United States Department of Defense Research in Robotic Unmanned Systems for Combat Casualty Care

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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 international and coalition troop deployments for peacekeeping operations, counter terrorism, and humanitarian assistance missions that involve highly visible, politically sensitive low intensity combat in urban terrain. The United States Department of Defense (DoD) has significantly invested in autonomous vehicles, and other robots to support its Future Force. By leveraging and augmenting funding from these efforts, the US Army Telemedicine and Advanced Technology Research Center has established a portfolio of projects aimed at developing, integrating or adapting robotic and unmanned ground and air systems to extract battlefield casualties from hostile environments and from under fire. Work continues on a prototype dynamically balanced bipedal Battlefield Extraction Assist Robot (BEAR) which is capable of extracting a 350 pound casualty from various rugged terrains including urban areas with stairs. Another DoD sponsored project is aimed at exploiting Unmanned Aerial Systems (UAS) to bring sophisticated telemedicine and patient monitoring equipment such as "smart stretchers" directly to military medical first responders and troops engaged in combat. In this arena TATRC is collaborating with DARPA to investigate use of UAS to conduct casualty evacuation (CASEVAC) missions and also participating in the NATO HFM-184 "Safe-ride" Technical Panel convened to investigate safety aspects of such missions. Other projects are intended to bring telerobotic and near autonomous casualty assessment and life saving treatment to the battlefield. These have included the DARPA Trauma pod and several TATRC efforts to integrate robotic arms with the Life Support for Trauma and Transport (LSTAT) litter for robotic implementation of noninvasive technologies such as acoustic cauterization of haemorrhage via High Intensity Focused Ultrasound (HIFU). TATRC has also sponsored research in robotic implementation of Raman and Laser Induced Spectrometry (LIBS) to detect and identify potential chemical and biological warfare agents and explosive hazards to casualties and first responders. Focus is on sensor selection and integration as well as electronic command and control messaging

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14. 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 international and coalition troop deployments for peacekeeping operations, counter terrorism, and humanitarian assistance missions that involve highly visible, politically sensitive low intensity combat in urban terrain. The United States Department of Defense (DoD) has significantly invested in autonomous vehicles, and other robots to support its Future Force. By leveraging and augmenting funding from these efforts, the US Army Telemedicine and Advanced Technology Research Center has established a portfolio of projects aimed at developing, integrating or adapting robotic and unmanned ground and air systems to extract battlefield casualties from hostile environments and from under fire.

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via the Joint Architecture for Unmanned Systems (JAUS) to include sensors and telemedicine payloads. In an attempt to generate operational concepts, tactics, techniques and procedures for implementing medical robotic unmanned systems in combat, as well as the technical requirements to enable those procedures, a computer simulation of the BEAR was created for use in the US Army Infantry Center Maneuver Battle Lab's OneSAF (One Semi-Autonomous Forces) tactical operations modelling and simulation system. An initial series of platoon level assaults and clearing operations in both wooded and urban terrain were executed in ONESAF to include casualty extractions using both conventional litter rescues and rescues with the BEAR. This process has great potential for overcoming the numerous barriers to transitioning research prototypes or new and emerging technologies to operational systems. Even our initial simulation and live operational assessments point to significant research challenges ahead in developing and fielding unmanned systems for Combat Casualty Care. We discuss ongoing projects, operational assessments and research challenges.

1.0 INTRODUCTION

Advancement in telecommunication and robotics continue to shift the paradigm of health care delivery. The United States military has provided significant impetus, focus and funding for telemedicine and medical robotics. The US Army Medical Research and Materiel Command (MRMC) Telemedicine and Advanced Technology Research Center (TATRC) and the Defense Advanced Research Projects Agency (DARPA) have spurred innovation in areas such as surgical robotics and the emerging field of "telesurgery". Telecommunication and robotic limitations that prevent robust intervention at a distance are areas of continued military research and development. Medical robots are force multipliers that can distribute expert trauma and subspecialty surgical care across echelons of care. This paper provides a historical context of and future opportunities in military robotic casualty extraction and care that will save the lives and limbs of our deployed warfighters.

Military robotic combat casualty care has three primary goals: safely extracting patients from harm's way; rapidly diagnosing life threatening injuries such as non-compressible hemorrhage, tension pneumothorax and loss of airway; and delivering life-saving interventions. For optimum effect, medical robots must robustly operate in extreme environments and provide effective combat casualty care as close as possible to the point and time of injury. Robotic tactical combat casualty care begins with the extraction of casualties from the battlefield. In the short term, extraction robots will decrease the risk to the soldier and combat medic by safely moving wounded warfighters out of the line of fire. In the longer term, teleoperated and autonomous surgical robots will deliver expert surgical care within the "golden hour" on the battlefield as well as during transport to military treatment facilities.

Beginning in 1999, DARPA and MRMC / TATRC partnered to develop the Digital Human Robotic Casualty Treatment and Evacuation Vision with robotic systems targeted on these priorities:

- Mobility
- Plan/execute search in unmapped interior environments, find and identify wounded soldiers
- Track, record, transmit and act upon real-time physiological information
- Conduct both remote and real-time diagnosis using heuristic algorithms integrated with pattern recognition imaging systems and physiological sensors
- Perform semi-autonomous and autonomous medical procedures and interventions
- Evacuate casualties from the battlefield using semi-autonomous and autonomous evacuation platforms and patient support systems like LSTAT

2.0 ASSESSMENT OF CURRENT STATE AND FUTURE POTENTIAL FOR ROBOTIC COMBAT CASUALTY CARE WITHIN THE ARMY

The Training and Doctrine Command (TRADOC) is the Army's organization for developing new doctrine on how the Army will fight in the future and what capabilities will be needed to support that operational doctrine. In 2009 we contributed to TRADOC's assessment of the state of medical robotics and their potential application to combat casualty care. Currently only a few Warfighter Outcomes are involved with robotics use in medical and surgical tasks. The U.S. Department of Defense Uniformed Joint Task List suggests several topics for improvements in the areas of field medical care and force health protection through robotics. Areas of focus in combat casualty care and surgery are faster casualty recovery and evacuation by fewer personnel, faster and more certain recognition of injuries, and communications supporting remote telemedicine. TRADOC's desired future "Force Operating Capabilities" publication states that: "Future Soldiers will utilize unmanned vehicles, robotics, and advanced standoff equipment to recover wounded and injured Soldiers from high-risk areas, with minimal exposure. These systems will facilitate immediate evacuation and transport, under even the harshest combat or environmental hazard conditions; medical evacuation platforms must provide enroute care", and TRADOC's "Capability Plan for Army Aviation Operations 2015-2024, " states that "unmanned cargo aircraft will conduct autonomous ….. extraction of wounded " . Following was our assessment of the current state and future potential for the combat casualty care robotic applications cited by TRADOC:

2.1. <u>Perform battlefield first aid (tourniquets, splints, shots, IV drips, etc.):</u> Self-assistance by the soldier or the availability buddy care cannot be assumed in all combat situations; likewise, there are never enough combat medics or combat life savers (combat arms soldier with additional medical training) to treat and extract all casualties, especially during intense close combat or in contaminated or otherwise hostile environments. The Army Institute for Soldier Nanotechnology at MIT has ongoing basic research in uniform-based diagnostics and emergency injections. Further, sewn-in tourniquet loops on uniforms are under consideration for fielding, with Soldier-actuation required. Autonomous and robotic first aid treatment may dovetail well with robotic recovery and evacuation tasks. Slow progress is being made in development of sophisticated sensors, autonomous analysis of sensory input, and autonomous application of intervention and treatment procedures, but deployment of such robots is years away. Likewise, local cultural concerns, or confusion among wounded may complicate acceptance of close contact by a first aid robot.

2.2. <u>Recover battlefield casualties</u> : As with battlefield first aid, universal availability of combat medics, combat life savers , or other soldiers assigned to perform extraction and recovery of casualties under fire or in otherwise hostile environments cannot be assumed. Therefore, a means to autonomously find, assess, stabilize, then extract casualties from danger for further evacuation is needed. This may be complicated by unknown nature of injuries, which may complicate or confound a rote mechanical means of body move. For example, a compound fracture or severed limb might not be gripped, or gripping may increase injury. As part of several ongoing research and development efforts in both unmanned ground and air systems for casualty evacuation (CASEVAC), the MRMC is actively addressing the potential complications of robotic casualty extraction. Discussed further below, the tele-operated semi-autonomous Battlefield Extraction Assist Robot (BEAR) represents a developing casualty extraction capability which can carry a 500 pound load while traversing rough and urban terrain with dismounted soldiers. A fully autonomous version of the BEAR would need significant additional artificial intelligence programming and a transparent hands-free soldier-robot interface to integrate the performance of this mission in combat while keeping the soldier-operator focused on their primary mission. Research in autonomous flight control and navigation technologies needed for CASEVAC via Unmanned Air Systems (UAS) is ongoing but actual employment of operational systems is probably years away because of the current immaturity of autonomous en route casualty care systems.

2.3. Robotic detection, and identification of force health protection threats: Detection and identification of chemical and biological threats to which combat casualty patients may have been exposed, and segregation and containment of contaminated casualties prior to receiving casualties in forward medical and surgical treatment facilities are critical capability needs. The MRMC has several completed and ongoing research projects in robotic detection and identification of chemical and biological and agents and chemical contaminants. The goal is to produce modular threat detection and identification systems that can be implemented on robots performing other missions, such as casualty extraction. These efforts utilize robotic enabled RAMAN, Florescence, and Laser Induced Breakdown Spectroscopy (LIBS) as well as antigen-based technologies.

2.4. Perform telemedicine/surgery: Remote tele-operated medicine is feasible, but with limitations. Visual examination information is planar, and may lack depth and full 5-sense information (e.g., tactile feedback). As a human assistant will likely be required, a question arises as to the feasibility of doing better than having a trained human assistant, local to the patient, relaying information back to the remotely located surgeon. However, vital signs (e.g. skin temperature, pulse, blood pressure) may be available via biomonitors contained on a simple robotic platform arm. Proof of concept projects have demonstrated the feasibility of remote robotic diagnosis and treatment of patients. The DARPA 'Trauma Pod' project discussed below was an attempt to leverage emerging advanced imaging technologies and robotics to enable autonomous casualty scan, diagnosis and intervention, MRMC also has several physiological sensor and image-based robotic casualty assessment and triage research projects underway. However, these capabilities are currently only experimental and are non-ruggedized, tele-operated component capabilities at best. The idea of far forward combat telesurgery in combat is compelling; a surgeon controlling a robot's movements in a distant location to treat an injured soldier could serve as a force multiplier and reduce combat exposure to highly trained medical personnel. At first glance, remote tele-operated surgery capability appears to already exist since minimally invasive operations have been remotely performed using dedicated fiber optic networks, the Zeus and daVinci surgical robots have been and are currently used in civilian hospitals and many other telesurgery demonstrations and experiments have been conducted around the world. Military funded research as discussed below has demonstrated that surgical robotic systems can be successfully deployed to extreme environments and wirelessly operated via microwave and satellite platforms. However, significant additional research is required to develop supervisory controlled autonomous robots that can overcome the operational communication challenges of limited bandwidth, latency, and loss of signal in the deployed combat environment. Addressing acute and life threatening injuries such as major non-compressible vascular injury requires development of new surgical robots that move beyond stereoscopic, bimanual telemanipulators and leverage advances such as autonomous imaging analysis and application of directed energy technologies already used in non-medical military robotic systems.

Figure 1. DaVinci Robotic Surgery System

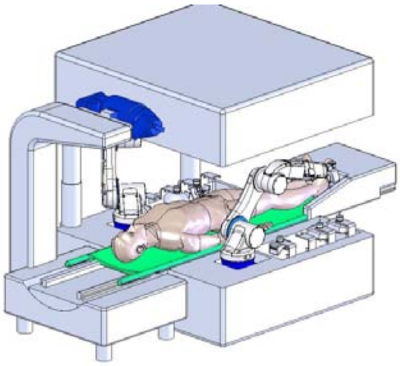

Figure 2. Portable Trauma Pod Concept

3.0 ROBOTIC CASUALTY EXTRACTION, EVALUATION AND EVACUATION

The US military has funded multiple robotic projects focused on casualty extraction, evaluation and evacuation. Robotic casualty extraction research is focused on the development of semi-autonomous systems that will safely extract the casualty from the line of fire, deliver the casualty to medical care, and limit risk to care providers. Representative systems are briefly described below:

3.1 TAGS CX (Tactical Amphibious Ground Support system – Common Experiment)

The Army Medical Robotics Research through the Army's SBIR (Small Business Innovation Research) Program through TATRC contracted Applied Perceptions Inc. (Cranberry Township, PA) as the primary research entity for an extraction and evacuation vehicle. A tele-operated semi-autonomous control system capable of maneuvering a marsupial robotic vehicle was developed with a three module concept. The TAGS-CX novel dual design vehicle consists of a small, mobile manipulator (REX) for short-range extraction from the site of injury to the first responder and a larger faster vehicle (REV), which would deliver the wounded soldier to a forward medical facility. The smaller vehicle resides within the larger REV, which is equipped with two L-STAT stretchers and other life support systems. The TAGS-CX platform provides a modular and interoperable ground robot system that could be modified for multiple purposes. The Joint Architecture for Unmanned Systems (JAUS) control platform was used to enable a standardized C2 interface for the OCU (Operational Control Unit) along with standardized mechanical, electrical, and messaging interfaces capable of supporting multiple unique "plug and play" payloads. This prototype robotic extraction vehicle also integrated other control technologies. These include GPS-based autonomous navigation, search and rescue sensing, multi-robot collaboration, obstacle detection, vehicle safe guard systems, autonomic vehicle docking and telemedicine systems.

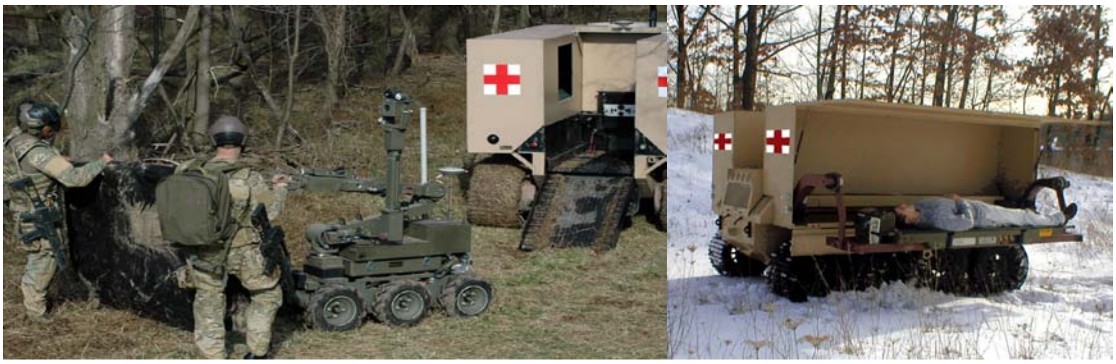

Figure 3. Robotic Evacuation & Extraction Vehicles (REV/REX)

The US Army's TARDEC (Tank-Automotive Research, Development, and Engineering Center) has developed a ground mobility, robotics systems integration and evaluation laboratory, TARDEC's Robotic SkunkWorks facility. This laboratory's goal is to assess and integrate novel unmanned systems technologies to support efficient conversion of these technologies to PM/PEO (program managers/program executive officer) and ATO (Advanced Technology Office) programs. The first unmanned system evaluated was the TAGS-CX, an enhanced version of the TAGS designed to support multiple modular mission payloads. The most significant identified issue during the trials of the original REV vehicle was that the REV was designed to be completely unmanned and as a dedicated MEDEVAC vehicle. Currently and for the foreseeable future the US Army would not allow wounded soldiers to travel without a human medic or attendant. Based on this feedback the TAGS-CX concept was redesigned to incorporate a removable center module for an on-board medic and would allow for manual operation of the vehicle. Additionally the patient transport bays were designed and constructed as modular "patient pods" which would enable the TAGS-CX to be used for multiple combat support missions, CASEVAC being just one.

Figure 4. Tactical Amphibious Ground Support System – Common Experimental (TAGS-CX) with Patient Transport and Operator/Attendant Modules

3.2 BEAR – BATTLEFIELD EXTRACTION ASSIST ROBOT

The BEAR (Vecna Technologies Cambridge Research Laboratory, Cambridge, MA) prototype was initially started with a TATRC grant in 2007 with the objective of creating a powerful mobile robot, which was also highly agile. It would have the capability to find and then lift and carry a combat casualty from a hazardous area in varying terrain. Vecna Technologies was founded in 1998 and initially produced a proof of concept prototype (Bear Version 6), which was featured in Time Magazine's Best Inventions of 2006. This machine was intended to be capable of negotiating any general hazardous terrain and not be limited only to the battlefield. The Bear robot is extremely strong and agile approximately the size of an adult male. The original prototype was is composed of an upper torso with 2 arm actuators and a lower body built around the Segway RMP base with additional tank tracks on its analogous thighs and calves. It is designed to lift 500lbs (the approximate weight of a fully equipped soldier) and move at ~10 miles per hour. It utilizes gyroscopic balance that enables it to traverse rough and uneven terrain.

The latest iteration of the Bear (version 7) has several redesigned components. These include a sleeker, stronger, and more humanoid appearing upper torso, integration of NASA's Actin software for coordinated control of limbs and upper torso, and a lower body with separately articulating tracking leg subsystems, a novel connection and integration of the lower body and upper torso components, completion of the "finger-like" end effectors, and a Laser Induced Breakdown Spectroscopy (LIBS) detector for chemical, biological, and explosive agents. The system will incorporate a variety of input devices including multiple cameras and audio input. The initial control of the BEAR is via a remote human operator but work is underway for more complicated semi-autonomous behaviors in which the robot understands and carries out increasingly higher-level commands. Other planned inputs include pressure sensors that will allow it to have sensitivity to a human cargo. Another milestone is the completion of the first phase of continuing BEAR characterization and operational simulation and assessment at the Army

Infantry Center Maneuver Battle Lab (MBL), The humanoid form enables the robot to access most places that a human would includes stairs. The versatility of this robot includes applications within hospitals and nursing homes where infirmed patients with limit mobility could be easily moved.

Figure 5. Battlefield Extraction Assist Robot (BEAR)

3.3 COMBAT MEDIC UAS FOR RESUPPLY AND EVACUATION

TATRC has also provided support for aerial robotic systems. This project focused on autonomous UAS (Unmanned Aircraft System) takeoff, landing, navigation in urban and wooded environments and the coordination and collaboration between UAS ground controllers and human combat medics to that proper care and evacuation can be performed during the golden hour. Five Phase I SBIR grants were given out to identify notional concepts of operation as well as develop technical models that recognize requirements in implementable UAS system designs. Phase 2 grants went to Dragon Fly Pictures Inc. and Piasecki Aircraft both of Essington, PA. Phase II focuses on navigation through urban/wooded terrain to combat site of injury, selection of a suitable autonomous landing and takeoff site with minimal human input, autonomous safe landing and takeoffs, communication with a human medical team, and carrying a payload of medical supplies including a Life Support for Trauma and Transport (L-STAT) system. Phase II concludes with live demonstrations of these capabilities using real aircraft.

3.4 RAMAN CHEM/BIO/IED IDENTIFICATION DETECTORS.

Research interest in providing these unmanned ground vehicles (UGV) extraction platforms with chemical, biological, and explosive (CBE) detection systems based on Raman spectroscopy so that they have the operational ability to identify environmental toxins and provide force protection. Currently UGVs are unable to provide any early information as to the possible toxic hazards in the environment. TATRC along with MRMC and other governmental agencies have funded development of several JAUS compliant robotic CBE identification systems that could be placed on unmanned extraction vehicles.

The Raman detection technological advantages are that it is reagent less, which simplifies deployability and can detect a broad range of CBE threats in a single measurement cycle. Reagent based detection methods must start with some assumption as to the possible threat. The Raman Effect has been used for years and depends on the phenomenon that when a photon encounters a molecule it imparts vibrational bond energy to this molecule. This exchange creates a slight disturbance in the frequency in a small amount of scattered light. Each chemical bond has its own unique frequency shift, which allows for creation of the Raman spectrum and the identification of chemicals.

Figure 6. Proximity Raman CBE Detector

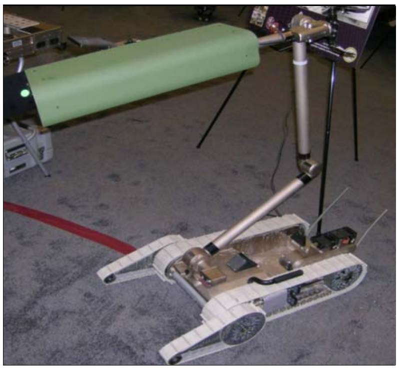

Figure 7. Standoff Raman/Florescence CBE Detector

The overall concept of this technology is to integrate a Raman sensor head onto a manipulator arm on the UGV, which is then coupled to an onboard or self contained spectrometer analyzer. When integrated with a robot, Raman spectroscopy detectors contain a video camera and fine positioning system that will allow for targeting of the head, laser illumination of the sample to induce the Raman Effect, optics to collect and focus the scattered light, a fiber optic bundle to transport the scattered light to a spectral analyzer. In proximity applications, the Raman detector needs to be close but not necessarily touching the object; in stand-off applications the laser, spectroscope, and analysis computer can operate from a distance. Once the materials unique Raman effect has been detected it can then be compared to a spectra library of known materials to provide robust identification of whether the chemical is a threat. Several TATRC funded proximity and stand-off prototypes have been developed and integrated with robots.

3.5 L-STAT system (Life Support for Trauma and Transport)

The L-STAT system (Life Support for Trauma and Transport, Integrated Medical Systems Inc., Signal Hill, CA) was developed by a DARPA funded grant in 1999 in conjunction with the United States Marines. This system has seen deployed to the 28th and 31st Combat Support Hospitals (CSH) in Iraq and Afghanistan, Navy amphibious assault ships, national guard units in Alaska and Hawaii, special operations teams in the Philippines and Cambodia, and also domestically at select United States trauma centers (University of Southern California and the Navy Trauma Training Center both in Los Angeles, CA). L-STAT could integrate components of intensive care monitoring and life support functions. This platform acts as a force multiplier and allows for patients to be cared for with less direct attention by medical personnel during transport to Combat Support Hospitals or Battalion Stations. As stated before focus on the golden hour of trauma is due to the fact that 86% of all battlefield mortality occurs within the first 30 minutes. The majority of which are due to hemorrhage (~50%) followed by head trauma which leads to seizures and ischemic reperfusion injuries and these are the focus of L-STAT. The original version of L-STAT was extremely cumbersome and weighed 200lbs which severely limited its utility. Some more recent systems are much more mobile and include the L-STAT Lite, MOVES, and Lightweight Trauma Module.

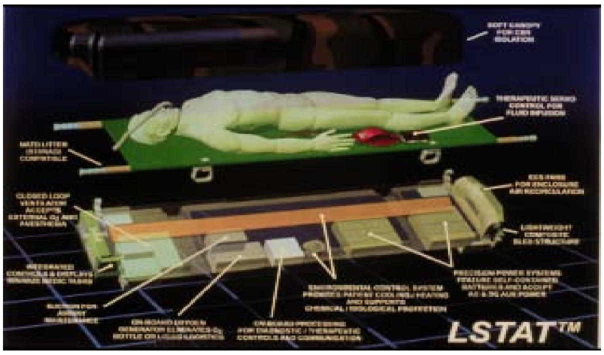

Figure 8. Life Support for Trauma & Transport System

Figure 9. MedEx 1000 (L-STAT Lite)

A review of L-STAT identified possible future technologies for the next generation L-STAT (NG-LSTAT) and concluded there were multiple areas of potential improvement in diagnostic and therapeutic capabilities. The possible diagnostic additions included digital X-ray, portable ultrasound, medical image display and telediagnosis via remote controlled camera. Prospective therapeutic additions included the utilization of serpentine robotic manipulators for performing intubation, ultrasound catheterization for intravenous access and assisting in the application of HIFU (High Intensity Focused Ultrasound) for treating hemorrhage. The addition of bioinformatics, wireless data communication, additional imaging capabilities, robotic manipulators, and increased mobility would move the NG-LSTAT further toward the goal of an autonomous field deployable surgical platform. A lightweight version of the LSTAT called the MedEx-1000 which weighs less than 40 pounds and can be used independently of a litter was developed and released for sale in 2009.

4. 0 SUMMARY

The technological revolution of the past three decades is catalyzing a paradigm shift in the care of battlefield casualties. Telecommunications and robotic technology can revolutionize battlefield care by safely extracting patients from harm’s way, rapidly diagnosing life threatening injuries, and delivering life-saving interventions. Telecommunication and robotic limitations that prevent robust intervention at a distance are areas of continued military research and development. As these limitations are overcome, medical robots will provide robust casualty extraction and care that will save the lives and limbs of our deployed warfighters.

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