

Center of Excellence for Small Robots

Daniel M. Carroll*, Hoa G. Nguyen, Robin T. Laird, H. R. Everett
SPAWAR Systems Center, San Diego, 53560 Hull St., San Diego, CA 92152

ABSTRACT

The mission of the Unmanned Systems Branch of SPAWAR Systems Center, San Diego (SSC San Diego) is to provide network-integrated robotic solutions for Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) applications, serving and partnering with industry, academia, and other government agencies. We believe the most important criterion for a successful acquisition program is producing a value-added end product that the warfighter needs, uses and appreciates. Through our accomplishments in the laboratory and field, SSC San Diego was designated the Center of Excellence for Small Robots by the Office of the Secretary of Defense (OSD) Joint Robotics Program in 2002.¹

This paper covers the background, experience, and collaboration efforts by SSC San Diego to serve as the “Impedance-Matching Transformer” between the robotic user and technical communities. Active projects, past efforts, and architectures are provided as success stories for our Unmanned Systems Development Approach. Special attention is given to our Unmanned Systems Technology Imperatives for Research, Development, Testing and Evaluation (RDT&E) of Small Robots.

Keywords: robotics, C4ISR, unmanned systems

1. INTRODUCTION

The Assigned Mission for SPAWAR Systems Center, San Diego (SSC San Diego) is “to be the Navy’s full-spectrum research, development, test and evaluation, engineering and fleet support center for command, control and communication systems and ocean surveillance and the integration of those systems which overarch multiplatforms. SSC San Diego’s expertise is Command, Control, Communications, Computer, Intelligence, Surveillance and Reconnaissance (C4ISR)”. The SSC San Diego Corporate Vision is “to be the pre-eminent provider of integrated C4ISR solutions for warrior information dominance.”² SSC San Diego and its predecessor organizations (NRaD, NOSC, NUC, etc.) have been involved in various aspects of robotics since the early 1960’s. In accordance with the Center’s Mission and Vision, the mission statement of SSC San Diego Unmanned Systems Branch, Code 2371, is:

We are the robotics laboratory for the Space and Naval Warfare Systems Command, providing *network-integrated robotic solutions for C4ISR applications*, serving and partnering with industry, academia, and other government agencies.

Our vision is:

To provide *innovative networked robotic applications and distributed sensing solutions* that advance our customer’s mission through research, development, and integration, in an environment that encourages leadership, technical advancement, teamwork, and personal growth.

We envision our role in robotics as an “Impedance-Matching Transformer” between the robotics users and the technical communities to connect the “Requirements Pull” with the “Technology Push” (see Fig. 1). We believe the most important criterion for a successful acquisition program is producing a value-added end product that the warfighter needs, uses and appreciates. Our Unmanned Systems Development Approach is based upon iterative spirals with the following tenets:

- Close loop with users throughout the design and development process.

*daniel.carroll@navy.mil;tel: 813-281-0560 x171;FAX: 813-281-0560 x181;URL: <http://www.spawar.navy.mil/robots/>

Report Documentation Page			Form Approved OMB No. 0704-0188		
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 2005		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Center of Excellence for Small Robots				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) SPAWAR Systems Center 53560 Hull Street San Diego, CA 92152				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 10	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

- Implement phased rapid-prototyping approach.
- Provide users extensive hands-on evaluation of prototypes.
- Leverage existing experience, systems, technology.
- Keep designs modular and upgradable with new technology.

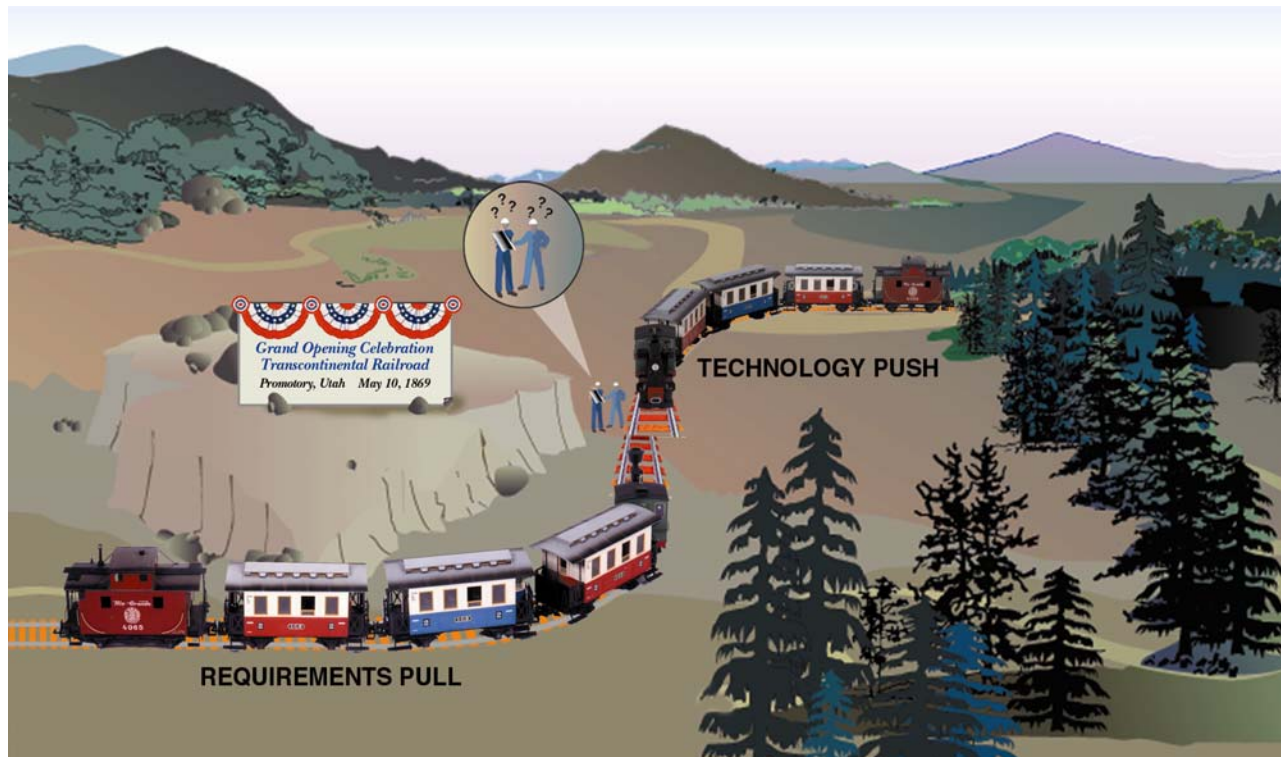


Figure 1. Serving as the “Impedance-Matching Transformer” Between the Robotic User and Technical Communities

One of the keys to our successes has been to collaborate and to team with other research labs, government agencies, industry, and universities. An abbreviated list of our partners on current projects includes:

Organization	Project/Focus
Joint Robotics Program	Joint Architecture for Unmanned Systems (JAUS)
Army Dismounted Battlespace Battle Lab	Army user test and evaluation
Jet Propulsion Laboratory	Robotics technology transfer
Idaho National Laboratory	Collision avoidance/target tracking
BBN Technologies	Ad hoc self-healing networks
Southwest Research Institute	Robotics test and evaluation
Stanford Research Institute	Mapping and localization
University of Southern California	Robotics simulation and device drivers
University of California, San Diego	Advanced machine vision
Naval Undersea Warfare Center	SPARTAN Advanced Concept Technology Demonstration (ACTD)
Naval Surface Warfare Center	Joint Unmanned Systems Common Control (JUSC2) ACTD
Army Maneuver Support Center	Countermine
Air Force Research Laboratory	Remote Detection Challenge and Response (REDCAR)
Carnegie Mellon University	Beacon-based landmark referencing
Naval Postgraduate School	Surveillance and Target Acquisition Network (STAN) experiments
Joint Robotics Program	National Unmanned Systems Experimentation Environment (NUSE2)
University of Texas Austin	Human Presence Detection and Assessment (HPDA)

2. ROBOTICS RDT&E EFFORTS

SSC San Diego Unmanned Systems Branch is currently the technical lead on over 15 active projects for Research, Development, Testing and Evaluation (RDT&E) for C4ISR of unmanned ground vehicles (UGVs), unmanned aerial vehicles (UAVs), unmanned surface vehicles (USVs), unattended ground sensors (UGS), and unattended munitions.³ In addition the SSC San Diego Ocean Systems Division performs RDT&E for unmanned undersea vehicles (UUVs). We summarize below some of our current efforts, grouped into focus areas of research, development, testing, and evaluation.

2.1 Unmanned Systems Research

Fig. 2 shows a number of SSC San Diego Unmanned Systems research projects. The Segway Robotic Mobility Platform (RMP) is a mobile platform based on a Segway Human Transporter. It is faster, cheaper, more rugged, and can carry a greater payload than existing comparable robotic platforms. The platform geometry presents researchers with an opportunity to examine novel topics, including people-height sensing and actuation modalities. A simple high-level software API and CAN Bus interface allows researchers to simply mount their laptop on the RMP and test software under development without the necessity of cross compilation and downloading. SSC San Diego oversaw the conversion of the Segway platforms by Segway LLC, managed a pool of RMPs for loan to various universities and research institutions, provided an interactive web site for exchange of research information and feedback, as well as conducting our own explorations of their possible military applications.^{4,5}

The Unmanned Surface Vehicle (USV) project investigates autonomous mobility and payloads on USVs. It also supports development of USV Command and Control (C2) software for the SPARTAN Advanced Concept Technology Demonstration (ACTD) and the Joint Unmanned Systems Common Control (JUSC2) ACTD. Teleoperation and waypoint navigation behaviors have been demonstrated in San Diego Bay, with radar-based obstacle avoidance scheduled for the later part of 2005.

Unmanned Ground Vehicles



Segway RMP

Delivered 15 units to 9 universities and 4 research organizations

Unmanned Surface Vehicles



USV

Developing USV C2 for SPARTAN ACTD

Unmanned Aerial Vehicles



AUMS

UGV/UAV Teaming for Army FCS

Unattended Sensors



DIVA

Producing 80 prototypes for collaboration with academia

Unattended Munitions



NROWS

Designing lethal response based on non-lethal prototype

*Sponsors:
DARPA
NUWC
OSD
ONR
DTRA*

Figure 2. SSC San Diego Unmanned Systems Research

The Autonomous UAV Mission System (AUMS) project is working to develop technologies for automated launching, landing, refueling, and relaunching of small Vertical Take-Off and Landing (VTOL) UAVs. The objectives are to increase the effective payload-range of VTOL UAVs via automated replenishment and provide support for cooperative tasking of UAVs and UGVs.^{6,7}

Distributed Interactive Video Array (DIVA) is a network of wireless, portable vision sensors for: 1) the detection, tracking, and classification of moving targets in a variety of tactical environments, and 2) the autonomous coordination of a UGV response to detected events. Each self-contained node includes an omni-directional camera and a pan-tilt-zoom camera controlled by object detection, recognition, and tracking software.⁸

Networked Remotely Operated Weapon System (NROWS) provides real-time networked weapon pods that extend delay/denial response capabilities at high-value installations or in tactical scenario.⁹ They can be placed in fixed installations or deployed by unmanned vehicles, with automatic target detection and tracking provided by DIVA nodes.

2.2 Unmanned Systems Development

The Joint Robotics Program (JRP) Technology Transfer (Tech Xfer) project, managed by SSC San Diego (Fig. 3), is a centralized mechanism of the JRP for harvesting the best features of prior/ongoing research efforts at various university and industry research laboratories into an optimized, standardized system that can be easily ported to robotic platforms used service-wide. To facilitate integration and ensure the success of ultimate transfer to ongoing programs, the intent is to adapt and standardize a reconfigurable software framework that can be easily ported from one robotic system to another.¹⁰ Research results are compared, down-selected, or integrated on robotic test beds (SSC San Diego's ROBERT III, iRobot ATRV, or Segway RMP) in preparation for ultimate transfer to ongoing programs.

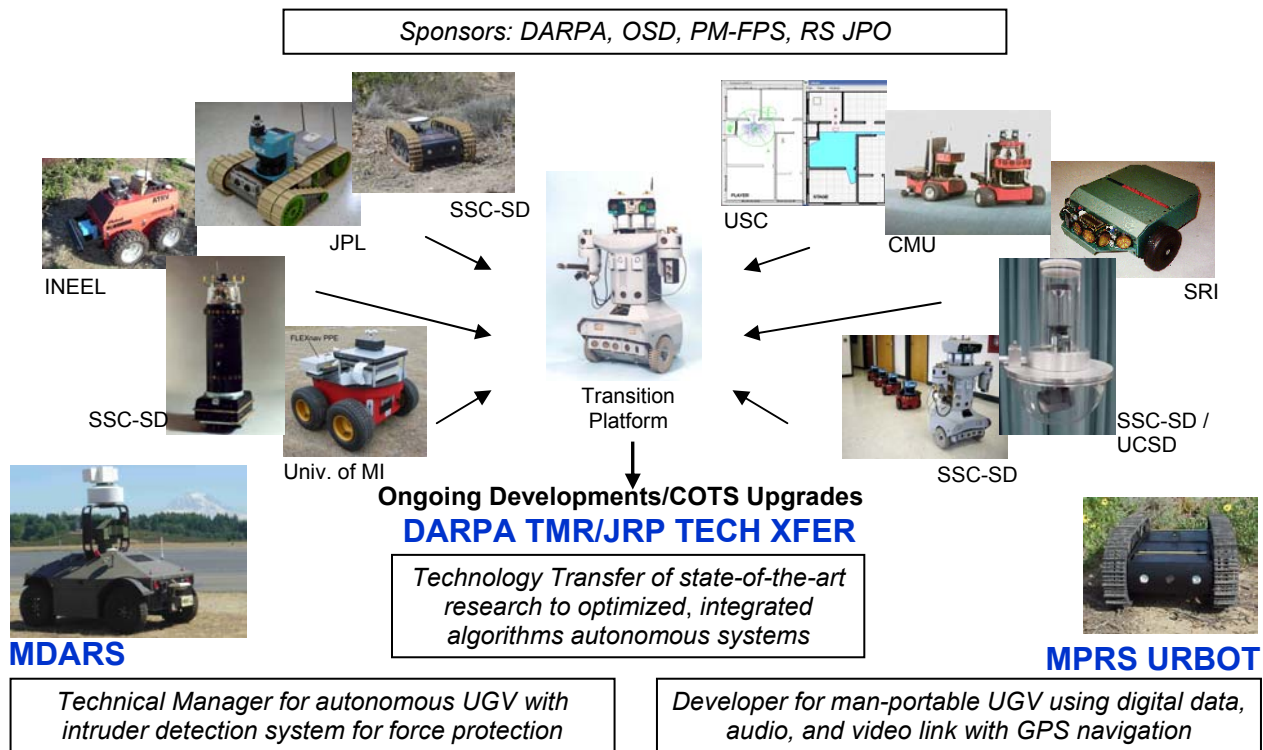


Figure 3. SSC San Diego Unmanned Systems Development

Target robotic programs for Technology Transfer include the SSC San Diego's Mobile Detection Assessment Response System (MDARS)^{11,12} and Man Portable Robotic System (MPRS)¹³ projects. MDARS provides an automated intrusion detection and inventory assessment capability for Department of Defense warehouses and storage sites using multiple

coordinated patrol unit vehicles. MPRS develops technologies for lightweight mobile robots for operation in urban environments.

2.3 Unmanned Systems Testing

The MDARS Early User Appraisal (EUA) and the Naval Postgraduate School (NPS) Surveillance and Target Acquisition Network (STAN) experiment, now called Tactical Network Topology (TNT), are representative of testing efforts by SSC San Diego's Unmanned Systems Branch (Fig. 4). MDARS is currently undergoing a 12-month Early User Appraisal (EUA) at the Hawthorne Army Depot (HWAD), Nevada. HWAD is a 147,000 acres facility located in west central Nevada. For the MDARS developmental and operational testing, four MDARS UGVs will patrol during evenings and weekends providing security for 270 storage igloos grouped in 15 bunker sites on a section of HWAD. The entire depot has over 2000 storage igloos along 72 miles of base roads.

For the NPS STAN experiment, SSC San Diego integrated and tested the UGV component to network unmanned vehicles and remote sensors to increase effectiveness of special operations teams to detect, localize, and identify missile launchers and personnel.

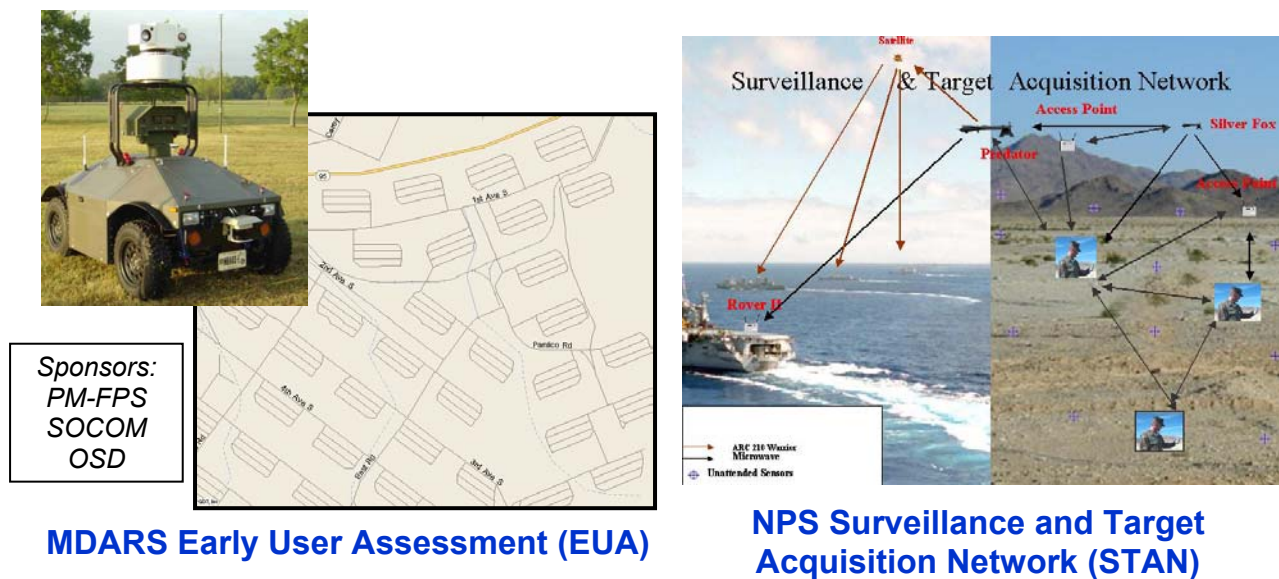


Figure 4. SSC San Diego Unmanned Systems Testing

2.4 Unmanned Systems Evaluation

As noted above, the driving force for our Unmanned Systems Development Approach is Evaluation (Fig. 5). Representative projects in this focus area include the JRP Robotic Systems Pool (RSP), the Mobile Robot Knowledge Base (MRKB) and the Unmanned Systems Reserve Unit (USRU) - also known as the Robotic Systems Combat Support Platoon (RSCSP).

RSP provides commercial-off-the-shelf (COTS) robotic systems to users for evaluations (with priority given to military units, followed by local law-enforcement agencies). Feedbacks are collected to ensure appropriate modifications are included in next generation systems. Also with RSP assets, SSC San Diego provided onsite operations and engineering support to the World Trade Center recovery efforts. User interest in RSP mission and capabilities initiated procurement by the JRP of an additional 200+ Explosive Ordnance Disposal (EOD) robots to support theater operations.

MRKB provides an online resource for information on robot components, subsystems, mission payloads, platforms, and Department of Defense (DoD) robotics programs. It also provides an interface for the JRP Robotic Systems Pool for users and support teams to request systems and provide operational insight. In addition, it provides a forum for technology and information transfer within the DoD robotics community.



Figure 5. SSC San Diego Unmanned Systems Evaluation

The Unmanned Systems Reserve Unit (USRU) is staffed by highly skilled Navy Reservists, who typically work as engineers and/or electronic technicians in their civilian lives. The Reservists serve two primary roles: to provide robot operator training for deploying EOD teams, and to provide in-theater maintenance and repair for deployed robotic systems.

One of the success stories of our Unmanned Systems Development Approach – spiral technology development driven by user feedback – is the operational deployment of the Chemical and Radiological Sensors (CHARS) payload. Demonstrations in early 2003 to the Combined Joint Task Force – Consequence Management in Kuwait included a MATILDA platform equipped with CHARS, initially developed by SSC San Diego on the MPRS URBOT for the US Army Chemical School at Ft. Leonard Wood, MO. Subsequent to these demonstrations, the Army’s XVIII Airborne Corps at Fort Bragg, NC, requested robotically deployed chemical and radiological sensors to search for potentially hazardous agents in Iraq. SSC San Diego and iRobot adapted the modular CHARS payloads to the PackBot. The initial set of 4 CHARS payloads for the iRobot PackBot were deployed in November 2003.

3. UNMANNED SYSTEMS TECHNOLOGY IMPERATIVES

In conjunction with the above focus areas, SSC San Diego Unmanned Systems Branch also operates under four technology imperatives: (1) Command and Control, (2) Communications, (3) C4I Interoperability, and (4) Multi-Dimensional ISR.

3.1 Unmanned Systems Command and Control (C2)

SSC San Diego has developed a scalable family of systems for Unmanned Systems C2 (Fig. 6).

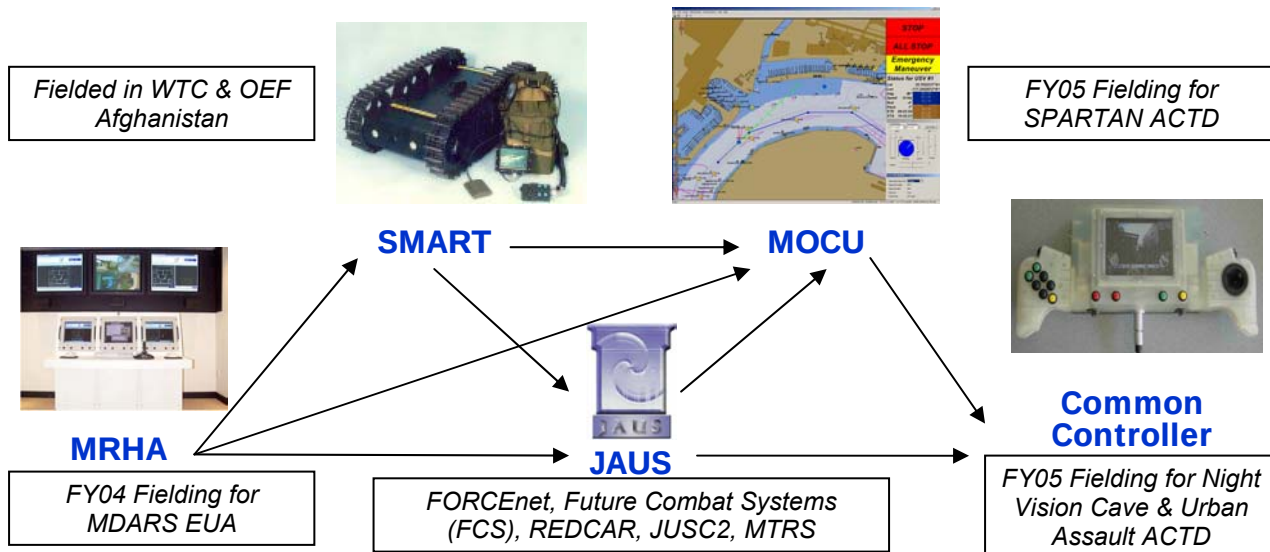


Figure 6. SSC San Diego Unmanned Systems Command and Control (C2)

The Multiple Resource Host Architecture (MRHA) is a distributed multiprocessing system to provide coordinated control of up to 255 unmanned systems from a single host console. MRHA Interface Design Document (IDD) defines C2 messages built on top of the UDP/IP protocol. Small Robot Technology (SMART) is a robot communication protocol for C2 messaging that extends the MRHA IDD with self-registering capability, and allows multiple robots and sensors to communicate peer-to-peer over a wireless network. The Multi-robot Operator Control Unit (MOCU) was designed to control multiple resources using a single laptop computer. A key feature of MOCU is a flexible drag-and-drop interface using high-resolution, ortho-rectified digital maps is the ability to create and download waypoint navigation paths for unmanned vehicles. The Common Controller is a wearable operator control unit (OCU) that uses interchangeable control pendants to operate a variety of robotic platforms. The SSC San Diego C2 technologies support the development and implementation of the Joint Architecture for Unmanned Systems (JAUS). JAUS is a standards-based message set and protocols for internal and external unmanned systems communications.

3.2 Unmanned Systems Communications

SSC San Diego is involved with all levels of communication RDT&E for manned and unmanned systems (Fig. 7).

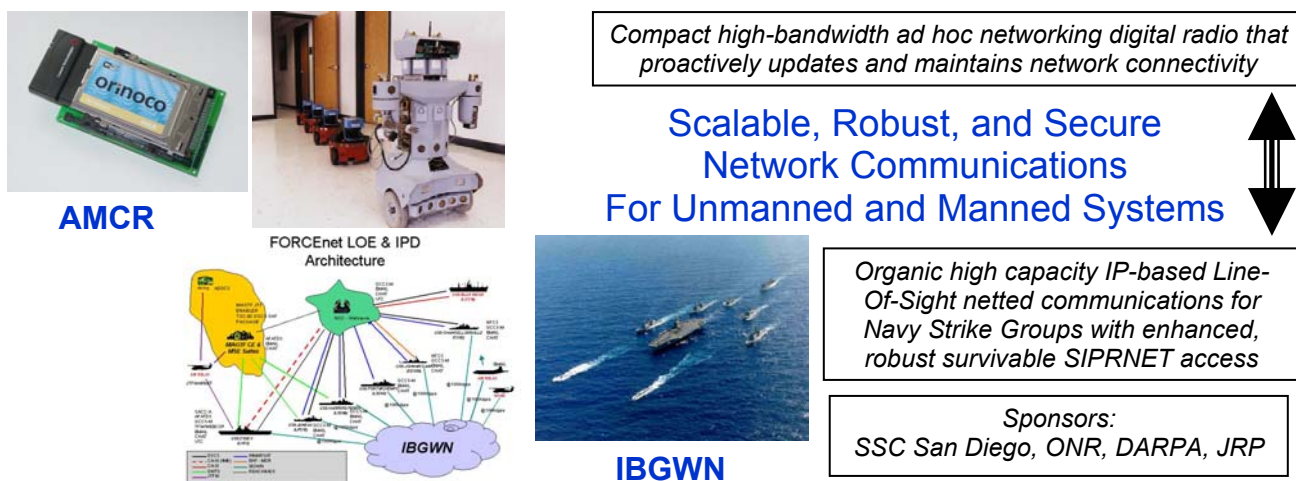


Figure 7. SSC San Diego Unmanned Systems Communications

The Autonomous Mobile Communication Relays (AMCR) project^{14,15} demonstrates intelligent use of autonomous mobile radio frequency (RF) repeaters to maintain a solid radio communication link between a robot entering a building and an external base station. The robot automatically deploys mobile repeaters (which are slave robots with RF relays conveying behind it) at strategic locations as it penetrates the building interior. A follow-on project, geared towards fielded systems, is providing relay “bricks” that are automatically dropped by tactical and EOD robots.¹⁵ The Intra Battle Group Wireless Network (IBGWN) is an effort to connect ships in a battle group using high-bandwidth IP-based line-of-sight ad hoc networks.

3.3 Unmanned Systems C4I Interoperability

SSC San Diego is a leader in Command, Control, Communications, Computer, and Intelligence (C4I) Interoperability with our contributions to the JAUS Working Group and JAUS standards development process. In December 2003, the JAUS OCU and Payload Committee planned a sequence of experiments to demonstrate and expand the level of interoperability between OCUs and unmanned vehicles (Fig. 8). SSC San Diego hosted and participated in the first JAUS OCU and Payloads Committee experiment where nine organizations implemented a JAUS message set for teleoperation on their OCUs and unmanned vehicles; each OCU was then able to control any of the unmanned vehicles. In 2004, SSC San Diego and the JAUS Working Group expanded the experimentation domain to assess JAUS message sets required for payloads and missions.

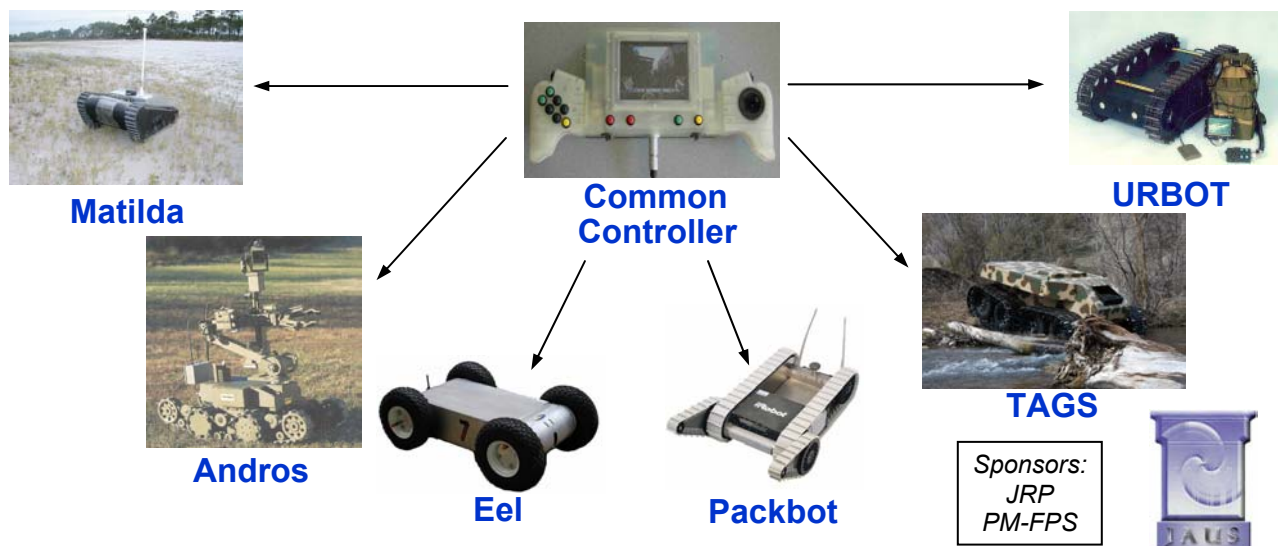


Figure 8. SSC San Diego Unmanned Systems C4I Interoperability

3.4 Unmanned Systems Multi-Dimensional ISR

A scenario for Multi-Dimensional Intelligence, Surveillance, and Reconnaissance (ISR) is Integrated Force Protection (Fig. 9).

Autonomous UGVs, UAVs, and USVs are directed as Force Projection units. Unmanned Vehicle (UxV) payloads and UGS provide situational awareness while unattended munitions provide a response capability. Remote resources serve as automated interfaces to legacy physical devices such as manned response vehicles, barrier gates, fence openers, garage doors, and remote power on/off capability for unmanned systems. Our Robotic Operations Command Center simultaneously controls multiple heterogeneous unmanned systems with graphical displays for video, map, and status of each resource using wireless digital communications for integrated data, video, and audio. Events are prioritized and the user is prompted with audio alerts and text instructions for alarms and warnings.

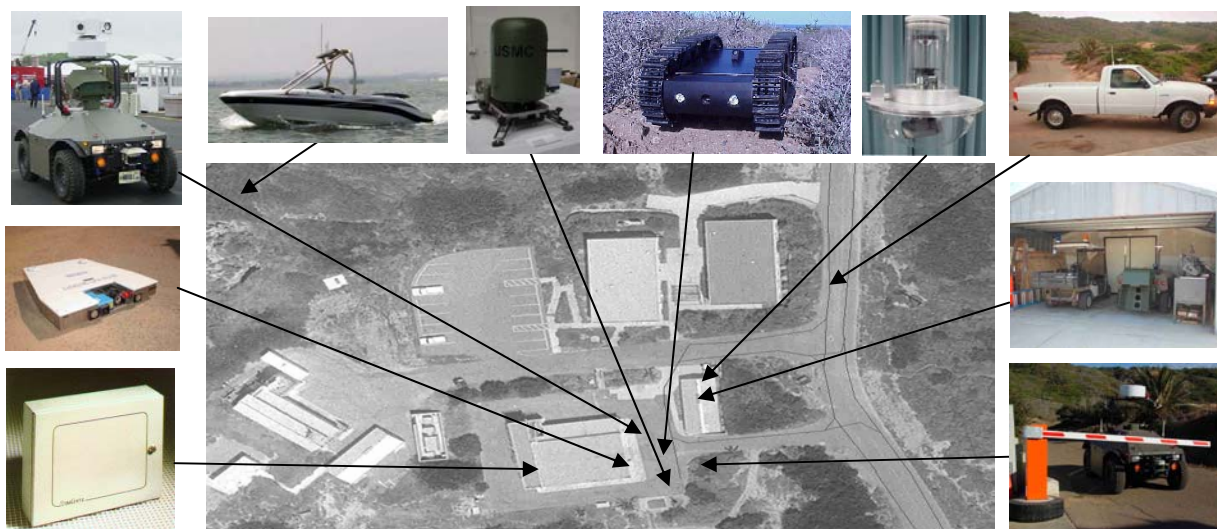


Figure 9. SSC San Diego Unmanned Systems Multi-Dimensional ISR

4. SUMMARY

SSC San Diego and its predecessor organizations (NRaD, NOSC, NUC, etc.) have been involved in various aspects of robotics since the early 1960's. Our vision is: "To provide *innovative networked robotic applications and distributed sensing solutions* that advance our customer's mission through research, development, and integration, in an environment that encourages leadership, technical advancement, teamwork, and personal growth." Through our accomplishments in the laboratory and field, SSC San Diego has been designated the Center of Excellence for Small Robots by the Office of the Secretary of Defense Joint Robotics Program.

We envision our role in robotics as an "Impedance-Matching Transformer" between the robotics users and the technical communities to connect the "Requirements Pull" with the "Technology Push". We believe the most important criterion for a successful acquisition program is producing a value-added end product that the warfighter needs, uses and appreciates. Our Unmanned Systems Technology Imperatives are Command and Control (C2), Communications, C4I Interoperability, and Multi-Dimensional ISR.

REFERENCES

1. OUSD (AT&L) Defense Systems/Land Warfare and Munitions, Joint Robotics Program Master Plan, FY02.
2. "SSC San Diego Strategic Plan," SSC San Diego Technical Document 3000, Revision 3, November 2001.
3. "ROBOTICS at the Space and Naval Warfare Systems Center, San Diego," <<http://www.spawar.navy.mil/robots/>>.
4. Nguyen, H.G., Morrell, J., Mullens, K., Burmeister, A., Miles, S., Farrington, N., Thomas, K., and D. Gage, "Segway Robotic Mobility Platform," SPIE Proc. 5609: Mobile Robots XVII, Philadelphia, PA, October 26-28, 2004.
5. Nguyen, H.G., Kogut, G., Barua, R., Burmeister, A., Pezeshkian, N., Powell, D., Farrington, N., Wimmer, M., Cicchetto, B., Heng, C., and V. Ramirez, "A Segway RMP-based robotic transport system," SPIE Proc. 5609: Mobile Robots XVII, Philadelphia, PA, October 26-28, 2004.
6. Mullens, K.D., Pacis, E.B., Stancliff, S.B., Burmeister, A.B., Denewiler, T.A., Bruch, M.H., and H.R. Everett, "An Automated UAV Mission System," AUVSI Unmanned Systems in International Security 2003 (USIS 03), London, England, September 9-12, 2003.
7. Mullens, K., Burmeister, A., Wills, M., Stroumtsos, N., Denewiler, T., Thomas, K., and S. Stancliff, "Automated Launch, Recovery, and Refueling for Small Unmanned Aerial Vehicles," SPIE Proc. 5609: Mobile Robots XVII, Philadelphia, PA, October 26-28, 2004.

8. Kogut, G., Blackburn, M., and H.R. Everett, "Using Video Sensor Networks to Command and Control Unmanned Ground Vehicles," AUVSI Unmanned Systems in International Security 2003 (USIS 03), London, England, September 9-12, 2003.
9. Kogut, G., "A Vision System for an Unmanned Gun Pod," SPIE Proc. 5608: Intelligent Robots and Computer Vision XXII, Philadelphia, PA, October 25-27, 2004.
10. Pacis, E.B., Everett, H.R. Farrington, N., and D. Bruemmer, "Enhancing Functionality and Autonomy in Man-Portable Robots," SPIE Proc. 5422: Unmanned Ground Vehicle Technology VI, Orlando, FL, April 13-15, 2004.
11. Carroll, D., Gilbreath, G., Grant, K., and L. Day, "Command and Control for Mixed Manned and Unmanned Security Forces," AUVSI Unmanned Systems in International Security 2003 (USIS 03), London, England, September 9-12, 2003.
12. Carroll, D., Jaffee, D., and K. Mullens, "Automating Barrier Assessment with Mobile Security Robots," AUVSI Unmanned Systems in International Security 2003 (USIS 03), London, England, September 9-12, 2003.
13. Bruch, M.H., Laird, R.T., and H.R. Everett, "Challenges for deploying man-portable robots into hostile environments," *SPIE Proc. 4195: Mobile Robots XV*, Boston, MA, November 5-8, 2000. Nguyen, H.G., Pezeshkian, N., Raymond, M., Gupta, A., and J.M. Spector, "Autonomous Communication Relays for Tactical Robots," IEEE 11th Int. Conf. on Advanced Robotics (ICAR 2003), Coimbra, Portugal, June 30-July 3, 2003.
14. Nguyen, H.G., Pezeshkian, N., Gupta, A., and N. Farrington, "Maintaining Communication Link for a Robot Operating in a Hazardous Environment," ANS 10th Int. Conf. on Robotics and Remote Systems for Hazardous Environments, Gainesville, FL, March 28 - 31, 2004.
15. Nguyen, H.G., Farrington, N., and N. Pezeshkian, "Maintaining Communication Link for Tactical Ground Robots," AUVSI Unmanned Systems North America 2004, Anaheim, CA, August 3-5, 2004. Networks to Command and Control Unmanned Ground Vehicles," AUVSI Unmanned Systems in International Security 2003 (USIS 03), London, England, September 9-12, 2003.