Army Medical Robotics Research

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Abstract: Buddy treatment, first responder combat casualty care, and patient evacuation under hostile fire have compounded combat losses throughout history. Force protection of military first responders is complicated by current troop deployments for peacekeeping operations, counter terrorism, and humanitarian assistance missions that involve highly visible, politically sensitive low intensity combat in urban terrain. Research progress has been made in the areas of robotics; artificial intelligence; sensors; computer vision; mechanical, electrical and biological engineering; noninvasive diagnostics; and wireless digital communications. Academic institutions have demonstrated intelligent robots that execute functions ranging from performing mechanical repairs to playing soccer. The military has significantly invested in autonomous vehicles, and other robots to support its Objective Force. By leveraging several Department of Defense funding sources the Army Telemedicine and Advanced Technology Research Center has established a growing portfolio of projects aimed at adapting, integrating, or developing new robotic technologies to locate, identify, assess, treat, and rescue battlefield casualties under hostile conditions.

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1. Early collaborative medical robotics projects with the Defense Advanced Projects Agency (DARPA):

a. Telepresence Surgery System (TESS). Stanford Research Institute International (SRI) delivered a prototype TESS to the USUHS in July 1997. This system consisted of a remote surgical unit with 6 Degrees-of-Freedom manipulation remotely controlled by a surgeon at the Telepresence Workstation. It incorporated 3-D stereo imaging, several surgical manipulators with sensitive haptics (force-feedback) and a capability for high bandwidth remote function.

b. Enhanced-Dexterity Surgical Hand. Daum, Inc. developed a three-finger “hand” grasper (DaumHand™) for minimally invasive therapy. The DaumHand™ fits through a 10mm diameter trochar, which is controlled by a unique DataGlove (Daumglove™). The purpose of this project was to provide proof of concept only. No animal or human use studies were involved.

c. Miniature Laparoscopic Gripper - Brock Rogers Surgical, Inc. developed a miniature “hand” for micro-dexterity tasks, complementary to the DaumHand™, with a higher level of dexterity and smaller size, but with lower forces/torque than for large-scale surgery. It incorporated haptic feedback with micro-sensors.

2. Recent projects initiated by or with the participation of the USAMRMC:

a. Medical robots, such as Intuitive Surgical Robot called DaVinci, is a commercial robot which was a successful DARPA program, handed to MRMC, and then commercialized. Another surgical robot, Zeus by Computer Motion, is also a DARPA program turned commercial success. The surgical robots are currently being purchased throughout the world for clinical practice. Even though these systems were initially developed by DARPA and demonstrated for remote surgery to the far forward battlefield, remote surgery has not turned out to be a practical application of the technology.   Nevertheless, two trends in modern surgical practice have emerged from this work: 1) surgery is evolving toward minimally invasive videoendoscopic approaches and 2) robotic systems are gaining a foothold in the operating room. The daVinci Surgical System makes complex surgical procedures accessible to laparoscopy that previously were amenable only to open surgery or to a limited number of advanced laparoscopic surgery experts. The daVinci system is an ideal platform for telesurgery because it consists of two separate components connected by computer cables: 1) the surgeon-controlled “robot” with mechanically driven laparoscopic operating instrument “arms,” and 2) the control console through which the surgeon and the “robot” interface. The daVinci system affords a number of distinct advantages: 1) dual offset video cameras provide a three-dimensional view of the operative field, 2) articulating laparoscopic instruments move with the same number of degrees of freedom as human hands in open surgery, and 3) magnification of the operative field, motion scaling, and elimination of surgeon tremor allow a level of operative precision never before achievable in surgery.

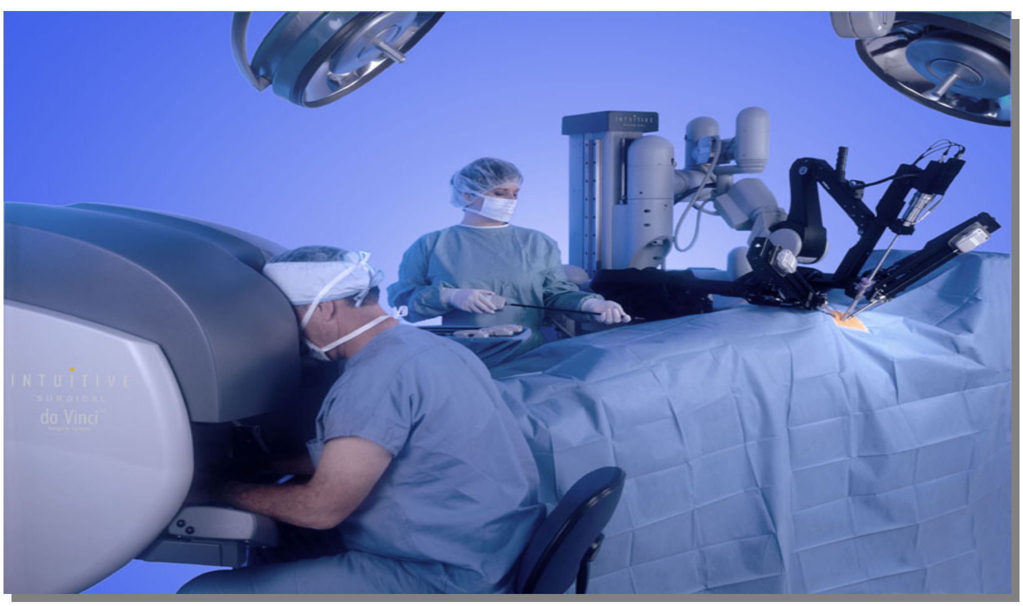


Figure 1. DaVinci Robotic Surgical System, Intuitive Surgical, Inc.

b. Telepresence “Microsurgery” System for Uniformed Services University of the Health Sciences (USUHS) - Stanford Research Institute International (SRI) - This robot was intended to augment the current DARPA Telepresence Surgery System located at USUHS. The proposal was developed by SRI/USUHS to improve microsurgical dexterous manipulations, specifically to optimize fine motor control and minimize hand tremor and fatigue. This robotics device will allow a surgeon to operate in a magnified workspace (1x1x1 cm^3) in which the surgeon can work with hands-on, full-size instrument handles, using normal hand motions and experience the tactile feedback that a surgeon would expect in a magnified environment. These advances in microsurgery would make possible procedures such as small vessel anastomosis, nerve reconstruction, and microdissection and repair of ocular injuries. Funding: $250K – Combat Casualty Care Research Program 6.3 (Project Line 840).

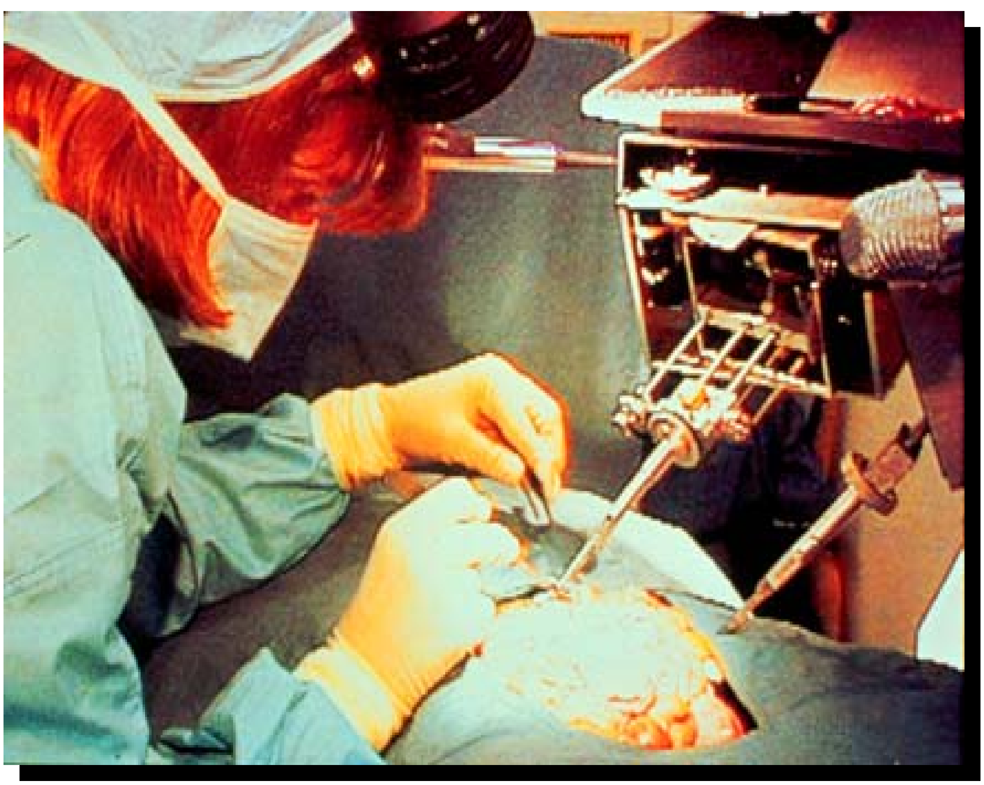


Figure 2. Telepresent Surgery.

c. Automated System for Percutaneous Needle Insertion - Johns Hopkins University Urobotics Laboratories has developed a robotic device to accurately place a needle tip at a predetermined 3-D coordinate. This device has been demonstrated in Percutaneous Access of the KidneY (PAKY) using fluoroscopy. A new initiative, in conjunction with Georgetown University's Periscopic Spine surgery congressional appropriation, involves wider application of PAKY. The PAKY robot will be further developed to function with fluoroscopy, CT, MRI and ultrasound to perform all types of percutaneous needle placement. Funding: Original development by Johns Hopkins University. Planned follow-on funding: 120K-$220K Congressionally directed Periscopic Surgery.

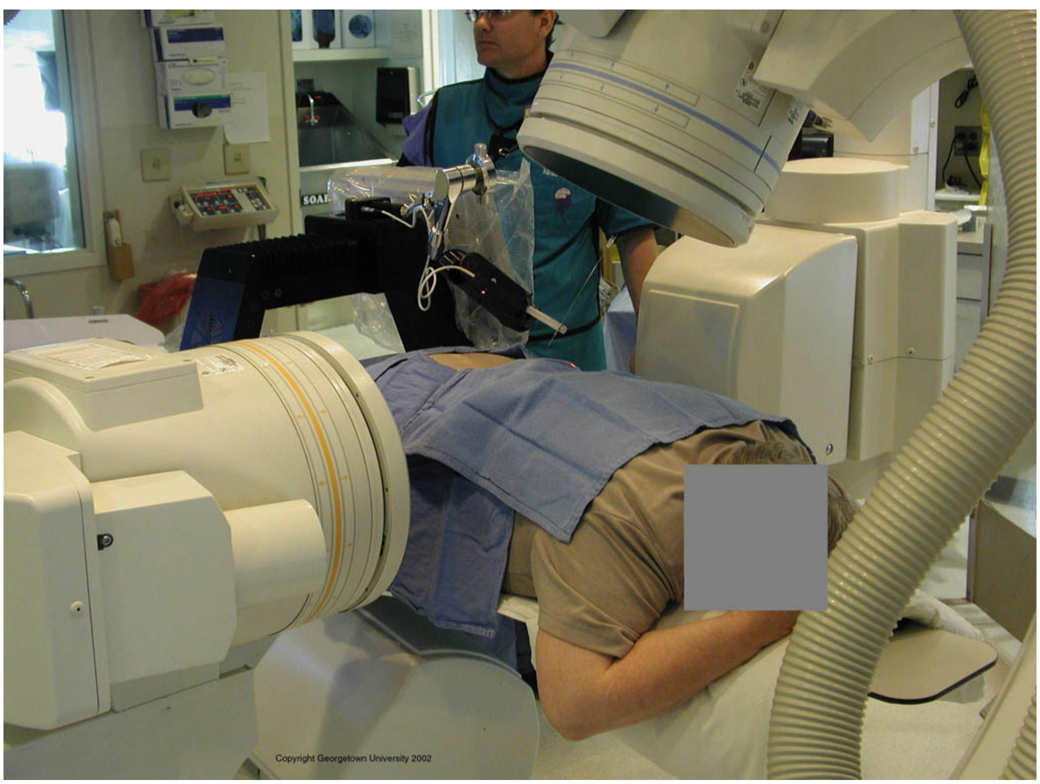


Figure 3. Robotic percutaneous needle insertions system.

d. Informatics-based Medical Emergency Decision Tools (IMED-Tools) was a Congressionally directed research and development program designed to effectively utilize medical informatics decision support advances, medical modeling and simulation, and wireless telecommunications on the battlefield and other first responder settings, including frontier, rural, and urban environments. It supports the Army mission by investigating and prototyping medical informatics tools and medical databases with potential for contributing to information analysis and situational awareness in support of (1) joint medical readiness, (2) battlespace medical awareness, and (3) effective employment of medical forces. It was specifically intended to address the deficiencies in both wartime and peacetime military health information analysis for the first responder provider. One of the six prime tasks of the IMED-Tools program was to extend the design and development of available robotic prototypes for a functional robotic medical assistant (MEDBot) to enhance the capabilities of the first responder medic at the point-of-injury for monitoring and supporting mass casualties in combat, frontier, rural and urban battlespace environments. Some work was completed and a basic capability demonstrated but funding was not renewed by Congress.

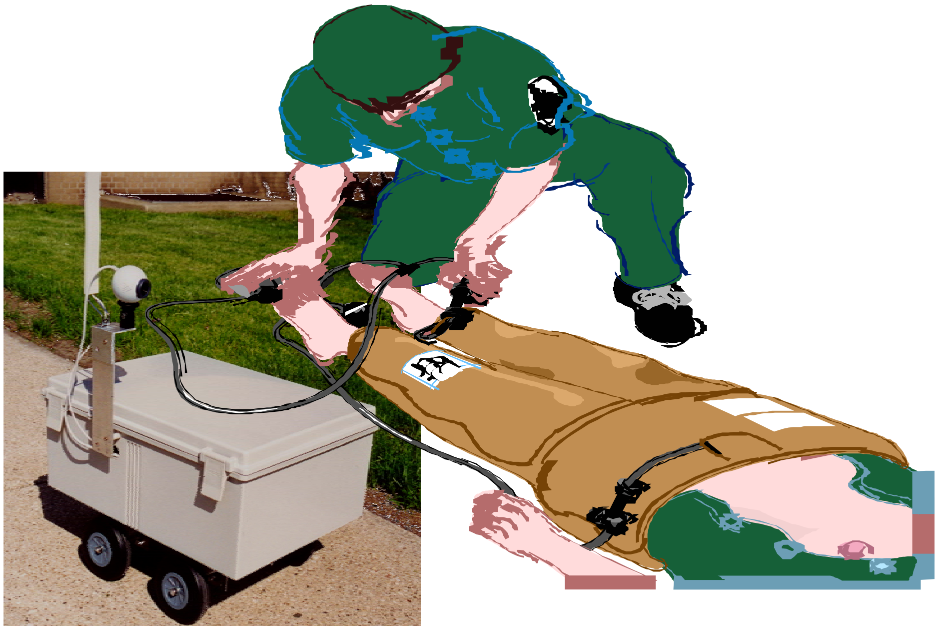


Figure 4. IMED-Tools MEDBOT concept.

f. Robotic Medical Assistant Army SBIR. USAMRMC authored an Army SBIR initiative (#A01-184) aimed at designing, modeling, and prototyping an intelligent autonomous prototype robotic medic or system of robots that can assist civilian emergency personnel or the military in locating, stabilizing, and recovering sick, wounded or otherwise injured personnel in hostile or caustic environments.

1. Phase I provided for conceptual and technical models which identify and translate functional requirements into implement able technical robotic medic designs which demonstrate feasibility of the robotic medic assistant concept. Irobot Inc received a Phase I SBIR award and designed a prototype robotic medic assistant called "Bloodhound" which was based on its small (40 pound) dual tracked military "Packbot" platform.

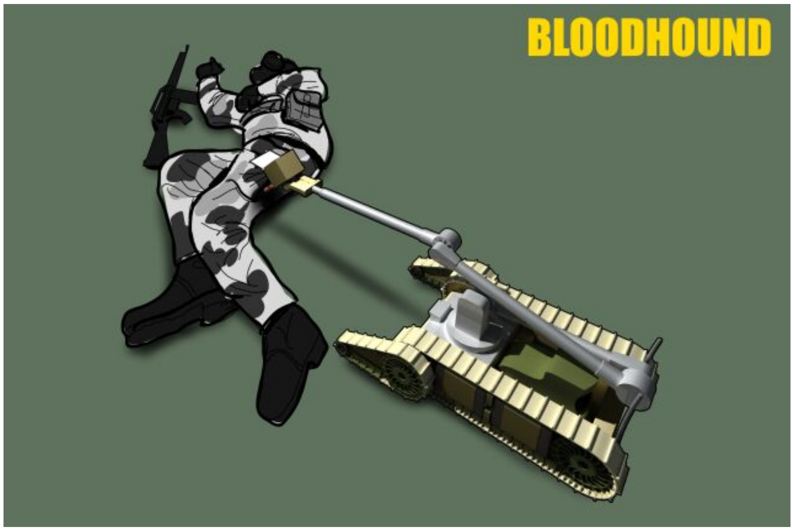


Figure 5. Irobot Bloodhound Packbot concept.

2. Phase II was intended to provide for construction of working laboratory prototype robot or team of robots, which implements the model and demonstrates the concept . The prototype was to be able to demonstrate a representative sample of the following tasks:

a. Find patients in urban and field terrains.

b. Identify patients as friend or foe.

c. Communicate with and facilitate communications between patient and medic.

d. Assess patient to determine via noninvasive methods whether the patient is alive or dead, determine most critical injuries, perform remote triage (expectant, immediate, routine).

e. Perform some simple first aid functions such as clear the airway, apply pressure bandage, inject narcotics or hemorrhage retarding drugs (e.g. Factor 7), immobilize serious fractures, etc.

f. Protect patient from further injury and from hostile attack.

g. Lift, move, carry, tow, or otherwise execute patient recovery from hazardous to safe areas where they can be attended by human medics.

An SBIR Phase II was not awarded because the proposals were deemed to be insufficient; however, refocused work now continues leveraging several funding sources (3c,d & e.).

3. Current USAMRMC robotics projects:

a. Operating Room of the Future Portfolio:

(1) The Periscopic Spine Surgery project is aimed at improving the state-of-the-art of image-guided and minimally invasive spine procedures by developing new clinical techniques along with the computer-based hardware and software needed for their implementation. Key milestones for the first three years of the project include:

a. Integrating the mobile CT scanner into the interventional suite and operating

b. Demonstration of a robotic biopsy test bed.

c. Completed a cadaver study of a robotically assisted spinal nerve blocks and received FDA approval for a clinical trial.

d.Designed and constructed a liver respiratory motion simulator and demonstrated the use of magnetic tracking for internal organ motion

Current work is aimed at:

e. Designing spinal robotics for precision placement of instruments

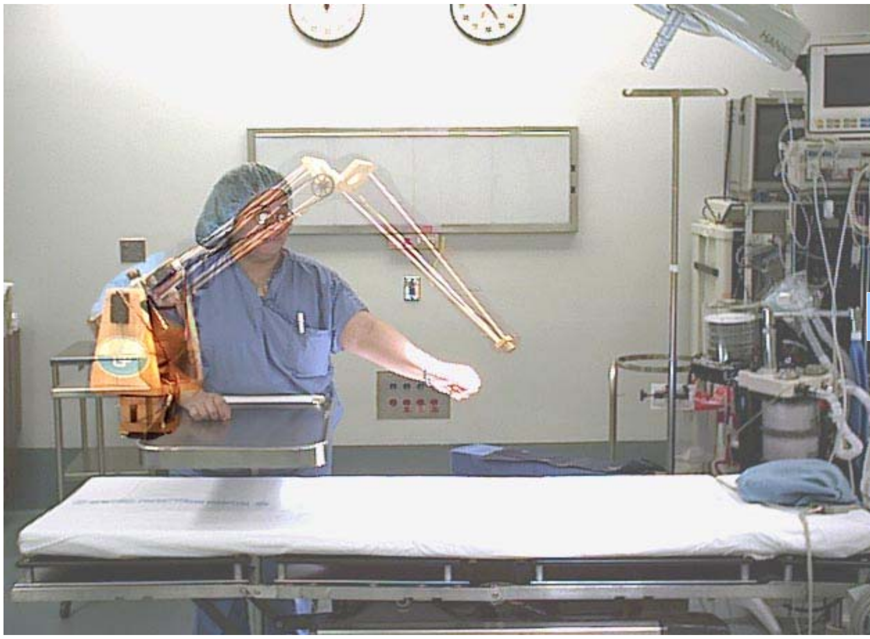
f. Completing robot biopsy testbed incorporating mobile CT scanner

g. Developing internal organ tracking and demonstrate using liver motion simulator

h. Demonstrating the use of skin motion in precision radiation treatment

i. Developing a new initiative in tele-rehabilitation robotics.

2. The “Penelope” Robotic Scrub Nurse is a research project being conducted by Michael Treat, MD, at Columbia with participation by Computer Motion Inc. It is intended to produce a robotic scrub technician that will fully replace a human scrub technician in the operating room. The robot scrub tech will listen to the surgeon’s verbal request for an instrument, such as forceps or a hemostat. When the robot “hears” a request, it will select that instrument into the surgical field as would usually be done. The robot will then use its visual capability to locate and retrieve that instrument and return it to the Mayo stand, in order to be able to give it to the surgeon when requested to do so. The robot uses the technology of machine vision to locate and identify a surgical instrument that the surgeon has put down onto the surgical field, in order to retrieve the instrument and return it to the Mayo stand where all of the instruments in use are cached. The robot uses a mechanical arm to move a requested instrument from the Mayo stand out to the surgeon’s hand or to retrieve an instrument from the surgical field back to the Mayo stand. The robot also uses voice recognition/synthesis technology to respond to the surgeon’s request for an instrument from the Mayo stand. The timetable is to have an FDA approvable device that can enter initial clinical use by the end of 2004. A company, Robotic Surgical Tech Inc., has been formed, in order to provide a focal point for business development leading to a commercially available robotic scrub technician. A prototype machine has been developed that can perform, on a limited basis, the essential functions of a human scrub technician.



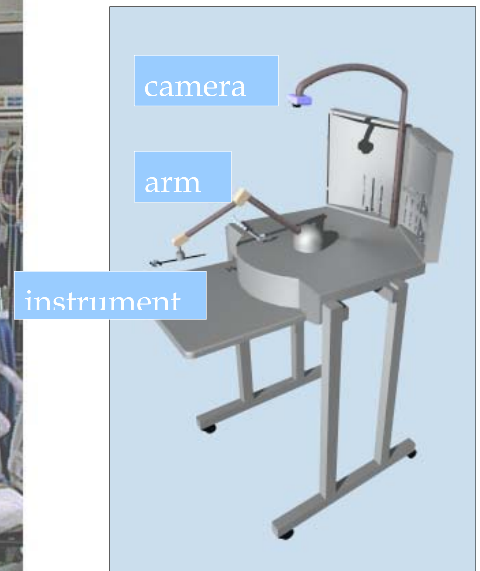


Figure 6. Penelope III Robotic Scrub Nurse.

b. Telesurgery Using a Minimally Invasive Surgical Robotics System is project that employs two surgical robotic systems to perform telesurgery between Walter Reed Army Medical Center (WRAMC) and Johns Hopkins Hospital (JHH), a distance of 40 miles. The project is being executed in a 4-step approach: 1) telementoring and telemanipulation “proof-of-concept” with the daVinci device in inanimate models, 2) telesurgery (telemanipulation) in a porcine model, 3) telementoring (no telemanipulation) in human patients, and finally, 4) telesurgery (telemanipulation) in human patients. The first step involves establishing a telementoring link between WRAMC and JHH. Telementoring consists of a mentoring surgeon’s watching a procedure and giving verbal guidance and visual cues to the mentored surgeon from a remote location. Once trouble-free surgical telementoring is established, telemanipulative capabilities can be evaluated, again using inanimate models. Once a reliable telemanipulative link has been proven, telesurgery can be performed on animals in the JHH laboratory using the WRAMC daVinci console to control the JHH robot. After all additional technical issues are worked out in the animal model, the technology will be introduced into live patient surgery. The first goal will be to establish an active surgical telementoring program. After telementoring has proven safe, telesurgery (remote manipulation) will be performed on WRAMC patients enrolled in a research protocol. For these cases, a WRAMC-credentialed surgeons use the JHH console to control the WRAMC robot. The long-term goal to validate use of the daVinci Surgical System to perform surgical procedures over a long distance. The availability of such a system has significant ramifications for the military. Surgical robotic systems equipped with telesurgical capabilities will allow military specialty surgeons to mentor and perform advanced surgical procedures from great distances with the aid of on-site general surgeons. This technology will eventually bring cutting edge surgical procedures to patients in the combat theater and will save valuable resources by extending the range of specialty surgeons.

c. Robotic Casualty Extraction and Evacuation Project Portfolio. Through the Army SBIR program and unrelated Congressionally directed R&D programs TATRC is overseeing and coordinating several robotic casualty recovery R&D efforts. SBIR Phase I awards were made to Irobot Inc and Applied Perceptions Inc. to design robotic casualty and evacuation robots.

(1). The Irobot Valkyrie Casualty Extraction concept consisted of employing its military "Packbot" robot to carry a rope and sled to a combat casualty which would then be towed by one or more Packbots or pulled by soldiers to safety. Irobot developed a basic Extraction Payload which the robot could deliver the EP to a conscious casualty, who will roll onto the extraction payload sled. Other soldiers then towed the extraction sled and casualty to safety. Additional work was planned to extend the extraction capabilities of the system, enabling one or more robots to rescue casualties and tow them to safe cover while protecting them from enemy fires using Casualty Protection Payloads (CPPs) equipped with smoke grenades and ballistic blankets.

Though this concept was not taken to Phase II under the SBIR program a limited demonstration was partially funded under the USAMRMC Broad Agency Announcement (BAA) and the Packbot platform is being integrated with other platforms to realize a broader collaborative robotic casualty monitoring, treatment and evacuation concept.

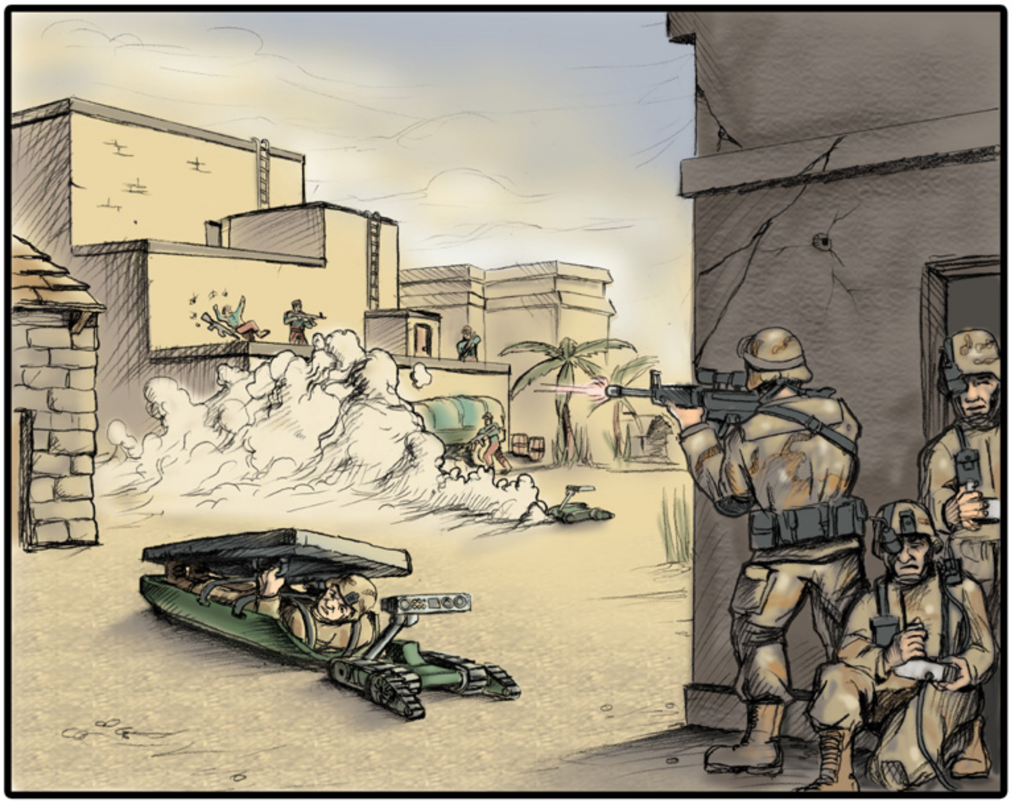
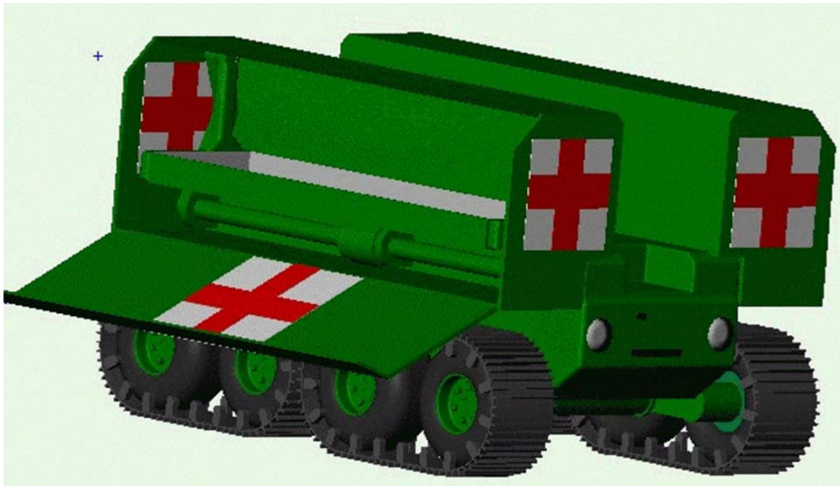


Figure 7. Irobot Valkyrie Casualty Extraction Concept.

Figure 8. Irobot Valkyrie Casualty Extraction Payload.

(2). The Applied Perception concept has moved into Phase II of the SBIR program. The USAMRMC Telemedicine and Advanced Technology Research Center (TATRC) has been collaborating with the US Army Tank Automotive Research and Development Engineering Command (TARDEC) on a program to develop a, multi-mission, collaborative robot team. This effort involves building a prototype robotic patient extraction and evacuation system with tele-operation, semi-autonomous, and autonomous control capabilities implemented on a marsupial robotic vehicle pair, a larger for long-range patient evacuation (from first responder medic to forward casualty collection and treatment site, e.g. Battalion Aid Station), and a smaller Robotic Extraction Vehicle (REX) for short-range patient extraction (from site of injury to first responder medic).



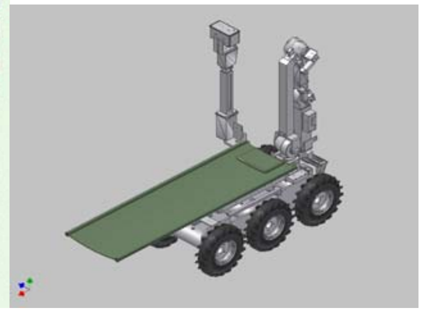


Figure 9. Robotic Evacuation Vehicle (REV) . Figure 10. Robotic Extraction Vehicle (REX)

Patient location will be accomplished using several technologies including the Air Force Remote Casualty Location and Assessment Device (RCLAD) which employs wide-band radar to detect motion through up to 30 feet of concrete and at close range can detect heartbeats and respiration.

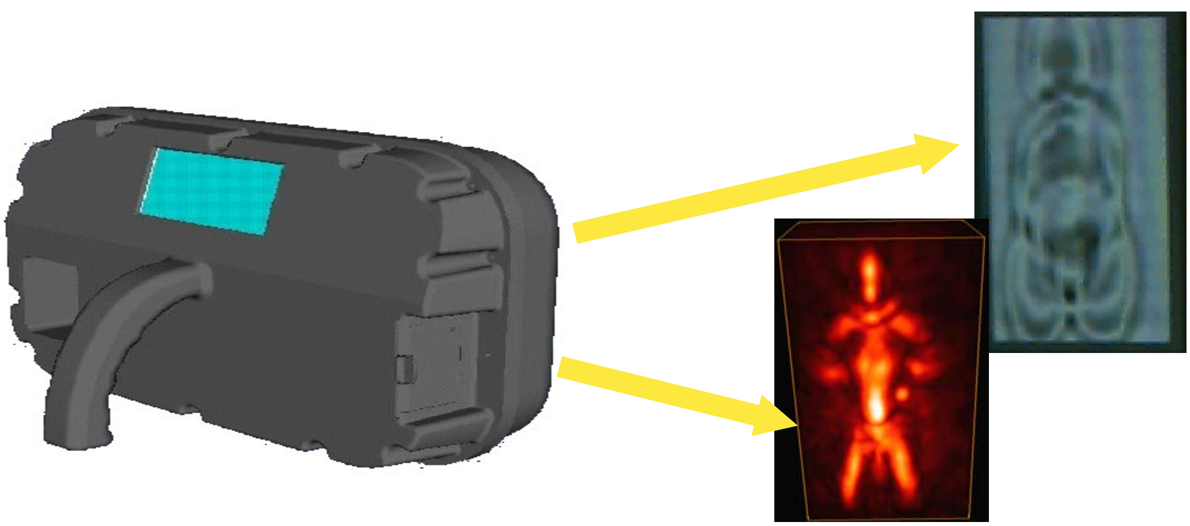


Figure 11. Remote Casualty Location and Assessment Device.

Autonomous and semi-autonomous patient monitoring and support is being built in to the REV using the USAMRMC Walter Reed Army Medical Center and Integrated Medical Systems (IMS) Life Support for Trauma and Transport (LSTAT) system.

Figure 12. Integrated Medical Systems Life Support for Trauma and Transport (LSTAT) Litter.

TATRC's objective is a proof of concept feasibility demonstration of potential medical applications of the Army Future Combat System (FCS) Small Unmanned Ground Vehicle (UGV) and the FCS Multifunction Utility Logistics Equipment (MULE) robot. These robot vehicles have also been identified by the U.S. Army Tank-Automotive Command (TACOM) as having potential for robotic sentry monitoring and reconnaissance tasks. The hardware and software required for both the medical and sentry applications are substantially similar, with the main systematic differences being in the mission specific payload and application of the underlying robotic vehicle functions. TARDEC, TATRC, DARPA and the DOD Joint Robotics Program Office (JRPO) are now collaborating to 1) conduct a proof of concept for a FCS casualty extraction functionality as a modular (versus stand-alone) capability of the standard Army small UGV and MULE robots; 2) conduct concurrent development of a cooperative capability between the two or more robots for casualty extraction as well as for sentry missions and; 3) facilitate collaboration among several robotic firms to integrate and consolidate ongoing military and civilian casualty recovery and rescue robot R&D efforts. In addition to producing working proof of concept prototypes, the strength of TATRC's effort is the integration of its various SBIR, TARDEC, JRPO, and Congressionally supported projects using the Joint Architecture for Unmanned Systems (JAUS) for command and control of multiple robot systems.

d. Another TATRC robotic casualty extraction project funded under the USAMRMC Broad Agency Announcement (BAA) is being conducted by Foster-Miller Inc. The concept involves design and development a self-extracting robotic NATO standard litter that can be integrated with an LSTAT for casualty life support.

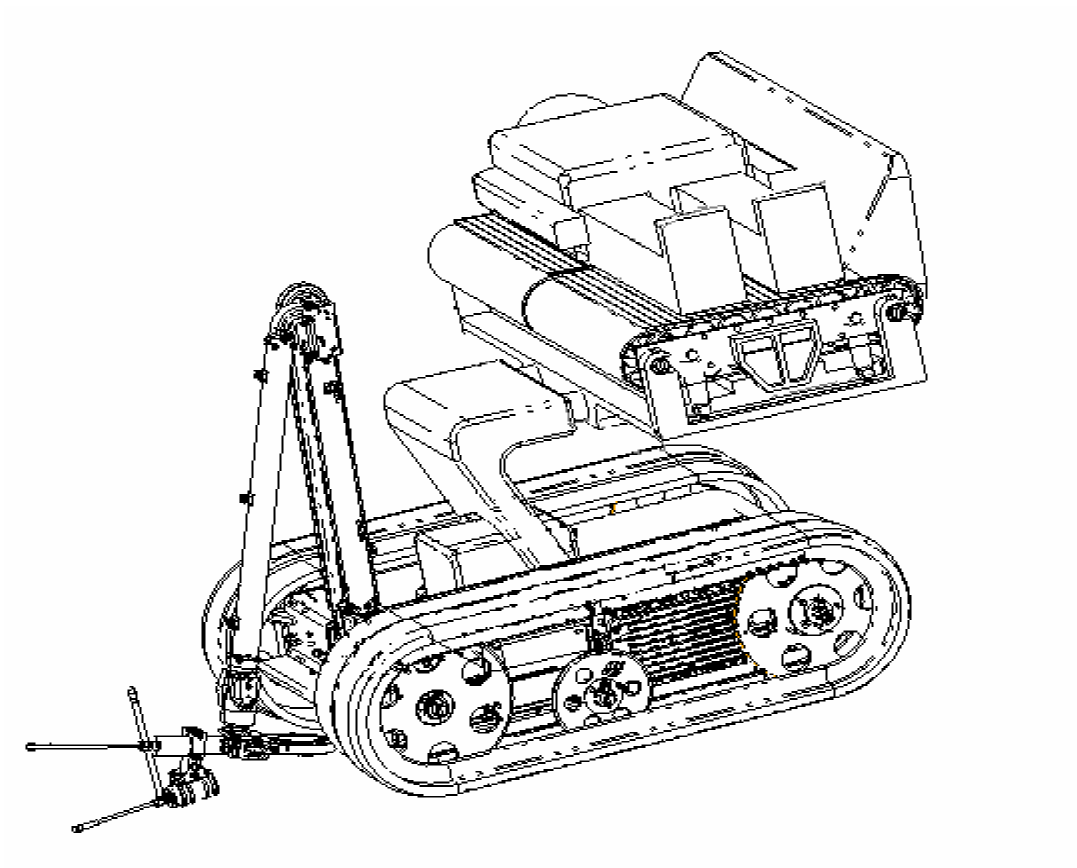


Figure 13. Foster-Miller Casualty Extraction Payload System for Robotic Platforms.

Designed to be carried on one of the FSC UGV robots, the robotic litter research objectives are intended to achieve the following:

(1). Casualty Alignment.   The robot must align the casualty's body, arms and legs with the axis of the stretcher. This will be accomplished using an onboard, extendable arm, and, if necessary, the stretcher itself in a "plow-like" mode.

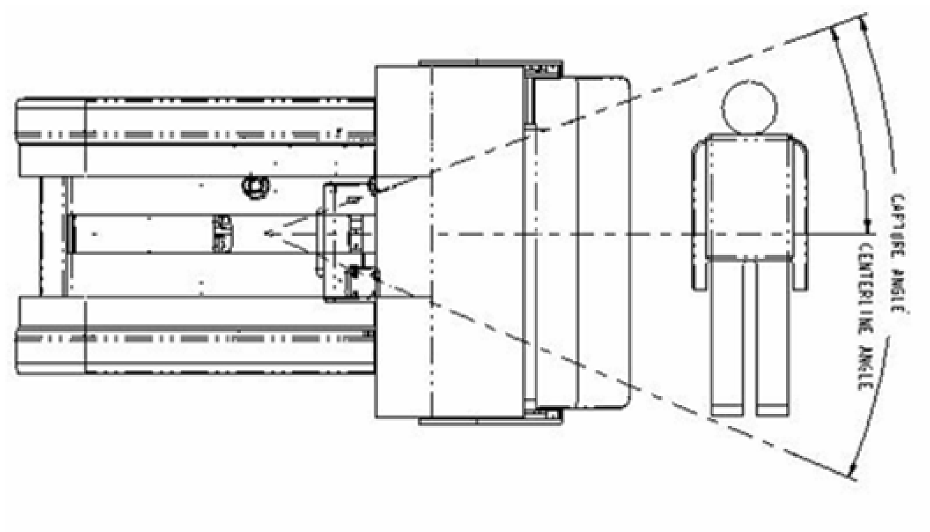


Figure 14. Casualty Alignment..

(2). Casualty Elevation. In an effort to minimize any further injury to the soldier, it is important that the lifting step be performed with minimum movement of the body. Therefore, the payload package will be designed to reach beneath the soldier and gently lift the torso up to an angle of 15 to 30-deg. At this point, the robotic litter can be placed beneath the torso to gain "contact" with the body.

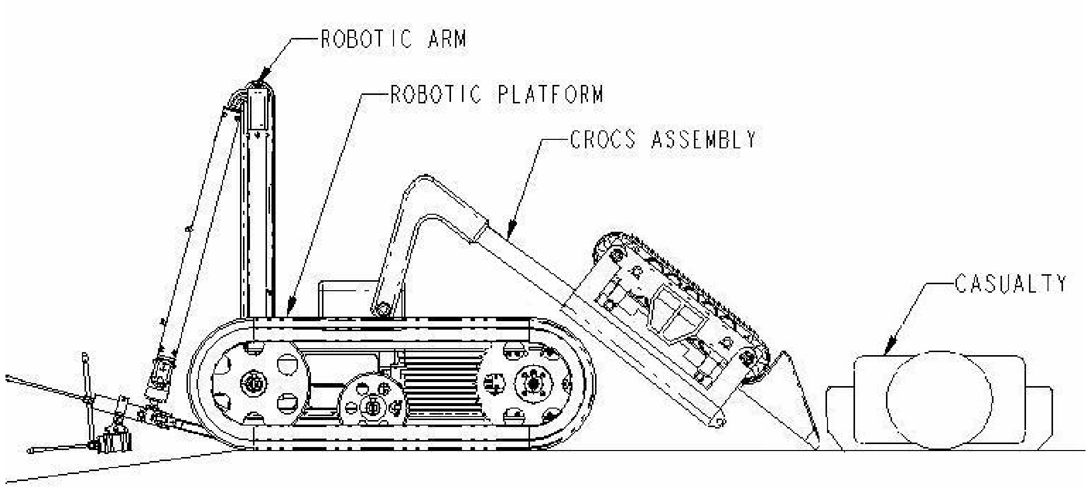


Figure 15. Casualty Elevation.

(3). Casualty Lifting/Carrying. The design of the litter includes an angled shape and motorized rollers at its leading edge. Once the casualty's body is lowered onto the edge of the stretcher, the first few rows of rollers are engaged, to essentially "snag" the casualty's uniform allowing his body to be drawn up and onto the litter.   The position of the loaded litter relative to the UGV transport platform will be adjusted "on-the-fly" in order to maintain the lowest possible center of gravity as the terrain varies. The litter is being designed so that it can be rotated 90-deg on the UGV platform base once the soldier is onboard so that it can pass through doors and maneuver up and down stairs. Casualties will protected from injury by protective railings and a Kevlar cover.

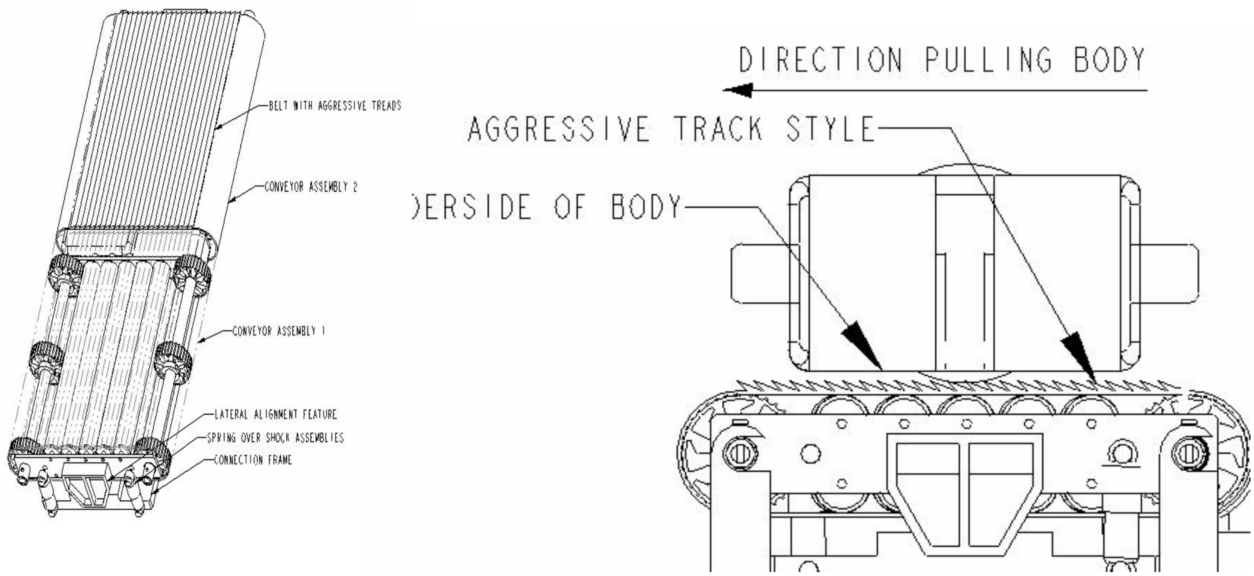


Figure 16. Casualty Lifting..

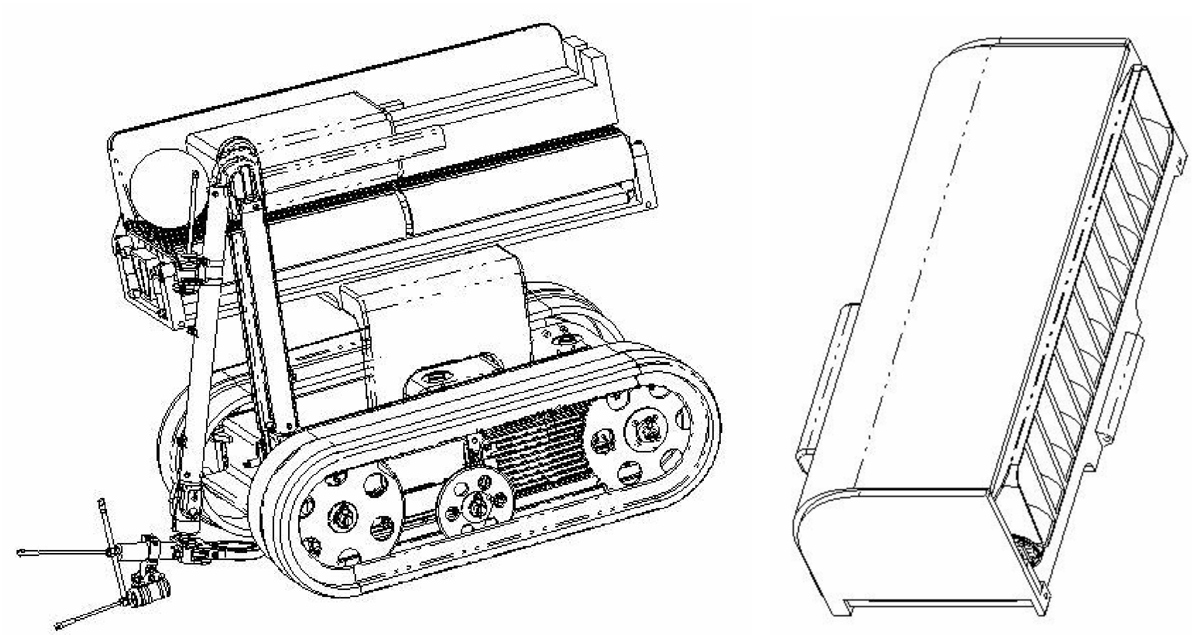


Figure 17. Casualty Carrying and Protection.

e. In a Congressionally sponsored rural telemedicine research effort, the Saint Francis University (Pennsylvania) Center of Excellence for Remote and Medically Under Served Areas

(CERMUSA) is leveraging the ongoing casualty extraction and evacuation projects discussed above for use by civilian emergency personnel and first responders in remote rural areas. Combining the robots discussed above with their prototype Rural Telemedicine Vehicle, CERMUSA is attempting to provide a complete mobile system for responding to natural and man-made disasters and acts of terrorism in remote rural areas where medical facilities and resources are limited.

f. DARPA Digital Human Robotic Casualty treatment and evacuation vision. DARPA has recently initiated a long range program (2025) as a partnership with MRMC /TATRC to develop medical and surgical robotic capabilities including:

(1). Mobility.

(2). Plan and execute search in unmapped interior environments; find and identify wounded soldiers.

(3). Track, record, transmit and act upon real-time physiological information describing location and number of wounded soldiers as well as their positions.

(4). Conduct both remote and real-time diagnosis using heuristic algorithms integrated with pattern recognition imaging systems and physiological sensors.

(5). Perform semi-autonomous and autonomous medical procedures and interventions including surgery with tactile sensing and dexterity.

(6). Evacuate casualties from the battlefield using semi-autonomous and autonomous evacuation platforms and patient support systems such as an advanced LSTAT.

Figure 18. DARPA/USAMRMC Digital Human Robotic Casualty treatment and evacuation vision