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# Imaging Components for a Robotic Casualty Evaluation System

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*Abstract*—**Combat medics have a vital role in the protection of wounded soldiers in the battlespace. However, their duties expose them to great risks. Furthermore, these medics are a limited resource and must be carefully tasked in order to provide maximum benefit to their units. For these reasons, we are applying the American GNC Corporation's (AGNC) Coremicro® Robotic System for autonomous evaluation of battlefield casualties. These robots are intended to navigate to a casualty, determine his/her overall health status, and perform limited diagnostic imaging in order to assess the presence of injuries that would prevent or complicate extraction. In this paper, we describe development work on some of the key components of the proposed robotic system, namely the overall concept of operations (ConOps) and initial testing of infrared and ultrasound imaging cameras. When fully deployed, this system will act as a medical force multiplier, enabling improved care of wounded soldiers and protecting the health and safety of military medical personnel.**

## I. Introduction

THE combat medic has a vital role in protecting the wounded soldier on the battlefield. However, the very nature of the medic's work exposes them to significant risks. In addition to the hazards associated with ordinary trauma care, military medics must operate in hostile environments where dangers include enemy combatants, concealed explosives, chemical hazards, biological weapons, and radioactive materials. Historically, the casualty rate for medics has been much higher than for other soldiers.

For these and many other reasons, there are strong motivations to develop robotic systems that can act as force multipliers for military medical personnel. AGNC's Coremicro® Robot is used for casualty identification and assessment, delivery and transport of medical supplies, and evacuation from the battlefield to a higher level care facility. In order to realize such goals, numerous technical challenges must be overcome. An AGNC Coremicro® 4D GIS [1] sophisticated command and control system is used since information from the battlefield comes in many forms and then must be translated into coherent unit activities.

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To meet these challenges, we are designing workflows and imaging components that could support an integrated robotic casualty evaluation system. In this paper, we describe engineering studies for these important subsystems. The first section deals with the Concept of Operations or triage workflow. The second section covers pilot studies using infrared and ultrasound cameras for casualty assessment.

## II. Concept of Operations (ConOps)

The vision for a robotic casualty evaluation system is to preserve the basic elements of established combat casualty care while using advanced methods to more thoroughly evaluate patients. Our system also specifically addresses important questions relating to robotic casualty extraction from the battlefield, since this is another area of strategic research and development for the military.

When the system first becomes aware of a casualty (either through reports from other soldiers or a wide area scan), it dispatches a Coremicro Robot system for triage. When the triage Coremicro Robot first arrives on scene (having established that there are no major environmental hazards) it can begin the triage process. Initially this involves standoff measurements or contact measurements of vital signs and visual evaluation. Several companies (e.g., PERL Research, Huntsville, AL) are developing such measurement methods under the Department of Defense Joint Architecture for Unmanned Systems (JAUS) protocol, so it will be straightforward to integrate these components into our system. If the casualty is obviously dead, the Coremicro Robot will report the location back to its central control and then await further instructions.

If the casualty is alive, the Coremicro Robot then moves through a series of other evaluations. Since uncontrolled bleeding is a major cause of death, the first check is whether such bleeding is occurring. Vital signs from stage 1 triage can be used to indicate potential internal bleeding, and infrared imaging can then be used to home in on the source. The Coremicro Robot may then apply pressure (depending on its design) or direct other caregivers to do so.

The next step is to determine if the casualty is under respiratory distress. If so, the Coremicro Robot may be able to provide an artificial airway or oxygen, depending on its payload.

Next, the Coremicro Robot will check for sensorimotor integrity and establish a Glasgow Coma Scale (GCS) score. This requires action from the casualty (for example, moving the hands or feet and looking around). Simple recorded voice commands can be used to prompt the casualty, which will ensure that the motions are voluntary. Should these signs indicate possible spinal cord injury, a further evaluation using ultrasound or infrared imaging will be required. If this imaging reveals a definite (or very likely) spinal cord injury, the system will be able to notify its central command that stabilization is required before the casualty can be evacuated.

The last step is similar to that used for spine imaging, but the focus is instead on extremity fracture. The imaging components used for the spine will be able to assess the severity of injuries to the arms, legs, and skull in order to better characterize the patient's condition, and whether or not further immobilization is needed before evacuation. The new proposed triage workflow is shown in Fig. 1.

## III. Ultrasound Imaging for Casualty Assessment

Battlefield assessment of injuries requires that the imaging/sensing system be compact, low power, and ideally free from any potentially harmful side effects while still maintaining diagnostic accuracy. Given the fact that many casualties will be lying on the ground and not movable, transmission imaging systems such as x-ray radiography would be difficult to implement. Other conventional imaging modalities such as MRI and nuclear medicine are similarly limited by power and form factor considerations.

Ultrasound is potentially an ideal modality because the device can be made into small probes that could be carried by the Coremicro Robot. Ultrasound also produces no ionizing radiation and can penetrate several cm into the human body, enabling the assessment of deeper structures.

There are naturally some challenges to using ultrasound in this setting, namely that ultrasound cannot penetrate clothing or armor and normally needs a coupling gel between the skin and the sensor to provide impedance matching. Locations on the body that are normally uncovered, such as the hands and cervical spine, will be easily accessible, but accessing the ribs might require cutting through clothing. This task could be performed by the Coremicro Robot's built-in arm, or a fellow soldier could be directed to assist the robot in this task. Coupling gel or fluid will be released from reservoirs in the ultrasound sensor housing so that the sensor is fully covered before it contacts the skin.

For initial testing of the ultrasound system, we used an Imperium I500 (fifth-generation) ultrasound sensor in a water tank. The Imperium ultrasound system is unique in that it produces a view of the object being imaged with the viewing plane parallel to the sensor ("C-mode"), as opposed to a conventional B-mode ultrasound system which images a wedge-shaped single plane extending into the material. This capability makes it much easier to scan over a surface for defects or hidden objects. However, the sensor can only operate as a detector, so an external transducer is required. For these tests, the sample was a segment of swine tibia where a fracture was simulated by cutting a small notch (0.6 mm wide and 2 mm deep) in the bone using a saw. The sample was insonated by a 3.5 MHz transducer through an angled beamsplitter, which allowed the ultrasound sensor to be perpendicular to the transducer face as shown in Fig. 2. Because the transducer and the sensor are separate components, other geometries and multi-transducer/multi-sensor arrangements that could provide increased detection capabilities are possible, and will be investigated in the future.

Results from the ultrasound imaging are shown in Fig. 3. The defect in the bone is easily visible as a bright line on these images, corresponding to the increased reflection from the defect.

## IV. Infrared Imaging for Casualty Assessment

Infrared (IR) imaging could be a very useful tool for the Coremicro Robot casualty evaluation, as the body's thermal signature is closely related to blood flow. In addition to having no harmful side effects, IR can potentially cover a large field of view. This makes it an intriguing complementary modality to ultrasound, because the infrared can be used for wide field imaging whereas the ultrasound can be used for detailed near field imaging.

We used an infrared camera (Model: Photon 160, by FLIR Inc.) interfaced to a frame grabber (Model: Canopus, by MATROX Inc.) for this study. Though the image is enlarged to 640 by 480 pixels for display purposes, the real image data are captured at 160 by 128 pixels corresponding to each of the array elements of the CCD (Charge Coupled Device) of this infrared camera. This camera is compact and lightweight, allowing it to be easily deployed in austere environments such as the battlefield. Although we intended to take infrared images from a living swine, the swine died before a scheduled experiment. Therefore, we had to take pictures of the dead swine body. A veterinarian at Georgetown University helped us to create a simulated injury by making an incision on the neck of the swine. The size of the wound was approximately 6 cm width by 10 cm length. Infrared images were taken before and after the injury and compared to measure intensity differences.

For comparing the images acquired before injury (BI) and after injury (AI), we selected 10 reference points across the swine body and away from the injury site for calibration. At each reference point we computed the average value of 5 by 5 pixels. By using these reference points we could map image values acquired after injury into image values acquired before injury, thereby allowing us to correct for global changes in image intensity. Using this calibration, we then compared the gray scale values at 7 points of interest in the injured region.

We observed that the gray scale values in the wound area were significantly decreased (intensity change of 30 to 50 compared to a background variability of approximately 5) in terms of gray scale values. This effect was observed in the region surrounding the injury as well. These results imply that the surface temperature decreased at the wound site and its surrounding region on the dead body.

We have not yet been able to scan a live swine with a similar wound to determine what differences would be present. However, the presence of active tissue perfusion and blood on the surface of the wound will certainly alter the temperature profiles and emissivity of the inspected area.

## V. Conclusion

This paper provides an overview of important components for the Coremicro Robot system designed to provide triage and medic support in the battlefield environment. In the initial phase of the project, we have developed a triage workflow, tested a novel ultrasound system for use as a contact sensor to determine the presence of bony fractures, and investigated the use of infrared imaging for surface wound detection.

Many challenges still remain for the development of the complete and final system. In the next phase of the research, we will improve on the existing ultrasound system and perform more extensive testing of the ultrasound system using patients from an emergency room setting and animal models. We will also investigate the use of infrared imaging for non-contact casualty assessment in a similar trauma population.


## VI. Acknowledgment

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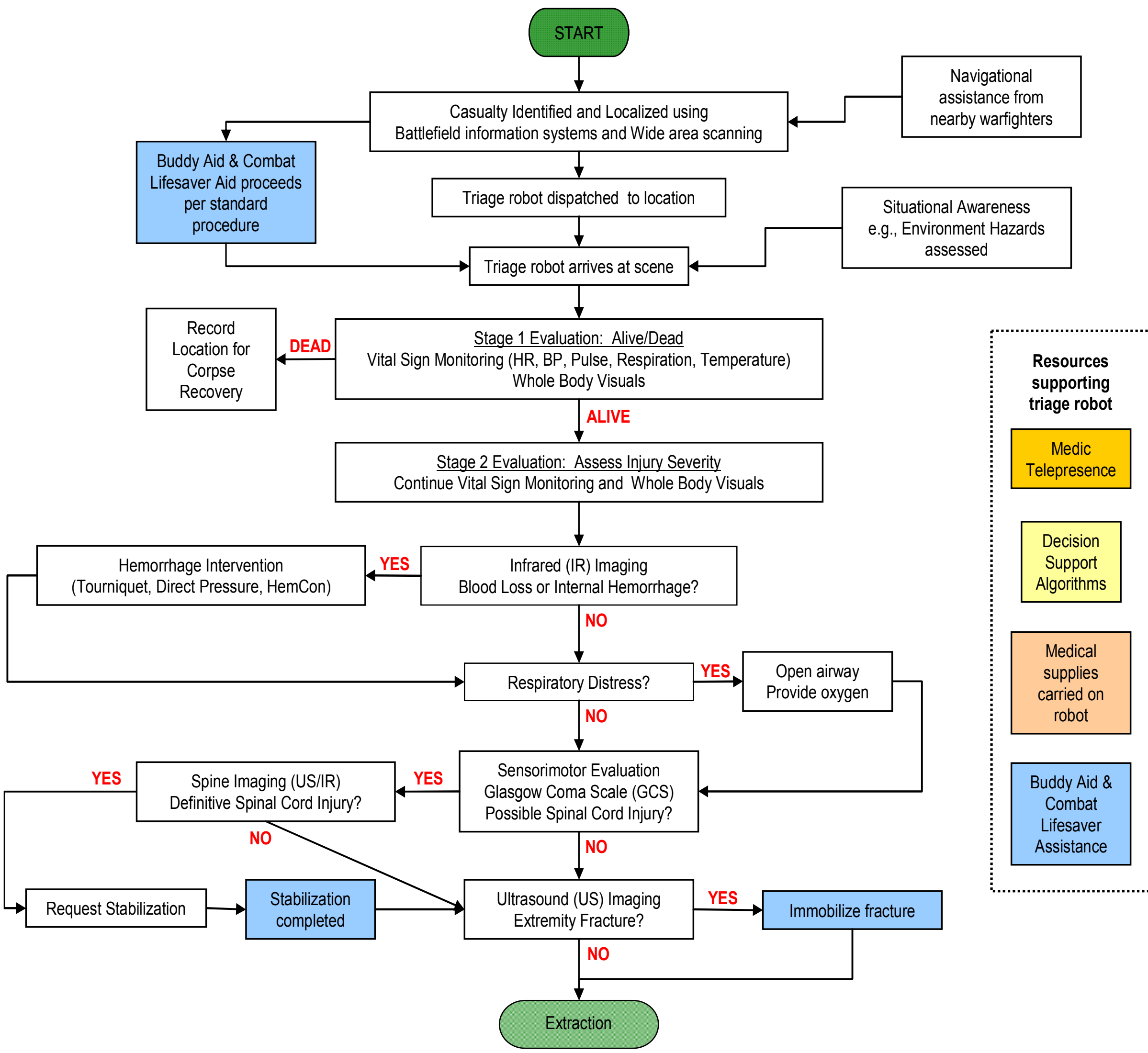


Fig. 1. Workflow for a Coremicro Robot triage system. The system moves through different stages of evaluation using a variety of sensors, at each stage assessing medical factors in order to determine whether the casualty is stable or requires additional assistance before being evacuated.

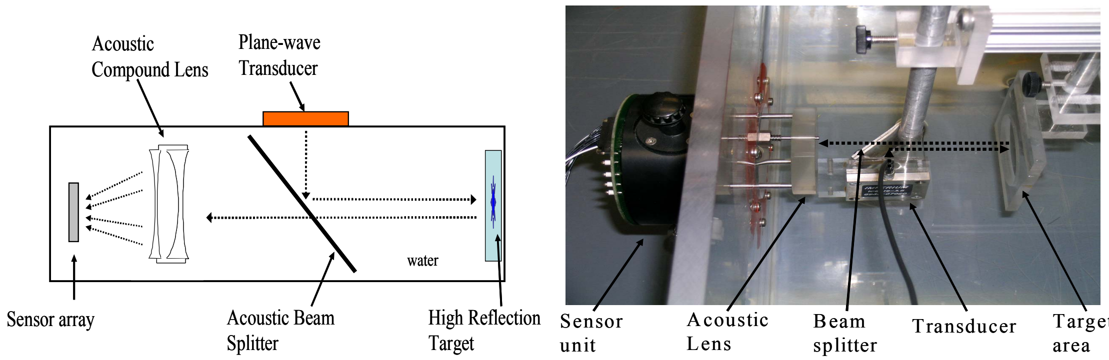


Fig. 2. Diagram (left) and photograph (right) of the ultrasound imaging setup.

(A) (B-1) (B-2)

Fig. 3. Results from the ultrasound imaging test, showing the defect in the bone as a bright hyper-reflective region of the image. Image A is taken without skin and tissue (bone only), whereas images B-1 and B-2 are taken with the skin and tissue in place. B-1 and B-2 are taken from slightly different angles relative to the bone sample.

(A) (B) (C)

Fig. 4. Images from the infrared swine study. (A) Photo image after injury; (B) Zoomed infrared image before injury; (C) Zoomed infrared image after injury.

## References

[1] 4D-GIS Virtual Reality for Controlling, Monitoring, and Prediction of Manned/Unmanned Systems (Coremicro 4D GIS), American GNC Corp., http://www.americangnc.com/products/4DGIS.htm.