# The Combat-Wireless Health Monitoring System

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*The proposed combat-wireless health monitoring system (C-WHMS) allows for the seamless monitoring of a unit's medical health during combat operations, facilitating rapid injury identification and treatment. The C-WHMS quickly identifies soldiers who may have sustained traumatic injuries and whose lives may be saved by attending to them during the so-called "golden hour," as well as provides historical data to improve re-deployment and post-deployment health assessments.*

Soldiers deserve the best medical care technology has to offer and should be the direct beneficiaries of technological advancements in trauma care. Such advancements include a comprehensive battlefield recording medical system, which is known as the Medical Communications for Combat Casualty Care (MC4).

The normal flow of events involves casualty identification by self-aid, buddy aid, or combat lifesaver. Once the casualty is identified, the combat medic provides tactical trauma care using appropriate medical equipment and supplies. In the past, the combat medic recorded medical care given to the casualty on a DD Form 1380 (Field Medical Card). In recent years, however, combat medics have used the MC4 system to record medical care given. The MC4 system is supported by a suite of applications that are included in the Defense Health Management Information System line of products. The MC4 has a store-and-forward capability, sending patient information forward when connectivity is available. Once the casualty is triaged with pertinent patient information captured on the MC4 system, the casualty is transported either to a battalion aid station or major treatment facility, as required.

As of today, the MC4 system has recorded more than 10 million electronic patient encounters using the MC4 system [1]. This technology, however, does not dynamically track injured soldiers at the point of injury. Research is underway to do just that by providing combat medics a means to remotely monitor casualties. One such technology is the Warfighter Physiological Status Monitor (WPSM). The WPSM will provide commanders and medics with the ability to actively monitor vital signs, core temperatures, and skin temperatures. Based upon acoustic measurements, ballistic impact detection will be monitored by the WPSM [2]. Researchers successfully test-ed the WPSM during a WMD exercise, remotely measuring vital signs and core temperatures of test subjects donned in chemical protective suits [3]. This research did not monitor concussions sustained by casualties.

This article proposes the development of a new C-WHMS as an alternative to the WPSM. The C-WHMS enhances the diagnostic capabilities of

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combat medics. The C-WHMS has yet to be built, but the reference technology is currently available. This article serves as a blueprint for combining technology into a single system.

Without replacing the assessment or decision-making responsibilities of unit leadership and medical staff, the role of the C-WHMS will allow the combat medic to perform real-time monitoring of the unit's medical readiness during combat operations, aiding the rapid identification of soldiers who may have sustained traumatic injuries. Telemedicine is a component of the C-WHMS, and allows the combat medic to communicate directly with a doctor over a video-conferencing system.

The proposed C-WHMS also includes a Military Smart Shirt that monitors soldiers' vital signs as well as pinpoints entrance and exit wounds. The C-WHMS allows combat medics to make a more accurate medical assessment of a traumatic injury as well as the level of shock the soldier may be experiencing. The C-WHMS includes a concussion monitoring system embedded within the Advanced Combat Helmet (ACH), which measures concussions sustained during the execution of combat operations. The components of the C-WHMS are discussed in this article, as well as the logical flow of responses to sensed data by the C-WHMS and the handling of alert messages emanating from the C-WHMS.

Before discussing the C-WHMS, a quick overview of Bluetooth is in order since it is an essential part of the C-WHMS.

## Bluetooth Overview

Bluetooth networks (piconet) are generally comprised of seven slave nodes and one Master Node. If the Bluetooth is a Class I device, then the maximum communication distance is 100 meters in ideal conditions.

Bluetooth versions, prior to Bluetooth Version 2.1 + Enhanced Data Rate (EDR), communicate with their Master Nodes through a three-staged process: inquiry procedure, paging procedure, and established connection. Previous versions also supported the ability to avoid collisions with other slave nodes vying for the Master Node's attention via a back-off algorithm. According to researchers, this peer discovery and connection process led to a latency period not conducive to health care. They propose using Bluetooth Version 2.1 + EDR [4].

Researchers also argue that paging procedures—the main cause of connection latency—are not needed in Version

# Report Documentation Page

| 1. REPORT DATE<br>**DEC 2009** | 2. REPORT TYPE | 3. DATES COVERED<br>**00-11-2009 to 00-12-2009** | |
|---|---|---|---|
| 4. TITLE AND SUBTITLE<br>**The Combat-Wireless Health Monitoring System** | | 5a. CONTRACT NUMBER | |
| | | 5b. GRANT NUMBER | |
| | | 5c. PROGRAM ELEMENT NUMBER | |
| 6. AUTHOR(S) | | 5d. PROJECT NUMBER | |
| | | 5e. TASK NUMBER | |
| | | 5f. WORK UNIT NUMBER | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**Georgia State University,10810 Glenbarr Dr,Johns Creek,GA,30097** | | 8. PERFORMING ORGANIZATION REPORT NUMBER | |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | | 10. SPONSOR/MONITOR'S ACRONYM(S) | |
| | | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) | |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br>**Approved for public release; distribution unlimited** | | | |
| 13. SUPPLEMENTARY NOTES | | | |
| 14. ABSTRACT | | | |
| 15. SUBJECT TERMS | | | |

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **Same as Report (SAR)** | **6** | |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

2.1; thus, the previous Bluetooth versions' three-staged connection procedure is collapsed into two stages: inquiry procedure and data delivery. Version 2.1 provides extended inquiry response, allowing 240 bytes of data transferred, along with the slave node's inquiry procedure [5].

Through simple secure pairing, researchers indicate that Version 2.1 can use public and private key pairing. This allows limited protection against passive eavesdropping and *man-in-the-middle* attacks [5]. With 79 possible channels and a frequency hopping rate of 1,600 hops per second, security is enhanced with Version 2.1.

To validate this level of security, testing in an electronic monitoring environment that replicates the battlefield environment is needed. Various components of the C-WHMS are based upon technologies geared to support the civilian sector. Power emissions of the Bluetooth device may need to be reduced to present a smaller footprint and target.

Finally, an election process is needed to elect Master Nodes when the primary Master Nodes are not available due to power failure or when out of communication range. In this article, the slave node is referred to as the Soldier's Local Server (SLS). The Master Node, however, retains its designation.

## Components of the C-WHMS
### The Military Smart Shirt

The Military Smart Shirt concept is based upon research and development of a smart shirt prototype by Georgia Tech in 1996. Initially funded by the Defense Advanced Research Projects Agency through the Department of the Navy, the smart shirt uses optical fibers to detect bullet and shrapnel wounds, using special interconnected sensors to monitor the body's vital signs during combat conditions. The smart shirt provides, for the first time, a systematic and personalized way of monitoring soldiers' vital signs—such as heart rate, electrical activity in the heart, body temperature, and pulse oximetry ($SpO_2$)—in an unobtrusive manner [6]. According to the researchers:

> Just as special-purpose chips and processors can be plugged into a computer motherboard to obtain the desired information processing capability (e.g., high-end graphics), the chosen motherboard paradigm provides an
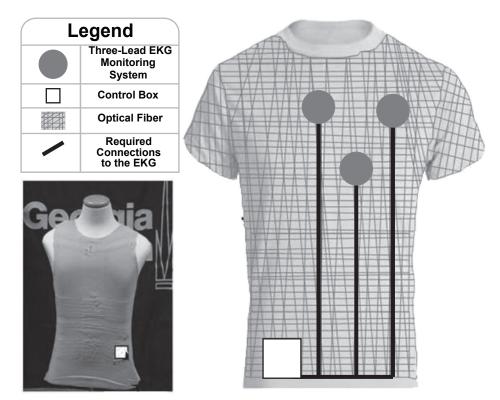


Figure 1: *Military Smart Shirt*

extremely versatile framework for the incorporation of sensing, monitoring, and information processing devices. [7]

Several versions of the smart shirt have been produced. With each succeeding version, the garment has been continually enhanced from all perspectives: functionality, capability, comfort, ease of use, and aesthetics. VivoMetrics provides a commercially developed example of another approach to monitoring vital signs with the LifeShirt [8].

Based upon Georgia Tech's initial research, Figure 1 illustrates a proposed Military Smart Shirt, consisting of a three-lead electrocardiogram (EKG) monitoring system, optical fibers, and a control box. Since the Military Smart Shirt can monitor multiple vital signs, it doesn't need to be restricted to taking an EKG. For instance, $SpO_2$ is very useful for seeing if there is enough oxygen in the blood (and going to the brain). The three-lead EKG monitoring system periodically performs a check of the soldier's vital signs. The control box receives vital

signs from the three-lead EKG monitoring system, then forwards sensed data to the SLS—a wearable watch (as shown in Figure 2).

In addition to the three-lead EKG monitoring system, the Military Smart Shirt consists of optical fibers. These fibers are interconnected with sensors that gauge whether or not they have been severed due to a foreign object, registering the exact location of an entrance or exit wound. After the penetration of the Military Smart Shirt, continuous monitoring of the soldier's vital signs is required. The control box monitors the system health of the shirt and records data from optical fibers and the three-lead EKG monitoring system.

In [9], the authors illustrate how data transfer paths for the Military Smart Shirt must be programmed to ensure effective integration and communication between the control box and sensors via optical fibers. The arrangement of the control box is critical in creating an architecture that is wearable, washable, and flexible, while serving as a motherboard that can fulfill stated requirements. Power consid-
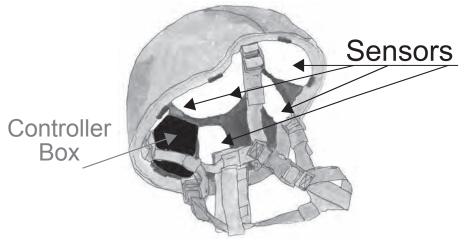
Figure 2: *Soldier's Local Server*

Figure 3: *ACH Concussion Monitoring System with Sensors*

erations are an important consideration as well. Ongoing missions will require a means to repower or replace power-depleted Military Smart Shirts.

### The ACH Concussion Monitoring System

The concussion monitoring system is the second component of the C-WHMS, as embedded in the ACH. Concussions sustained by soldiers are a major concern of military leadership. The goal is to quickly and accurately assess cases of suspected brain trauma injuries.
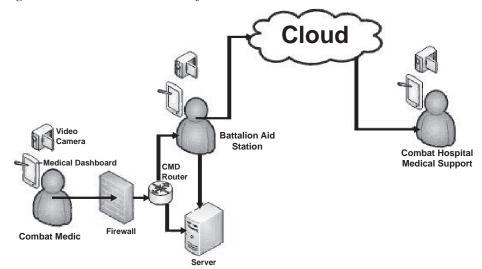
Currently, the Military Acute Concussion Evaluation (MACE) exam is used extensively by military medical personnel to confirm the diagnosis of a mild or severe case of brain trauma. As a tool, MACE is based upon the soldier's medical history of previous brain trauma injuries and uses standardized tests to gauge the impact of the brain injury on memory and concentration [10]. MACE lacks electronic records of actual brain trauma sustained during combat opera-

tions. The proposed concussion monitoring system provides an automated means to electronically record brain trauma injury, providing real-time notification to combat medics; it augments—but does not replace—MACE.

There are two options for automating the means of electronically recording traumatic brain injuries. The first option is based upon Riddell's product: Riddell Revolution IQ HITS. This system is a football helmet capable of storing up to 100 impacts. This equipment sends impact data to wireless monitoring systems located on the sidelines [11].

Figure 3 shows that an ACH can be retrofitted with sensors that serve dual purposes: as cushions and impact sensors. The control box would be located behind the rear stabilizing pad and would monitor data from impact sensors. As soldiers may potentially drop their ACH while not wearing it, false positives can be reduced by requiring all sensors to have positive contact with the wearer's head for the system to function.

If a severe impact is sensed, then the data is stored in the control box and is forwarded to the SLS. An outtake of the soldier's vital signs is taken to determine the medical status of the soldier and whether or not the soldier is in the beginning stages of shock. The control box can store 100 counts of impact that exceed threshold levels as well as associated vital signs, forwarding data to the SLS if a registered impact exceeds preestablished thresholds.

The second option is the Helmet Sensor as tested and fielded by the Project Manager Soldier Survivability Team at Fort Hood, Texas. Testing demonstrates that a one-ounce monitor can track the concussions and overpressure that a soldier experiences during a blast event. The sensor system can easily record a month's worth of data, downloading data via a USB port to a computer [12]. This is the more promising and viable of the two options. Adapting this technology to wirelessly forward traumatic brain injury information to the SLS could prove extremely beneficial.

### The SLS

The SLS is the third component and is a member node of the Bluetooth network, communicating with its controlling Master Node. This Master Node communicates with the combat medic's dashboard system (CMDS). Communication with the Master Node is not soldier-initiated, and is predetermined prior to the start of a mission.

There are many commercially available biometric watches that support Bluetooth technology. Such watches have the ability to monitor the wearer's heart rate. Such technologies demonstrate the feasibility of Bluetooth transmission of GPS signals to an array of devices, such as PDAs and smart phones, for the purpose of navigation.

In August 2000, a team of IBM researchers began the task of building a wearable server, designed as a watch. They developed a Bluetooth-enabled prototype that runs on Linux and X11 [13]. This system has the potential to run the services required to monitor the Military Smart Shirt and the concussion monitoring system, as it is able to store and transmit vital signs that cross preestablished thresholds. In addition, it is recommended to add to the wearable server the ability to conduct heart rate monitoring in the event the shirt becomes inoperable.

The SLS compares received vital signs

Figure 4: *Combat Medical Dashboard System*

against stored baseline averages. This is important because missions differ, requiring soldiers to put forth varying levels of physical exertion. Upon conclusion of the mission, vital sign values are transmitted to the medical server located at the battalion aid station via the Master Node and the CMDS. This data is relevant for both re-deployment and post-deployment health assessment as the data is included in the soldier's electronic medical record (EMR), facilitating communication between supporting healthcare professionals.

### The Master Node

The Master Node is the fourth component, Bluetooth-enabled to the Single Channel Ground and Airborne Radio System (SINCGARS), or a squad radio variant. This radio is operated by unit leadership. The authors of [14] indicate a need for the development of a communication link between a PDA and a SINCGARS radio, outlining functional and nonfunctional requirements to accomplish this capability [10]. Linking the SINCGARS radio with the Master Node and the CMDS can possibly augment communication distances.

The Master Node is the controlling member of a seven-member piconet. Since infantry squads are divided into two five-man teams, the seven-member is ideal to support team-level maneuvers, as well as a single High Mobility Multipurpose Wheeled Vehicle crew. This Master Node relays messages from its piconet to the CMDS; however, communication is not initiated by the squad leader. This allows vital medical information to be forwarded to the combat medic without impacting the overall mission. This seamless transmission of medical data does not exempt leaders from their responsibility of checking on the welfare of their subordinate soldiers as the mission dictates. It does, however, facilitate the rapid identification of soldiers who may have become casualties, requiring immediate evacuation.

### The CMDS

The last component, the CMDS, is based upon the principles of Business Activity Monitoring. Figure 4 illustrates the dashboard as adapted to the combat medic's needs. The CMDS provides an iconic view of the unit's medical readiness. The goal is to ultimately interface the CMDS with the Army's MC4.

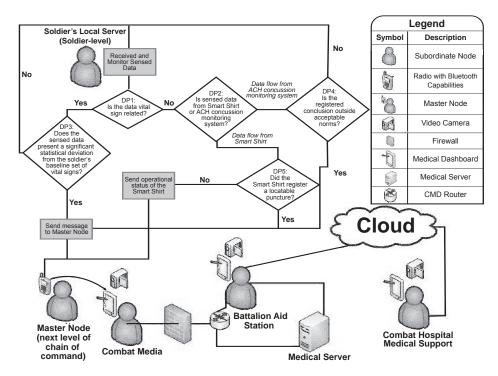There are four sets of icons at the heart of this notification; they show:



Figure 5: *Logical Flow of the C-WHMS*

vital signs, any optical fiber severing, ACH impact counts that exceed pre-established limits, and system diagnostics. Each icon has a number in the center representing the number of alert messages. As the combat medic receives an alert message on their CMDS, the combat medic has the ability to *drill-down*, reviewing individual alert messages (as needed) by simply double-clicking the icon.

The combat medic's prioritization of medical needs and medical resources is based upon a green, amber, and red color-coded scheme. A green icon indicates normal operation; an amber icon indicates caution; and a red icon scheme indicates a potential emergency situation that can lead to a loss of limb or life if left unchecked. The handling of alert messages is discussed later in this article.

The proposed CMDS has the capability to communicate with a doctor via video-conference. Telemedicine extends beyond diagnostic capabilities and tools already available to the combat medic. Telemedicine supports the combat medic as he or she stabilizes a soldier under the direct supervision of a doctor prior to transport, even though time and distance limit the doctor's ability to be physically present. In these critical cases, the CMDS allows combat medics to consult directly with a doctor or physician's assistant via an attached video camera, showing the extent of injuries. The CMDS supports the storage of the

soldier's EMR as synchronized with the medical server. This allows doctors to view the same EMR data as the combat medic has on the CMDS screen.

Telemedicine allows the combat medic to continue medical support while in transit to the battalion aid station or combat hospital. Also, the battalion aid station is equipped with a variant of the CMDS, allowing consultation over the Internet with other healthcare professionals (as needed). The next section demonstrates the logical flow of the C-WHMS in action, relating the five components of the C-WHMS.

## C-WHMS: How it Works

Figure 5 presents a logical flow of responses by the sensors to the operational environment, enhancing the medical status reporting of units conducting combat patrols or convoy operations. Figure 5 starts with the SLS. The SLS represents the soldier and the soldier's network of sensors, including the ACH concussion monitoring system and Military Smart Shirt. Embedded within the squad communication system, a Bluetooth-enabled device monitors the medical readiness of the soldier.

If the device detects an abnormality in sensed data, then that data is routed along five decision points (DPs). The first decision point, DP1, provides the first essential filtering function. DP1 asks if the abnormality of sensed data is vital sign-related only, related to a concussion

sustained by the casualty, or a puncture of the Military Smart Shirt, indicating the potential entrance of a bullet or shrapnel fragment.

If the answer is *yes*, then sensed data is routed to DP3, which asks: Does the sensed data represent a statistical deviation of the soldier's baseline of stored vital signs value? If the sensed data is not a statistical deviation from the norm, then the monitoring system continues its passive monitoring. If the sensed data presents a statistical deviation from the norm, then an alert message is routed from the Master Node to the combat medic.

If the answer to DP1 is *no*, then DP2 is queried: Is the sensed data coming from the Military Smart Shirt or the ACH concussion monitoring system? If the answer to DP2's query is related to the ACH concussion monitoring system, then DP4 checks to see whether or not a concussion is registered by the system. If a concussion is sensed, an alert message is sent from the SLS through the Master Node to the combat medic.

If the answer to DP2's query is Military Smart Shirt-related, then DP5 checks to see if it has registered a locatable puncture. The exact location of the puncture is essential. At this point, vital signs are measured regularly in order to determine whether or not the soldier is in shock. As this shock is a significant event, a high-alert message is immediately forwarded to the combat medic. If the exact location of the puncture cannot be determined, a check of the Military Smart Shirt's operational status is performed. If it is not functional, the combat medic receives a low-level alert message, and the soldier's vital signs are monitored as a precaution. The combat medic monitors the operational situation, contacting the soldier as the mission dictates.

At the conclusion of the military operation, the Master Node (as directed by the patrol or convoy commander) conducts a network call, retrieving data stored from all members of its piconet. This data is stored in the medical server and is accessible and used during redeployment and post-deployment health assessments.

## Handling of Alert Messages

Alert messages are handled in the following manner: Icons representing vital signs, the severing of optical fibers, and impact counts display a color code with a number representing the total number of associated alert messages. Alert messages are forwarded from the SLS through the Master Node to the CMDS.

Red alert messages are forwarded automatically to the unit's battalion aid station or supporting combat hospital. This allows the next level of medical care to prepare for a potential influx of casualties. Also, the soldier's EMR is forwarded to the next level of medical care: thorough review of the soldier's EMR (for allergies to any medications) and medical history (for mitigation of any potential complications). Red alert messages are of highest priority. Unit leadership is notified immediately of this type

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*"Red alert messages are forwarded automatically to the unit's battalion aid station or supporting combat hospital. This allows the next level of medical care to prepare for a potential influx in casualties."*

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of message because it indicates a high possibility that a loss of limb or life may result if left unchecked.

Alert messages contain sensed data as well as the GPS location of the injured soldier. If the sensed data pertains to the severing of optical fibers, the exact location is sent along with the alert message in order to help the combat medic accurately identify entrance and exit wounds (as needed). Vital signs are included in all alert messages as this allows the combat medic to monitor the soldier for shock.

Amber-colored alert messages are forwarded to the next level of medical care for information purposes only. This allows the battalion aid station to track changes as they occur, pre-position medical supplies as the condition deteriorates, and brief the battalion commander on up-to-the-minute medical readiness information. Amber alert messages are of medium concern, handled locally when the mission permits. Green alert messages are a low priority and handled

locally when the mission permits. They are not automatically forwarded to the next level of medical care unless the combat medic decides to send the data.

## Conclusion

This article shows it is demonstrably feasible to develop the C-WHMS with available wireless technologies. Tailoring such technology to meet the needs of the military could yield benefits in the arena of military healthcare and battlefield triage, potentially saving lives. Off-the-shelf software, specific to the medical community, should be evaluated in greater detail, modifying it as necessary to adapt to military uses for medical care.◆

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