Supporting the joint warfighter by development, training, and fielding of man-portable UGVs

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ABSTRACT

The Robotic Systems Pool (RSP), sponsored by the Joint Robotics Program (JRP), is an inventory of small robotic systems, payloads, and components intended to expedite the development and integration of technology into effective, supportable, fielded robotic assets. The RSP loans systems to multiple users including the military, first-responders, research organizations, and academia. These users provide feedback in their specific domain, accelerating research and development improvements of robotic systems, which in turn allow the joint warfighter to benefit from such changes more quickly than from traditional acquisition cycles.

Over the past year, RSP assets have been used extensively for pre-deployment operator and field training of joint Explosive Ordnance Disposal (EOD) teams, and for the training of Navy Reservist repair technicians. These Reservists are part of the Robotic Systems Combat Support Platoon (RSCSP), attached to Space and Naval Warfare Systems Center, San Diego. The RSCSP maintains and repairs RSP assets and provides deployable technical support for users of robotic systems. Currently, a small team from the RSCSP is deployed at Camp Victory repairing and maintaining man-portable unmanned ground vehicles (UGVs) used by joint EOD teams in Operation Iraqi Freedom.

The focus of this paper is to elaborate on the RSP and RSCSP and their role as invaluable resources for spiral development in the robotics community by gaining first-hand technical feedback from the warfighter and other users.

Keywords: robotics, unmanned ground vehicle, UGV, Explosive Ordnance Disposal, EOD, Improvised Explosive Device, IED, Operation Iraqi Freedom

1. INTRODUCTION

The Unmanned Systems Branch of Space and Naval Warfare Systems Center, San Diego (SSC San Diego) partners with industry, academia, and other government agencies to provide network-integrated robotic solutions for Department of Defense (DoD) related C4ISR applications. One of the projects managed by SSC San Diego for DoD (specifically the Joint Robotics Program) is the Robotic Systems Pool (RSP), a collection of small mobile robots, currently unmanned ground vehicles. For well over a year now the availability of robots in this pool has allowed SSC San Diego to play a more active role in the Global War on Terrorism, particularly in the area of Explosive Ordnance Disposal (EOD) robots. Support was provided in the procurement of EOD platforms, subsequent acceptance testing, training for deploying EOD technicians, and repair and maintenance field support to joint EOD teams in theater, as well as stateside training units. Because of this active involvement, SSC San Diego has been able to acquire first-hand knowledge of recurring maintenance issues for the various EOD platforms, and make recommendations to the respective robot vendors in collaboration with Naval EOD Technology Division (NAVEODTECHDIV) and the Joint EOD (JEOD) community.

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2. ROBOTIC SYSTEMS POOL

2.1 History of the Pool

The RSP was established in 2002 by the Joint Robotics Program (JRP), mainly to benefit DoD research and development (R&D) organizations in accelerating the spiral development process of small mobile robots. This philosophy ensures that joint forces are equipped in a timely fashion with the latest robotics technology to adequately meet their mission requirements and that defense funds are not wasted on procurement and subsequent operations and maintenance support of robotic assets by multiple organizations for relatively short uses. From conception, the focus of the RSP was understood to be dynamically situational, requiring proper balance between R&D and operations at any given point in time.[1] The RSP was initially populated with assets transferred from the Defense Advanced Research Projects Agency (DARPA) Tactical Mobile Robots (TMR) program, and additional assets purchased by the Office of the Secretary of Defense. SSC San Diego was designated as the lead for the execution and management of the project.

2.2 Management of the Pool

As designated manager, SSC San Diego has the responsibility to receive loan requests from potential users, to prioritize and submit recommendations quarterly for asset allocation, and to ensure the assets are properly maintained for optimal operational readiness.

Loan requests for robotic platforms in the RSP are made by filling out a concept proposal questionnaire on the RSP website, http://robot.spawar.navy.mil/. The questionnaire requests information on the intended use of the robot, objectives to be met including major project milestones, and the schedule of the experiment or evaluation. These loan requests are then presented to the JRP Management Board for approval. The Board consists of senior leadership from DoD organizations with an interest in robotics and so designated by the Deputy Director, Defense Systems, Land Warfare and Munitions. At the completion of each loan period, which is generally no more than six months, the receiving organizations are required to submit an evaluation report. This report, which can also be filled out on the RSP website, encourages users to detail the results of their experiments, recommend changes or modifications to improve the system for future users, and report any problems experienced.

3. SKISKY FIELDING EFFORT

With the escalated use of Improvised Explosive Devices (IEDs), commonly referred to as roadside bombs, by insurgents in Afghanistan and Iraq during the second half of 2003, United States Central Command (CENTCOM) identified an in-theater need for small robots to combat these devices (Figure 1). The JRP responded to this request and with other organizations collectively resolved to provide joint EOD teams with bomb disposal robots that were smaller, lighter, and more transportable than the previously fielded and commonly used MK 3 MOD 0 Remote Ordnance Neutralization System (RONS) platform, which requires a truck and trailer for transportation and deployment. With more portable robots, the EOD teams could more quickly deploy and have robots at the ready by just tossing them into the cargo bay of a HMMWV.

Figure 1. iRobot PackBot EOD destroyed by roadside bomb during SKISKY fielding effort

The resulting decision was to quickly procure and field over 160 commercial-off-the-shelf (COTS) systems in a fashion much more rapidly than traditional government acquisition cycles. The Robotic Systems Joint Project Office (RS JPO) was designated as the lead fielding agent, with Joint Service EOD maintaining technical authority. The responsibility for actual procurement of systems was spread among multiple organizations, to include SSC San Diego, RS JPO, and the Technical Support Working Group (TSWG). NAVEODTECHDIV served as the lead technical agency for the integration of EOD tools onto the COTS systems as well as qualifying the respective platform/tool combinations for contingency use. Five distinct COTS robotic platforms of similar capabilities were chosen from available vendors: EOD Performance's Vanguard, Foster Miller's Talon, iRobot's PackBot EOD, Mesa Associates' MATILDA, and Remotec's Mini Andros. This fielding effort was named SKISKY, in remembrance of the first two EOD technicians who were killed in action in support of Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF). (The word SKISKY is made from the combination of the last three letters in each of their last names.)

With the purchase of COTS robotic platforms for the SKISKY fielding in Iraq and Afghanistan, the focus of the RSP shifted somewhat to support this immediate need. While still offering loaned systems to users per the original charter, additional needs were identified, such as EOD technician training, mostly caused by a lack of man-portable robots stateside for pre-deployment training, and limited infrastructure for repair and maintenance support of the purchased systems. Navy Reservists affiliated with SSC San Diego were called upon to assist in providing the requisite support in both of these areas.

3.1 Acceptance Testing of Systems

SSC San Diego's acquisition role for the SKISKY fielding effort was to purchase nineteen PackBot EOD systems and ten MATILDA systems. SSC San Diego conducted acceptance testing of eight iRobot PackBot EOD systems in March 2004 and eleven more in early June 2004. Acceptance testing of the ten MATILDA systems was conducted in May of 2004. Seven of the PackBot systems were delivered to Iraq in support of OIF, ten were delivered to Afghanistan in support of OEF, and two remained stateside to be added to the RSP. All ten MATILDA systems were delivered directly to Iraq for OIF.

3.2 Robotic Systems Combat Support Platoon

In 2001, Congress enacted a bill drafted by the Senate Armed Services Committee, such that by the year 2010, 33 percent of ground vehicles and 33 percent of deep strike aircraft would be unmanned.[2] To provide support for this expected proliferation of robotic vehicles, the Reserve Robotics Program was organized by a loosely knit group of Reservists consisting of members from several of the twenty-one Space and Naval Warfare Systems Command (SPAWAR) Reserve units nationwide.

The Robotic Systems Combat Support Platoon (RSCSP) was established to support the training and in-theater repair and maintenance of assets purchased for the SKISKY fielding effort. This unique group of individuals not only retains the appropriate technical knowledge required to support the warfighter, but is also deployable, having necessary weapons training and issued combat gear and equipment. The team was originally established to provide maintenance and repair support to the SKISKY robots used by EOD technicians in the 1st Marine Expeditionary Force (IMEF) in Iraq. However, the RS JPO had assumed responsibility for the in-theater maintenance and repair of the SKISKY robotic platforms, and to prevent pockets of maintenance and repair specialists, SSC San Diego's team provided stateside support until the decision was made to deploy two members of the RSCSP to Camp Victory, Baghdad.

RSCSP members are individually selected from a pool of applicants based upon their technical qualifications, including their Navy experience and civilian skill sets, optimistic attitude, and willingness to learn. Many of the Reservists' civilian jobs relate directly to the field of robotics, such as mechanical and electronics design and repair, software design, testing and troubleshooting, wireless technology, and controls experience. To date, all Reservists who are members of the RSCSP and all members who have deployed to Iraq have volunteered their services, which is a true testament of their dedication and duty of service to the warfighter.

SSC San Diego is a Navy Working Capital Fund (NWCF) organization that provides engineering and research and development services on a funded basis to requesting sponsors. The RSCSP services are therefore available to any U.S. government organization that has a need for technical robotics support.

3.3 In-Theater Repair and Maintenance

In April 2004, RSCSP members Chief Electrician's Mate (EMC) Thomas Hoover and Electronics Technician Second Class (ET2) Jose Ferreira, were deployed to assist the RS JPO in setting up the EOD robotics repair facility in Camp Victory, near the Baghdad International Airport (Figure 2). At that time, the operational tempo was extremely fast-paced due to the widespread use of IEDs, and EOD robots were being brought to the shop for repairs at an alarming rate. Repair parts had not come through yet, so cannibalization of parts and makeshift repairs were common practice to ensure that robots were available for the EOD teams (Appendix A). The two-person team was working side-by-side with contractors from ManTech, reporting to the RS JPO senior military representative. The RSCSP continued to provide two-member support at Camp Victory throughout fiscal year 2004 for the RS JPO, and their services were requested again to cover all of fiscal year 2005.

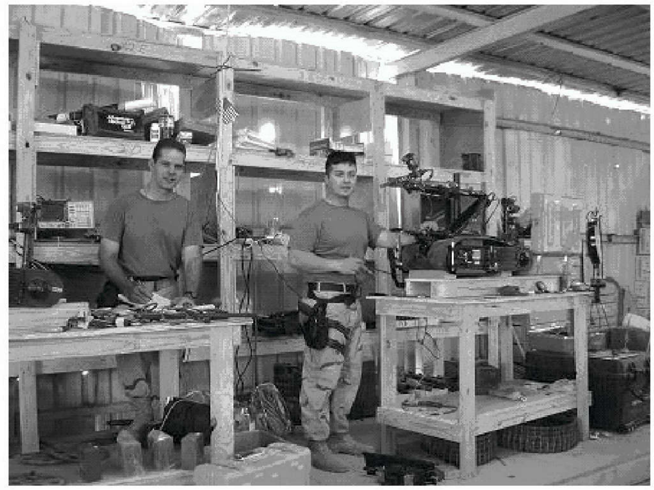

Figure 2. Initial repair shop, Camp Victory, Iraq

3.4 Pre-Deployment EOD Training and Technical Field Support

Reservist members of the RSCSP have been readily available in response to requests from operational commands as well as other users of unmanned systems to assist their robotic technical needs. For the past year, this has included providing pre-deployment operator and maintenance training for EOD technicians, technical field support for pre-deployment EOD exercises, RSP loans to support pre-deployment exercises, and repair of stateside EOD robots. These requests are more easily fulfilled with advance notice from the users. Such advance notice ensures that individuals with the appropriate skill sets can be identified for a particular mission or need, and enough time is allowed for drafting short-term Reserve orders.

Due to limited EOD robots stateside, an urgent need to fulfill pre-deployment EOD training requirements by using any available robots became apparent. Reservists from the RSCSP provided the labor and technical knowledge for administering the training, which consisted of basic robot operation and maintenance. Equipment for the training was provided in the form of EOD assets from the RSP. The basic robot operation training entailed mainly "stick time" for the EOD technicians to provide familiarity. The maintenance training included repairs that could be easily performed by the users and did not require any special tools, diagnostics, or detailed troubleshooting.

SSC San Diego is not an officially designated school house for robot operator training as is the Naval School EOD at Eglin Air Force Base or the Army's EOD school at Redstone Arsenal. And since the availability of EOD assets was contingent upon the allocation of RSP assets at the time, training opportunities could not be guaranteed. Fortunately over the past year all requests for training were fulfilled, but not all requests for providing assets for pre-deployment exercises could be entertained. From February through September 2004, four training sessions were held with over 60 EOD technicians trained.

Although valiant attempts were made by several different organizations to provide training to the EOD technician users, no standardized curriculum has yet been developed. The National Center for Defense Robotics (NCDR), an independent non-profit organization for robotics technology advancement, identified this shortfall and obtained funding to establish a robotics curriculum for the benefit of EOD technicians. As it now stands, curriculum development will only be for the Man-Transportable Robotic System (MTRS) platforms, which includes upgraded

Figure 3. IMEF field training, Camp Pendleton, July 04

versions of the iRobot PackBot EOD and the Foster Miller Talon systems. Program expansion to other platforms is dependent upon successful execution of the currently envisioned training plan. SSC San Diego, in conjunction with vendors and interested military organizations, is playing an active role in providing information to assist the NCDR's efforts in formulating a more robust robotics curriculum.

RSP assets as well as RSCSP training have been made available to many pre-deploying joint service EOD outfits, including multiple Camp Pendleton and Marine Corps Air Station (MCAS) Miramar Marine commands, Air Force EOD technicians for their national training at Ft. Carson, Colorado, and the Army's EOD School at Redstone Arsenal in Huntsville, Alabama.

In addition to training at SSC San Diego, RSCSP Reservists have provided technical field support for IMEF Marines from Camp Pendleton on multiple occasions (Figure 3). During these events, RSP assets were made available to the Marines for short-term loans, and Reservists were present for the pre-deployment field exercises in the event that a robot needed quick repairs to ensure it remained operational throughout the exercises.

The RSP/RSCSP combination has also supported Navy EOD Mobile Unit Three with an asset loan for their training and readiness department, as well as providing operator and maintenance training to the unit. RSCSP members conducted repairs and provided technical assistance for a Talon system belonging to Navy's EOD Training and Evaluation Unit One in San Diego. Navy EOD Training and Evaluation Unit One had been issued a robotic asset to be used in their training scenarios without receiving any user training on the system prior to their RSCSP/RSP training (Figure 4). Their robot was brought to the RSCSP training with a failed arm among a few other problems. An improperly tensioned chain had caused arm motor failure, which could have been prevented had proper training and awareness been initially applied. This would have resulted in both time and money savings as compared to subsequent repairs. Services provided included replacing a failed arm motor, recalibrating a pan-tilt-zoom-camera mast, and installing a new transmitter that would not interfere with other radio transmissions at their training location at Naval Weapons Center China Lake.

Operator training with a robotic system prior to deployment is an inherent benefit to the warfighter for familiarization purposes. Although familiarization training does provide the warfighter with improved skills to complete his/her mission more efficiently, it is perhaps only slightly less important from a reliability and maintainability standpoint. This prior operator training, provided by those that know the capabilities and limitations of the robots from an internal-design point of view, provides the warfighter with a deeper understanding of how the system is set up and why the system performs the way that it does. This approach contributes to increased awareness of why certain operations might need to be avoided or performed in a different manner because of the effect on the system and subsequent damage that may be caused. The operator training provided primarily to deploying EOD groups by the RSCSP was not intended to teach tactics, techniques, and procedures (TTP) to the EOD techs, but to instead provide general knowledge and ability with the system, and have the operators in turn apply that knowledge and ability to their specific tasks.

Figure 4. RSCSP operator training of Navy EOD T&E Unit One, SSC San Diego, Sept 04

3.5 RSP Field Support and Continuous Skill Enhancement

Reservist members of the RSCSP have also been readily available to provide technical field support to organizations receiving RSP assets on loan. As an example, the Sacramento Sheriff's Department began to have problems with the video feedback from a Talon. After preliminary troubleshooting over the telephone met with no success, a Navy Reservist repair technician from the RSCSP was dispatched from a nearby San Jose detachment to troubleshoot the system. The Reservist was able to isolate the video problem to a faulty monitor, whereupon a replacement monitor was shipped from SSC San Diego. Upon receipt of the replacement by the Sheriff's Department, the Reservist provided over-the-phone technical support to ensure the monitor was properly installed and working. This matter was resolved in less than a week, with the RSP/RSCSP combination eliminating the need to return the robot to SSC San Diego for repairs, saving both time and money. Cases such as this offer opportunities to keep RSCSP members' technical skills current.

Reservists in the program also provide invaluable assistance in the repair and maintenance of RSP assets. This method offers time and cost savings, as vendor repairs requiring the robot to be shipped to and returned from the factory can be expensive. Keeping up with the maintenance of the relatively large number of RSP assets allows for continuous honing of troubleshooting and repair skills, providing a myriad of training opportunities for RSCSP members.

4. SPIRAL DEVELOPMENT

With the RSCSP team providing in-theater maintenance and repair of deployed systems, supporting pre-deploying units, and repairing in-house RSP assets (Figure 5), much of the spiral development efforts for fiscal year 2004 were focused on making design-improvement recommendations to the Man-Transportable EOD platforms. Some of the technical issues with the deployed systems as well as their causes will be discussed in this section. Improvements suggested by the RSCSP/RSP combination are contained in section 4.3.2.

4.1 System Issues

Due to the urgent need and extremely short timeframe required for providing robotic assets to the SKISKY fielding effort, no single manufacturer had the capability to produce the necessary quantity required by DoD. The procurement was therefore spread across a handful of companies, which in combination were able to deliver the necessary quantities within the required timeframe. There were five robotic platforms deployed in connection with the SKISKY fielding effort: the EOD Performance Vanguard, the Foster Miller Talon, the iRobot PackBot EOD, the Mesa Associates MATILDA, and the Remotec Mini-Andros. Although each system possessed its own individual strengths, each also experienced its own unique technical problems. There were, however, some overriding issues that were common to all systems (Figure 6). As the SKISKY fielding effort was the first mobilization effort in history to rely so heavily upon robotics to aid the warfighter, it is particularly important to gather technical lessons learned from the fielding of robotic assets to aid in the development and improvement of all future systems.

Figure 5. RSCSP members investigating PackBot EOD during maintenance training

ISSUE	CAUSE
Tracks disengaging from wheels	Obstructions lodged between the track and wheels due to improper tensioning
Slop in elbow/shoulder/turret motor joints	Design flaw in securing part (guide pins)
Weak gripper force	Gripper motor slipping in arm housing/wear of gear assembly inside gripper
Circuit board failures	Surges, design, component failure/ no surge protection
Arm motor failure	Mistensioned chain, arm used for loading beyond intended use
Battery life shortened	120+ F temps caused decrease in power density/ chemical reaction caused battery swelling
Drive motor failures	Wiring short or loose connections to circuit board
Failure on antenna spring/mounting scheme	Endurance limit exceeded/ plastic deformation spring fatigue failure
Failed connectors/wiring	Manufacturing/assembly flaws/component failure/ Excessive wires and inadequate assembly
Turret baseplate deflection grounding leads	Pressure gradient during blast causes deflection in baseplate contacting leads
Arm mobility loss	Arm used for loading beyond design/robot undersized for procedures
Head mobility loss, firing circuit reboot, camera failure	Software issue, component failure/ camera relays sensitive to shock
Board failure solder joints breaking	Boards subjected to loads above design spec, solder joint assembly/manufacturing flaw
Gripper motor/rotation and gearing slips with wear.	Tolerances not adequate to allow for proper gear mesh/ locking pin or shim needed to secure gear
Inadequate video range	Heat transfer from video bridge
Front drive motor failure	Training/operator techniques/mounting/ Motors used beyond design parameters
Antenna base failure	Design load exceeded
Camera mount stress failure	Design load exceeded

Figure 6. Technical issues and corresponding causes from SKISKY-deployed unmanned ground vehicles

4.2 Overarching Technical Issues

The variety of technical issues along with their corresponding causes is outlined in Figure 6. Four overarching categories can be pulled as common problems from the large scope of issues experienced by all systems, and have been seen not only with the deployed systems but with RSP assets in general: 1) arm motor failure, 2) general ruggedization of components and the lack thereof, 3) low or rapidly depleting battery life, and 4) component board failure.

4.2.1 Manipulator Arm Failures

One of the most frequent problems common throughout almost all EOD robotic systems was the failure of the manipulator arm, particularly the wrist and gripper (Figure 7). These failures were most commonly caused by the use of these components above and beyond their designed limits. Without explicit direction to the warfighter as to what loads could be supported by the system, failure would routinely occur. In systems without chain-driven joints, failure would occur in arm motor components, motor hubs, support hardware, and gearing transitions. Chain-driven arms experienced their own unique problem sets. Improper tensioning of the chain led to dynamic impact loading of the motors and supporting components, causing overheating and subsequent failure in the motors themselves. Failure would also occur if the fatigue strength or endurance limit of the supporting arm-motor hardware, including gearing, was exceeded. This impact loading can be split into two separate cases that occurred both independently and in combination in the field: 1) striking impact, and 2) force impact. Striking impact refers to the actual collision of two bodies, where force impact refers to a suddenly applied load with zero collision velocity.[3] Implemented and suggested solutions to these issues will be touched upon in subsequent sections, although vendor upgrades have included material changes in components to increase strength, and improved tolerance and securing enhancements for better resistance to fatigue.

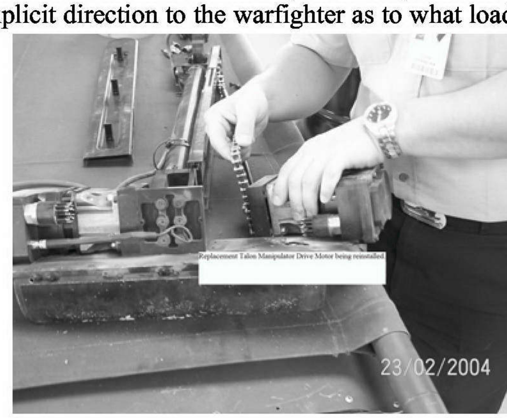

Figure 7. RSCSP members reinstalling Talon arm motor

4.2.2 Ruggedization of Components

Another frequently occurring failure that was common throughout all deployed systems was the lack of strength and resistance-to-wear of many of the hardware components used on the systems. All parts were generally subjected to dynamic vibration loading that was beyond their capabilities to withstand. Failure occurred in camera relays, circuit-board mounting interfaces, connectors, tensioners, wiring, and antennae design. An example of failure due to lack of ruggedization occurred in the turret base plate of one system. The blast pressure from an exploding IED caused deflection in the baseplate, contacting leads on the internal circuit board and rendering the manipulator arm inoperable. This blast pressure could be estimated at approximately 700 tons per square inch at the point of detonation.[4] Increasing the rigidity of the baseplate and/or adding an insulating cushion between the plate and the circuit board are solutions to this problem and are being addressed by the vendor.

4.2.3 Battery Life

Rapid depletion of available battery life was a common issue present with each system. Run time was reduced by as much as 50 percent in many cases, adversely impacting operational missions that were strained or could not be executed with depleted available power. Excessive-heat from ambient temperatures reaching 120+ degrees Fahrenheit initiated reactions internal to the nickel-cadmium and lead-acid batteries causing a loss of available power and swelling of the cells. Battery software issues in some cases also contributed to the lack of available power, as charger software would not allow for a full-cycle charge to take place.

4.2.4 Component Board Failure

Component failure on various circuit boards has caused partial loss of mobility, video, and/or complete functionality in the robotic systems. Many of these problems have occurred because of inadequate overload protection within the circuits. If an overload occurs due to an increase power draw and proper capacity is not available within the circuit, failure can result. On some boards, overload protection was not appropriately designed into the circuit causing component and/or system failure when a surge occurred (Figure 8). Other boards had adequate surge protection integrated into the circuit design that was sufficient to guard against system failure. However, repeated failure of specific fuses during normal operating conditions was a symptom of a greater design issue within that specific circuit. This issue suggests a closer evaluation be performed to determine which components are drawing excess current, and what the capacity should be. An example of this failure was noted on the arm turret board of one system, where an overload would occur during normal operation of the manipulator arm. Failure occurred in a 5 Amp fuse rendering the robot inoperable. This particular fuse needed to be replaced multiple times during consecutive operations, with each replacement requiring approximately 45 minutes of repair time. This problem has been addressed by the vendor and an investigation is underway into what changes could be made with board design and/or software modifications. Problems with overload protection were common throughout all systems and are a source of concern for future designs.

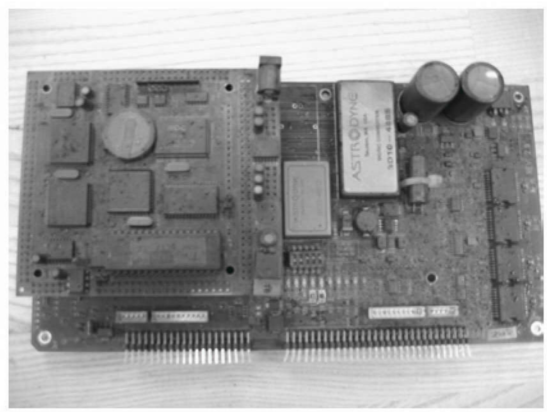

Figure 8. Failed circuit board after RSP loan

4.3 RSP/RSCSP Spiral Development

The role of the RSCSP in combination with the RSP is not only to provide service and expertise in the area of on-site technical training, repair, and maintenance, but also to facilitate the spiral-development of more capable fielded robotic systems. In addition to the training familiarization discussed in section 3.4, below are two examples that describe how the RSCSP/RSP combination has provided invaluable support to the warfighter.

4.3.1 Toolbar Liftkit

An example of the spiral development process is seen in the EOD toolkit development. As stated in section 4.2.1, manipulator failures have been one of the major problems with the majority of the fielded systems. These problems occurred primarily because of changes in enemy tactics upon application of robotic assets by U.S. forces as a solution for combating Improvised Explosive Devices. Manipulators were being used as excavation tools and lifting mechanisms, incurring loads that were beyond their design capabilities and causing subsequent failure. The RSP brought these issues to the attention of the system developers and produced a prototype design to an existing platform that would allow for the needed excavation capability with minimal required changes (Figure 9). This concept was a universal tool-mount kit that allows for the excavation of IEDs utilizing the iRobot PackBot flippers. The design also allows for the simple field interchange of various EOD tools for use in disarming IEDs as well as options for future fabrication of additional tools in theater. This solution incorporates a simple interface to the PackBot and was prototyped and used in training scenarios to receive initial user feedback. Concurrently, iRobot developed a lifting attachment that could be easily added for much improved lifting capabilities, allowing for the removal of 155mm artillery shells weighing approximately 80lbs (Figure 10). These designs are now being finalized by iRobot and are to be delivered to NAVEODTECHDIV for distribution and initial user evaluation in April 2005.

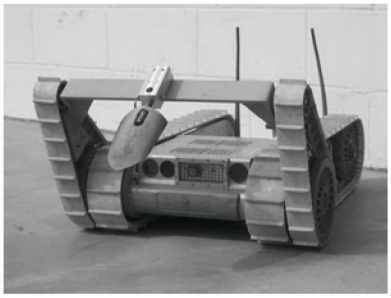

Figure 9. SSC San Diego prototype tool mount kit

Figure 10. SSC San Diego's prototype tool mount kit integrated with iRobot lifting mechanism

4.3.2 Suggested Vendor Improvements

As members of the RSCSP supported the 200+ robotic systems deployed with EOD units, they became intimately familiar with the failures and shortcomings of each system. Members of the RSCSP were able to suggest improvements and identify technical shortcomings of each of the fielded systems, both to the RSP and directly to the respective system vendors. A list of the suggested improvements is presented below where an asterisk indicates changes that have been implemented by the vendor.

1. Pan-Tilt camera shaft upgrade, orientation design change
2. Gripper dead spot fix, developed calibration procedures to eliminate problem
3. Battery separator addition and size change
4. Fiber optics mounting design changes to eliminate interference
5. Radio Frequency (RF) range antenna improvement by frequency separation
6. * Claw rotation gear fix, shims for interim fix before redesign
7. * Drive motor failure, faster, more robust motor
8. * Improvement in wiring and connections
9. * Turret fuse design changes
10. * Upper arm hub material change for increased strength
11. * Upper arm connector change to eliminate interference
12. * Drive motor upgrade, increase speed
13. * Long-range antenna upgrade
14. * Auxiliary power cable from operator control unit (OCU) to allow power from HMMWV
15. * USTI connector fix, mounting orientation
16. * Arm brake setscrew LOCTITE addressing quality assurance quality assurance issue
17. * Gripper motor gears wearing, increased robustness of gripper, increased strength, shims for tolerances
18. * Sprocket and drive belt timing error calibration procedures
19. * Claw redesign, pitch and orientation change

5. CONCLUSION

As demonstrated in the SKISKY fielding effort, unmanned systems have proven to be an effective tool in assisting the warfighter in fulfilling his/her mission and will continue to be so in the future. While the need for unmanned systems as a key component on the battlefield will continue to increase, a parallel requirement for continued training, maintenance, repair, and spiral development of those systems will likewise continue to increase at an equal rate. This need for support and sustainment coupled with spiral development will allow for adaptable systems to meet whatever need emerges wherever that need exists. The RSCSP/RSP combination has been instrumental in supporting the joint-warfighter with the unmanned systems knowledge and tools that are needed in order for them to more effectively and efficiently fulfill their missions.

APPENDIX A

Comments from communication with RSCSP members who have provided robotics repair support at Camp Victory in Baghdad, Iraq:

E-mail from ET2 Jose Ferreira
Monday, 21 June 2004

I wish you all could have seen the faces of the guys after we finished fixing and enhancing the robots. [text deleted] I wish you all could be here and experience the satisfaction in knowing you saved someone's life today, I wish you could see the fear in their eyes when they first walk in knowing that they could walk out with no robot, I wish you could see the smiles and feel the hugs and handshakes after they walk out of our shop knowing their "little Timmy" is ALIVE. Alive and well to go down range one more time.

E-mail from EMC(SS) Thomas Hoover
Thursday, 6 January 2005

During the initial couple of months that the shop was set up in Iraq, our sailors repaired items that technicians at the factory said were not repairable. Specifically, metal frames that were blast damaged and bent out of shape were "black smithed" and body worked back into structural members when the factory informed us they had no spares and could not make any. Additionally, sealed motors that failed in the abrasive environment were opened, cleaned, serviced and returned to duty even after the factory technicians indicated they had never even attempted such a repair. We have routinely provided feedback to the factories that have resulted in improved manufacturing and assembly practices.

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