Gesture-Directed Sensor-Information Fusion for Communication in Hazardous Environments

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ABSTRACT

This position paper describes a vision of how Chemical Biological Radiological and Nuclear (CBRN) situation awareness and threat assessment can benefit from the use of Gesture-Directed Sensor-Information Fusion (GDSIF). It describes a concept of operations for the war fighter's use of electronic wireless-communication gloves (eGloves) to communicate, plan, and react while wearing Mission-Oriented Protective Posture (MOPP) gear. It also suggests the benefit of using the hardware and firmware resident on the eGloves to perform data fusion from environmental sensors. It provides a roadmap of research issues and challenges that will need to be overcome to realize this technological advance, and provide inspiration for other problem domains.

Keywords: chemical, biological, radiological, and nuclear warfare; electronic data glove; gesture-signal communications; sensor-information fusion; situational awareness; human factors; design reliability.

1. INTRODUCTION

New modalities of computer interface are a prominent theme of the past few years. Touchscreen interfaces have exploded in popularity, especially with the iPhone and Android mobile operating systems. 'Touchless' interfaces are also gaining prominence. Just within recreation, the Nintendo Wii, Playstation Move, and Microsoft's Project Natal have recently come to the public's consciousness, fulfilling years of promise and research. This paper will describe a vision of how these types of technologies can be pushed even further, incorporating language, intent, and function beyond just a simple interface device. We hope this case study will provide inspiration for other problem domains.

The battle space is full of threats that would be better to detect earlier rather than later. War fighters are in the best position to detect CBRN threats in theatre. Current Chemical-protection for war fighters on the ground inhibit electronic communication via keyboards, cell phones, and remote-control devices. War fighters need better communication methods in hazardous environments characterized by CBRN agents. Important topics in wartime communications include but are not limited to situation and threat assessments. To improve communications capabilities for the war fighter wearing protective gear in hazardous environments, a series of eGloves have been developed with a view toward freeing the war fighter of the need to type on a keyboard while wearing a MOPP suit. (See, for example, [1] and [2].) These eGloves can help the war fighter transmit gestures with the hands and fingers from within the protective gear [1], [2], or they can be used to transmit encoded ASCII characters [1]. Fig. 1 shows an eGlove prototype.

Research has demonstrated that chemical and biological sensors can be made smaller, more sensitive, more species specific, and easier to deploy in a variety of ways. (See, for example, [6] and [7].) The current eGloves have magnetic and motion sensors for gesture recognition [1], [2]. An important future step to enhance the effectiveness of the war fighter is to integrate CBRN and other sensors into the eGloves. In addition to simply recording CBRN environmental data, development of efficient data-fusion algorithms to fuse the information from CBRN and other sensors with gestures from the eGlove operator will provide situational awareness beyond the readings from individual sensors.

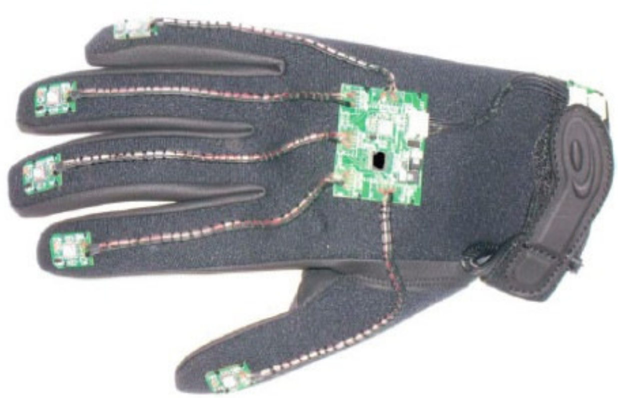

Figure 1. eGlove with motion sensors and CPU circuitry (Patents pending 12/323,986; 12/325,046)

The following sensors could be integrated with gestures transmitted using the eGlove: CBRN sensors, acoustic sensors, Geo-Positional Sensors (GPS), optical sensors, physiological sensors to monitor the health of the operator, and imagery

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sensory input from video cameras mounted in various strategic locations in the environment. The output of these passive sensors can be transmitted with the magnetic/motion sensor output. This will improve communications by providing explicit measurements or information without burdensome and error prone manual relay. Integrating the environment sensor data with the current eGlove gesture software would expedite communications by providing contextual information to the glove. For example, if the physiological sensors on the eGlove are detecting values beyond normal thresholds, different communications suggestions could be presented than during normal operating conditions.

The improved hardware alone provides tremendous value, especially in the extreme CBRN conditions. However, this paper will focus on one bridge further, a proposed interaction paradigm, rather than the interface technology.

2. DESCRIPTION & BENEFIT

Gesture-Based Sensor-Information Fusion (GBSIF) refers to the fusing of sensor data collected from the environment with data from motion sensors on the eGlove. The eGlove features a Central Processing Unit (CPU) that is used to fuse hand and finger motions and positions into gestures, as shown in Fig. 1. The same CPU can be used to fuse additional data from the environment. In GBSIF, the operator transports the sensor array but does not take an active role in determining the sensors that will participate in the fusion or the target subjects about which the data will be collected, with the exception of the sensors mounted on the eGlove. Data are collected from the environment and also from the glove sensors, and these data can be fused and integrated on a network site that differs from the user's node. Thus, gesture sensor data and environmental data are collected, fused, and integrated where appropriate. However, the gestures themselves are not the primary driving force in selecting information sources and controlling the fusion process.

GBSIF is passive from the point of view of the operator. They are serving to extend the battlespace sensor network in two very important and valuable ways: providing mobile environmental sensors that serve to augment everyone's situational awareness, and providing a new type of sensor reporting, gestures. For example, consider a simple eGlove instrumented with a chemical sensor and a GPS sensor in addition to the standard eGlove magnetic and motion gesture recognition sensors. War fighters progressing through a battlespace are now providing additional sensor information. This is additional data is not intended to replace, but to augment to unattended, remote operated, and autonomous sensors or robots. [3][4]

For example, some war fighters might be in close proximity to a chemical, so the combination of reports from all their sensors (some sensors reporting a negligible value, some reporting a mild value, some reporting a moderate value) in conjunction with the GPS sensors would provide a general idea of the location and concentration of a potential chemical plume. Continuing the example, sensors recorded and transmitted some of the war fighters were gesturing with 'warning' or 'stop' gestures. GBSIF allows for the chemical, GPS, and gestures to be fused providing new situational awareness, in this example the gestures would provide more information about the origin of the chemical detection.

In contrast, Gesture-Directed Sensor-Information Fusion (GDSIF) includes GBSIF but extends it to include the active participation of the eGlove operator to initiate sensor-information fusion. The concept of operation of the GDSIF is that the war fighter would point to or otherwise select a platform or another object in the battle space using a gesture while wearing a GDSIF-equipped eGlove, including sensors onboard the eGlove itself. The eGlove would be linked to reference sensors to determine orientation and azimuth of the operator's arm. The eGlove also would use GPS to determine the operator's geographic location. Gestures would cue sensors to send their data to the eGlove where these data would be fused with the gesture that prompted the data collection. Fusion would be accomplished in the CPU mounted on the eGlove.

The advantage of GDSIF over GBSIF is clear. The war fighter, with immediate access to the environment and data, can start to process and add value to the information being collected. Ideally, it will not only result in added value, but if the gestures are efficient, it can be faster as well.

The distinction of where computation is taking place is key, because GBSIF fusion is accomplished remotely, and can use the virtually unlimited resources available in the cloud. In order for the information to be available in a timely manner, given current battlefield bandwith constraints, GDSIF algorithms need to be able to be executed with the resources available to the operator.

In a scenario similar to the one described above, with a number of distributed war fighters equipped with eGloves with chemical sensors, and one individual war fighter wants to know what direction to proceed to locate and eliminate the source of the chemical. He is wearing heavy MOPP gear to protect against the chemical, but this also limits his communication ability. By sending a gesture to nearby sensors, the war fighter can receive feedback as to whether a particular direction would have a higher or lower concentration of the chemical than his current location. The fusion algorithm would be keyed by the war fighter's initial gesture. The information is fused from his own sensor, and the results of querying nearby sensors. An algorithm determines relative concentrations, and provides the result the war fighter desires.

More complicated fusion algorithms, in regards to correlation of multiple different types of sensors, as well as just higher levels of complexity [5], constitute their own area of research. GBSIF will incorporate advances in generalized data fusion, but is itself a more specialized area of research.

Sensors added which can detect imagery can add great meaning to the user's experience. Multiple sensors which can fuse imagery can provide a description of what the war fighter sees. Integration of visual imagery with gesture can yield much insight into the cognitive experience of the user. For example, if the user provides a gesture that represents alarm, he/she might not be able to have enough time to indicate what the alarm is, but with the fusion of the gesture and the imagery data, this can be more easily inferred. Further, with sensors providing imagery data, there might be too much information being sent to the cloud for accurate processing. However, if the user of can provide a start and stop mechanism, the linking between the gesture and the corresponding imagery can be made, giving more insight into the cognitive experience.

If the war fighter is given two gloves, then by using both hands, it is possible to select a region to be further investigated. Imagine looking across the street and then selecting a region of a building with two hands. If the location of the imagery data is known, than mathematical processing can be done to determine a specific region by simply holding two hands in the air. Similarly, with the thumb and index finger one can make a circular shape which can similarly be used to detect a specific region. Given the angle of the thumb and index finger, one can than determine the circumference of the circle made by these two fingers, and then locate the respective region on the sensor imagery data. These gestures are not unlike some current gesture systems, such as SixthSense[10], however, use of a camera for gesture recognition is absolutely not an option for a CBRN war fighter in a battlefield scenario.

Multi sensor fusion is commonly used for identifying specific regions. However, there is always a probability associated with this detection. Feature vectors comprise kinematics parameters such as position vector, velocity, vector, and acceleration vector [9]. These features are used to help determine the location of the specific regions. Estimated fused target probabilities are used to help predict which object is being recognized. Integrating a glove with sensory image data could improve these probabilities.

3. PROPOSED ARCHITECTURE

Preliminary experiments show that the current CPU will support additional sensors without difficulty. And new low-power CPU technology is available on a near-daily basis, so this will continue to be less of an issue. Of the many options for accomplishing this, the three subsequent architectures provide the best advantages.

1. Tracking the date-time group of the sensor data, the GPS geographic location, and the sensor type will provide the pedigree metadata [8] necessary to sort and fuse the information. CBRN, acoustic and GPS sensors can be mounted on the eGlove and the CPU can collect and fuse data from all sources on the eGlove. The CBRN, acoustic and GPS sensors would detect environmental conditions but not health-related conditions of the operator. Redundant sensors mounted on the eGlove could help reduce problems due to false alarms of any one sensor. CBRN Sensors with heightened sensitivity could transmit detection even before the war fighter is aware of the presence of a chemical or biological agent. These networked and fused sensors could provide warnings and alerts to be sent not only to the operator but also to the wireless network with which the operator is in communications. When applicable, these alerts could be localized to prevent ‘noise’ being sent to unaffected parties. This could be used to alert and send early emergency response team independent of any specific request from the war fighter.

2. This architecture is the same as the one described in item 1, but in addition to external sensors, the eGlove also would detect physiological data of the operator, such as pulse and Galvanic skin response (GSR). For example, if the chemical detectors sent signals about a plume and the operator did not transmit any gestures determined to have intent or meaning, this could mean that the chemical agent had attacked and incapacitated the operator. The pulse and other physiological signals could help determine the operator’s health.

3. The CPU mounted on the eGlove could be programmed to detect not only local signals from hand and finger gestures but also from a variety of wireless sensors throughout the battle space. This could include sensors mounted on or deployed from UAVs [7], motor vehicles, or even other war fighters. This provides a wider coverage of the battle space beyond the immediate vicinity of the operator. The obvious disadvantage of these extra sensors is that it adds complexity to the task of the CPU on the eGlove. The challenge is to develop effective data-fusion algorithms to manage the data streams and the metadata from an increased number and variety of sensors in the battle space.

The operator could select a 1) “Raw-data-only mode” to transmit the data to the wireless network, or 2) “fuse data” mode in which algorithms stored in the eGlove’s CPU would perform data fusion and then transmit the fused-data result to the wireless network. The operator could use gestures to control multiple modes of operation of the eGlove.

4. GESTURES

Simple gestures can be used to communicate information to improve situational awareness, send commands to personnel and to robots [2], and send commands to CBRN and other sensors in the battle space. For example, one potential information fusion would be to point at a sensor-data source in the battle space with the index finger extended and the other fingers touching the palm, (to distinguish it from similar gestures that use the whole hand to point.) This pointing gesture, when recognized, would signal the sensor and trigger a data stream or a single reading from the designated sensor to the local common-data backbone.

Successful transmission from the sensor would trigger haptic feedback [1] on the operator’s glove indicating that the data set has been sent to the network. Continuing the example, the war fighter could repeat the pointing process with a second sensor and then a second gesture, for example a fist with the arm held straight down, would trigger a pre-determined sensor-information fusion process. Using the fusion-fist gesture in this manner would distinguish it other gestures that employ a closed fist with the arm extended, which in some command contexts means “stop.” It also would avoid confusion with gestures in which the fist is held close to the chest.

CBRN sensor-information could be thus queried and fused with each other and also with information from other sources in the battle space, such as electromagnetic or acoustic sensors. In more advanced implementations of this methodology, the war fighter could provide some degree of input about what type of information is desired from the sensor-information fusion, such as a prediction of routes to use for relatively safe travel with respect to the deployment of CBRN agents.

Specific additional developments would likely arise organically from close collaboration with the war fighters using the tool, following an approach similar to the ‘User Centered Design’ software approach.

5. DIRECTIONS FOR FUTURE RESEARCH

Further research is needed in this area. To facilitate GBSIF and GDSIF, the vocabulary, syntax, and semantics of command gestures would need to be developed to include all possible modes of operation that the war fighter would require. Because the eGlove is designed for use in a variety of situations, the vocabulary of gestures for GDSIF ideally would build on the vocabulary of gestures already in use for similar purposes. For example, special forces, such as Navy Sea Air and Land (SEAL) teams and Army Rangers, use gesture-based communication designed for covert operations where stealth and silence are requirements. Human factors and physiology would help determine the ease with which some gestures rather than others could be used. Special fusion algorithms would process gesture data and fuse them with environmental and physiological data.

Advanced operators could be trained to issue gesture commands to determine which fusion algorithms to execute.

Maintaining the integrity and timeliness of the Common Operating Picture (COP) with existing information is already a challenge [5]. Integrating GDSIF information into the COP where other war fighters could benefit from local observations is an even greater challenge requiring further research and testing. Potential applications of the GDSIF can be integrated into the Joint Warning and Reporting Network (JWARN) program of record.

6. ACKNOWLEDGMENTS

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