subsystems to work effectively. The JAUS experiment demonstrated a key capability; dynamic registration of payloads for individual subsystems (robots) from different organizations.

Some engineers might argue that implementing a messaging interface layer adds development time and maintenance to their subsystem. Instead, Todd Jochem, president of API, found that by adopting JAUS they can leverage their work to other subsystems quickly and with low risk. API brought two vehicles, six payloads, a simulator for joint operations, a monitor, and an OCU to participate in the experiment.

Another potential penalty JAUS may carry is a latency to command the robot because of message length. None of the engineers interviewed found the JAUS messaging strings to reduce performance. According to one engineer, "They just aren't that long in the data stream to be of a concern." To demonstrate, a teammate started clapping his hands in front of the API infrared payload. The thermal image displayed at the OCU lagged slightly out of phase but seemed typical of any teleoperated camera over wireless connection.

PAYLOADS

The term *payloads* in JAUS refers to any device not intrinsic for the basic operation of the robot. "Cameras are not normally considered payloads," says English, "because every teleoperated robot requires them to navigate." API and NSWC-PC considered their cameras as payloads because they were used as supplementary sensors. For instance, API combined a color camera with LIDAR to form a side-scanner payload.

THE ABC TEST

With just one day remaining and Hurricane Charley approaching, members from API, the University of Florida, AFRL, NSWC-PC, and SPAWAR were able to demonstrate the ABC test. This involved using an OCU from Organization A to communicate with a robot from Organization B and control a payload from Organization C. In one of two demonstrations, OCUs from NSWC-PC and API communicated with the University of Florida's Mule and controlled the tag reader payload and lock reader payload from SPAWAR (Figure 7). JAUS messages were sent from the OCU's to the Mule, which forwarded them to the tag reader payload and lock reader payload. The other successful ABC demonstration integrated iRobot's wire spooler payload onto an API robot.

In JAUS terms, a robot is a subsystem and a system is a collection of robots. The economic savings of an OCU directing a family of robots is one reason the Department of Defense began JAUS development. The JAUS Web site (http://www.jauswg.org/faq.html) states:

"JAUS exists to ensure that [Department of Defense] UGVs are interoperable, can insert new capabilities easily, and remain open and scalable. Other architectures accomplish some—but not all—of these requirements."

Whether teleoperated or autonomously navigated, JAUS fits an enticing architecture by abstracting devices to generic components. Today, the systems engineer may assemble a waypoint follower component into his or her subsystem. Later, the designer can simply add a reflexive driver component for obstacle avoidance. In JAUS, these are component ID 45 and 43. Today, two companies offer JAUS-based controlling software, API and Autonomous Solutions, Inc. (ASI). The JAUS standard is open and available to all.

When vendors begin adopting a component UGV messaging standard, consumers have more choices. In JAUS, the selection of components is based on mission needs without worrying about interoperability—an economic model that raises quality and lowers pricing. The experiment in August 2004 was successful because it demonstrated technology independence and continued the effort for delivering a compliance standard.

Figure 5. *MULE from the University of Florida.*

Figure 6. *Gator 1, one of two API robots.*

Figure 7. *One of two ABC demonstrations.*

FUTURE SAE STANDARD

The Aerospace Council of the SAE recently voted to establish AS-4, an unmanned systems standard committee. JAUS will become an aerospace standard in the next 12 months. English believes his JAUS group will alternate meetings with SAE, resulting in JAUS folding into the National SAE meeting next quarter. The experiment at VIR was an important milestone in developing the meaning of compliance. To date, there is no test that guarantees JAUS compliance. The JAUS working group, however, has a specification circulating for comments. If the level of collaboration and dedication by the volunteer organizations last week is any indication, and the adoption of SAE AS-4 proceeds, the author and his colleagues are confident that "JAUS Compliant" will be the desired communication framework for the unmanned robot community.

More information about the companies and organizations mentioned here is available at the following Web sites.

- JAUS: Joint Architecture for Unmanned Systems: http://www.jauswg.org/faq.html
- API: Applied Perception, Inc.: http://www.appliedperception.com/
- ASI: Autonomous Solutions, Inc.: http://www.autonomous-solutions.com/products/mobius/index.html
- CIMAR: Center for Intelligent Machines and Robotics: http://cimar.mae.ufl.edu/CIMAR/
- SPAWAR: Space and Naval Warfare Command: http://enterprise.spawar.navy.mil/

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National Conference on Educational Robotics

The 2005 National Conference on Educational Robotics will be held 14–17 July in Jacksonville, Florida. The conference, which is sponsored by the nonprofit KISS Institute for Practical Robotics (http://www.kipr.org) features keynote speakers, breakout sessions for students and teachers, robot exhibitions, and networking opportunities. The conference will also feature the 2005 Botball Tournament (high school and middle school) and the Beyond Botball Challenge (collegiate level).

The NASA Robotics Education Project

The conference is dedicated to encouraging people to become involved in science and engineering, particularly robotics. The U.S. National Aeronautics and Space Administration (NASA) Robotics Education Project (REP) is a supporter of the conference. REP works to capture the educational potential of NASA's robotics missions by supporting educational robotics competitions and events, facilitating robotics curriculum enhancements at all educational levels, and maintaining a Web site clearinghouse of robotics education information. The Web site (http://robotics.nasa.gov/) provides information for programs that use robotics to teach mathematics and science at all levels as well as academic robotics programs at undergraduate and postgraduate levels.

REP seeks to "contribute to the future exploration of our solar system through the development of an educated robotics technology workforce." To achieve this goal, REP uses NASA's inspiring missions, unique facilities, and specialized work force in conjunction with the best emerging technologies to enhance the public's scientific and technical familiarity, competence, and literacy. REP activities also include supporting educational robotics competitions such as FIRST and BotBall. For more information, contact Joe Hering, REP coordinator by telephone at +1 650 604 2008 or by e-mail at jhering@mail.arc.nasa.gov; or contact Cassie Bowman, REP deputy coordinator by phone at +1 650 269 2787 or by e-mail at cbowman@mail.arc.nasa.gov.

World Robotics 2004

According to the 2004 edition of *World Robotics*, worldwide sales of multipurpose industrial robots surged 19% to 81,800 in 2003. This is short of the high of almost 99,000 units in 2000, but it represents a strong recovery from the 68,000 units sold in 2002.

The annual compilation of statistics on robotics manufacturing, sales, and application, jointly produced by the United Nations Economic Commission for Europe and the International Federation of Robotics, provides some fascinating insights to the rollercoaster events of the last several years in the world economy.

The tables and analyses presented are based primarily on statistics for 2003, although some data from the first half of 2004 are included. The numbers were gathered and submitted by trade organizations in Europe, North America, and Asia. In addition to the statistics, the report includes sales and production forecasts and a comparison of past predictions to actual events; an overview of emerging robotics applications in areas such as construction; and analyses of four case studies that demonstrate the profitability of introducing robots for tire production, tube bending, palletizing, and manufacturing tracks for heavy logging and mining vehicles. A detailed chapter on service robotics, coauthored by Martin Haegele, is also included.

World Robotics 2004—Statistics, Market Analysis, Forecasts, Case Studies and Profitability of Robot Investment (US$150) is available (Sales No. GV.E.04.020 or ISBN No. 92-1-101084-5) through United Nations sales agents in various countries, from the United Nations Office in Geneva, or from the International Federation of Robotics (IFR) Statistical Department. For more information contact:

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New Ph.D. Program in Biorobotics

A new Ph.D program in biorobotics science and engineering began in February 2005 at the IMT—Lucca Institute for Advanced Studies, a new graduate school founded by four Italian Universities—Politecnico di Milano Technical University, Sant'Anna School of Advanced Studies of Pisa, Luiss Guido Carli University of Rome, and University of Pisa—through the Consortium of Advanced Studies, Rome and funded by the Italian Ministry of Education, University and Research and by the Lucca Foundation for Higher Education and Research. According to the coordinator, Paolo Dario, of the University of Pisa, the biorobotics program aims at training highly competent researchers with the potential to lead biorobotics research worldwide.

Biorobotics is a new scientific and technological area with a unique interdisciplinary character. It derives its methodology mainly from the sectors of robotics and biomedical engineering, but it boasts a cultural and application scope that includes many sectors of engineering, basic and applied science (medicine, neuroscience, economics, law, and bio- and nanotechnologies in particular), and even the humanities (philosophy, sociology, psychology, and ethics).

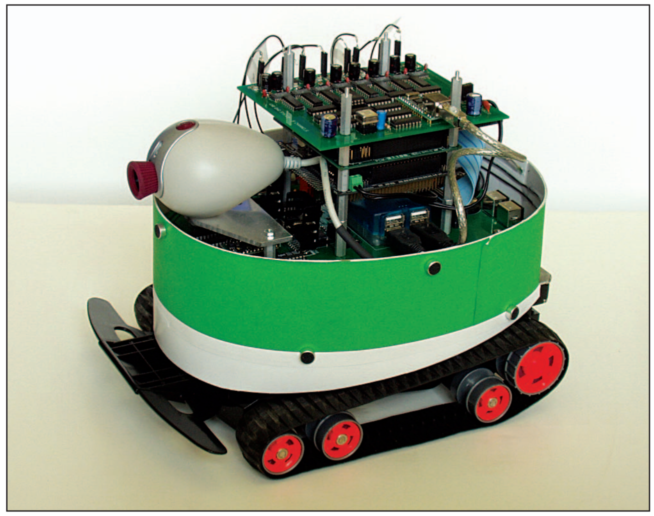
Biorobotics aims to increase knowledge on how biological systems work by analyzing them from a biomechatronic viewpoint and exploiting this knowledge in order to develop innovative methodologies and technologies—both for the design and construction of high-performance bioinspired machines and systems (at the macro, micro, and nano scales), such as animaloid and humanoid robots, and for developing devices for biomedical applications, e.g., for minimally invasive surgery and neurorehabilitation.

The program will impart to its graduates a professional profile combining substantial technical and scientific expertise in advanced areas and a system-oriented approach to design problems with a vision that retains man at the center of the development and the evaluation of technology, with the capability to conceive and design new and innovative (including industrial) research projects, and with an autonomous entrepreneurship capability.

For more information about the program, see http://www.imtlucca.it/index.php?idpagina=61 or contact Prof. Dario at dario@mail-arts.sssup.it.

Evolutionary Robotics Research Project

A research project in evolutionary robotics conducted by researchers at North Carolina State University (NC State) and the University of Utah was named one of 2004's top research advances by *TRNmag.com*, a technology news webzine. The project, which grew out of research sponsored by the Defense Advanced Research Projects Agency (DARPA), focused on evolutionary controller development based on artificial neural networks. To obtain performance metrics, controllers evolved in simulation were ported onto a team of real mobile robots (EvBots), which were designed and built specifically for this type of research. Experiments carried out in the Center for Robotics and Intelligent Machines (CRIM) at NC State demonstrated that the behavior necessary to play the game capture the flag can be evolved and tested against other forms of controllers and in worlds of increasing complexity.



Prof. Eddie Grant conceived the EvBot test bed and research at NC State. The versatility of the EvBot test bed was demonstrated when the robots were used for experiments related to distributed sensor networks. This research, which was initiated by Prof. Tom Henderson of the University of Utah, demonstrated the versatility of the EvBot test bed. This research continues and is currently being experimented in Monte Carlo sensor networks.

Collaborative research projects have also been worked on with Prof. Gordon Lee at San Diego State University (fuzzy neural controllers) and Dr. Choong Oh at the U.S. Naval Research Laboratory (evolutionary controllers). Andrew Nelson, then a Ph.D. student at NC State, developed many of the algorithms used. Eddie Grant says Andrew Nelson's contribution was "outstanding." Other students who contributed greatly to the development of the EvBot colony include Greg Barlow, Matthew Craver, John Galeotti, Kyle Luthy, Leonardo Mattos, and Stacey Rhody.

Robots and Thought

Carnegie Mellon University celebrated the 25th anniversary of its Robotics Institute with a four-day "robotics extravaganza," 11–14 October 2004. The public, interactive event was a symposium of world-renowned robotics experts discussing the "grand challenges" in the field and was a rare opportunity to hear the institute's founders, Raj Reddy, Tom Murrin, and Angel Jordan, discuss the evolution of the institute and robotics over the last 25 years. It also included the induction of new members, both real and fictional, into CMU's "Robot Hall of Fame." Visit http://www.ri.cmu.edu/events/25th/about.html for more information.