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Designing Future Disaster Response Team Wearables from a Grounding in Practice

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ABSTRACT

Wearable computers are poised to impact disaster response, so there is a need to determine the best interfaces to support situation awareness, decision support, and communication. We present a disaster response wearable design created for a mixed reality live-action role playing design competition, the *Icehouse Challenge*. The challenge, an independent event in which the authors were competitors, offers a simulation game environment in which teams compete to test wearable designs. In this game, players move through a simulated disaster space that requires team coordination and physical exertion to mitigate virtual hazards and stabilize virtual victims. Our design was grounded in disaster response and team coordination practice. We present our design process to develop wearable computer interfaces that integrate physiological and virtual environmental sensor data and display actionable information through a head-mounted display. We reflect on our observations from the live game, discuss challenges, opportunities, and design implications for future disaster response wearables to support collaboration.

CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality**; *Computer supported cooperative work*; Ubiquitous computing;

KEYWORDS

Wearable; head-mounted display; mixed reality; augmented reality; LARP; team coordination; collaboration; disaster response.

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1 INTRODUCTION

Disaster responders need to rapidly process information about themselves and team members, their environment, and those they are rescuing [22]. Wearable technologies are proliferating, enabling robust feedback (e.g., head-mounted displays (HMDs), haptic armbands) and sensing (e.g., physiological state) [5]. Wearables for disaster response are promising as responders' hands are busy and their awareness must be on their surroundings, rather than a screen. This makes it hard for responders to use common mobile computing devices. Disaster response is a dangerous enterprise, thus, there is a pressing need to design wearable technologies that meet responders' information needs. The present research describes the process of developing a wearable computer interface for responders and testing it in a mixed reality game competition.

The *Icehouse* Challenge offers a simulation game environment in which teams compete to test out wearable designs. We report on our submission to the *Icehouse* Challenge, held at the IEEE EMBS 13th Annual International Body Sensor Networks Conference in 2016. The challenge was developed and sponsored by the MIT Lincoln Laboratory. The competition was designed based on data from disaster response contexts and aims to capture the coordination and exertion components of actual disaster response. We report on the *Icehouse* Challenge in this paper, but note that the present team did not develop the challenge; our contribution is in reporting on a system design that was submitted to it, and tied for first place.

As part of the competition, our team developed software and interfaces for a wearable computer to be used during the mixed reality game. The game was played in a multi-room environment with digital support to simulate hazards and victims. During the competition, members of the U.S. Coast Guard, equipped with a smart phone, a smart band, and a pair of smart glasses, completed multiple rounds of the game with each competitor-developed system.

In this paper, we explore novel ways to support collaboration with wearable computers, integrating physiological and environmental sensor data and display actionable information in a see-through HMD that supports responders in performing their actions efficiently. We report on our iterative design process and our observations of using our system in the live mixed reality game. This paper contributes insights into designing wearables for disaster response teams, enabling researchers and designers to build future systems and games to support disaster response work and training.

2 BACKGROUND

The background for the present research includes the basics of team coordination, insight into disaster response work practice, wearable computing, and mixed reality.

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2.1 Team Coordination

A *team* is a collection of actors, who are assigned different roles and collaborate and share information [17]. To maximize performance, teams organize their activities and synchronize effort [1]. A *mental model* is the way in which individuals maintain and manipulate a representation of the functioning of an object or process in their heads [12]. *Shared mental models* support teams in working together efficiently, enabling implicit communication through the use of artifacts, reference signs, and deep understanding of team activities [15, 22]. *Situation awareness* is the ability to understand a complex situation and predict its future states to make decisions [9].

2.2 Disaster Response

Disaster response is a complex set of activities to mitigate the effect of a critical incident [25]. The term *incident* refers to "An occurrence, natural or manmade, that requires a response to protect life or property...." [25, p140]. *Responders* are people who contain the impact of disasters and prevent further loss of life and property. Such response is crucial, because disasters cannot be prevented entirely, but their impact can be contained and reduced. The activities in the *Icehouse* game most closely resemble those of fire emergency response, since players are moving room-to-room, mitigating hazards and stabilizing victims [21]. We draw on prior research around fire emergency response teams (e.g., [11, 13, 20, 22–24]) to drive the design of our wearable system.

2.3 Wearable Technologies

Wearable computers are computing devices that are worn and can be distributed on a person's body [3, 14]. These devices have constant interaction between the environment and the user and often form their own network of intercommunicating effectors and sensors. Wearables generally provide context-sensitive support, reducing the need for direct interaction. The availability of wearable technology including HMDs, audio headsets, armbands, and sensors that detect location, motion, and aspects of people's physical and mental state has opened up new opportunities for designing wearables for disaster response. Wearable computers function as an enabling technology for mixed reality systems.

2.4 Mixed Reality

Systems that connect virtual and physical reality in some meaningful way through sensors, networks, computers, and databases are *mixed realities* [4, 16, 18]. These range from augmented reality, in which conformal 3D imagery is integrated with a perspective on the physical world, as with most aircraft head-up displays and augmented reality games (e.g., *Pokèmon GO*), to augmented virtuality, in which physical-world artifacts and spaces are integrated into a virtual world [6, 16].

3 THE *ICEHOUSE* GAME

Icehouse is a mixed reality live action role-playing (LARP) game that takes place in "a fictional world not too different from our own." A team of players take on the role of disaster responders who enter the *Icehouse* world to rescue fallen fictitious victims. The game was designed based on data from disaster response contexts, combining aspects of multiple types of response, and focuses on capturing team coordination by developing interdependencies among teammates. It also develops an exertion component, requiring that players elevate their heart rate to accomplish tasks in game. In this section, we describe the general *Icehouse* game, followed by the specifics of the *Icehouse* Challenge, in which we were competitors.

3.1 Overview

The *Icehouse* virtual world includes hazards to which players are exposed (potentially removing them from play) and need to mitigate (to succeed). The players are equipped with standardized wearable computers, with interfaces developed by competitors, that enable them to interact with the digital components of the *Icehouse* world and provide players feedback on their virtual state. The *Icehouse* world is represented by a physical space, partitioned into rooms. Players generate a performance score in the game, which is largely affected by rescuing victims and, less so, by mitigating hazards and avoiding exposure.

As a mixed reality game, *Icehouse* includes both physical and virtual components. Each room of the physical space contains a computer terminal, an *electronic representation (eRep)*, to provide information on the virtual world and props to represent hazards and victims. The main objective of the game is to rescue victims, which is the main way to boost game performance.

Rooms contain hazards and victims, which have both an eRep and *physRep* (*physical representation* of a hazard) associated with them. Players need to make decisions to mitigate or avoid hazards and rescue victims. Mitigating hazards and rescuing victims are done by generating *progress points* toward an action. Progress points are the amount of player work needed to mitigate hazards and stabilize victims. The effort to mitigate a hazard or stabilize a victim is simulated by monitoring the heart rate of the players, via the smart band, and accumulating the time that they spend with elevated heart rate. Players elevate their heart rate by performing physical exercise (e.g., stair steps, push-ups, jumps), to simulate physical exertion. Multiple players may work on the same action simultaneously, summing progress points. One minute of elevated heart rate for one player is equivalent to one progress point; each hazard and victim requires a specified number of progress points based on severity level. Mitigating hazards improves the players' performance score, however, performance score is penalized for exposure taken.

4 THE *ICEHOUSE* CHALLENGE

In the *Icehouse* Challenge, teams of competitors develop wearable computer interfaces to the *Icehouse* game with the expectation that the game serves as a reasonable analog to actual reality. The goal of the challenge is to engage competitors in designing the future of disaster response wearables. The challenge began months ahead of a series of games of *Icehouse*, which would be used to compare the competitors' designs through the performance scores of players.

In the first round, competing teams were asked to submit a simple summary of their ideas and background, after which they were sent an initial package of hardware that included a smart band. In the second round, additional detail was requested from each competing team, including designs for the UI and integration descriptions between sensors and the HMD. The second round resulted in selecting the four top proposals. Successful teams were

Figure 1: The Sony Smart Band 2 (left), is a fitness tracker used to measure heart beat. The Sony SmartEyeglass (center), is a binocular see-through head-mounted display (HMD) with attached controller puck (right).

notified and sent additional hardware and software that included the smart glasses, the game server code, and example code.

The final phase of the challenge was to run a group of players (disaster responders) through *Icehouse* using the competitors' wearable interface designs. In this phase, *Icehouse* was conducted in a physical space that measured 12.1m × 9.8m and separated into eight rooms by pipe-and-drape (Figure 3).

4.1 Wearable Technologies

Competitors were provided with a specification for a configuration of wearables, which were provided to the finalists. While each team could supply their own additions to the configuration, the following devices were required:

Smart Glasses: The Sony SmartEyeglass is a binocular see-through HMD (Figure 1, middle). These glasses provide the equivalent of a 20° diagonal field of view that can display green monochrome with 8-bit color depth. The glasses are able to simulate stereoscopic 3D imagery, so interfaces can use depth, enabling augmented reality experiences. The smart glasses are powered and controlled from an attached controller, a *puck* (Figure 1, right), that contains a swipe bar and buttons. During the game, each player was equipped with one pair of smart glasses.

Smart Band: The Sony Smart Band 2 is a fitness tracker, worn around the wrist, to measure heart rate and acceleration (Figure 1, left). Additionally the smart band has three multi-color LEDs and haptic feedback. During the game, each player was equipped with one to track heart rate.

Smartphone: Each player was equipped with a Sony Xperia Z5 smartphone which contained the competitor-developed applications for the smart glasses and communicated with the game server. The smartphone ran Android 6.0 and included an NFC tag and reader, enabling it to interact with eReps.

In the course of the competition, each competing team designed and developed a system combining these wearables that was later used by the players in the mixed reality game.

Competitors in the *Icehouse* Challenge must design systems based on the organizers' requirements (Table 1), which were derived from disaster response. Special attention had to be paid to tools that work in conditions routinely experienced by responders, such as while wearing heavy gloves or in the presence of loud noise.

Design Requirement
"describes a tactical HMD design"
"tracks and displays user biometrics"
"allows user to triage victims"
"provides dynamic hazard and threat display"
"alerts users to hazard and threat types"
"accept user input/actions"
"tracks and displays users location"
"provides summary assessment of team performance"
"addresses hazard/threat escalation/changes"
"fosters communications and coordination between players"

Table 1: The *Icehouse* Challenge design requirements as specified in the call for participation.

5 WEARABLE COLLABORATION INTERFACE

Our design focuses on providing players with team state and team needs based on available data about the game state. The two motives that drove its development were:

- to support team situation awareness; and
- to support decision making in a complex environment by providing actionable recommendations.

The designed system mainly consists of two Android applications. One runs on the smart glasses and is intended to improve situation awareness and decision making. The other runs on the smartphone and is used to enter details about rooms[1]. The system provided the following information:

- exposure status, location, specialty, and tech of players;
- a recommendation on prioritization of game actions; and
- a 2D map of the physical space.

5.1 Design Approach

Our design approach, based on our prior experience designing for disaster response domains, is to make use of peripheral attention and avoid displaying any information to the central of the head-up display. User inputs were minimal, and only for either switching between the information views or to account for state changes that the system cannot detect automatically.

Components of the head-up display include a peripheral display of the health status of teammates and activity status. This enables players to attend to the information when they need it, yet enables attention to the physical environment.

5.2 Smart Glass Information Views

The primary elements of our design are information views provided through the smart glasses, facilitating play and communication. Using the swipe bar on the puck, players could cycle through the four views to the one that was most useful to them at the time. For the smart glasses, no further interaction was required.

5.2.1 ***Team Status View.*** The team status view (Figure 2.1) provides situation awareness, showing the state of each team member in a compact representation at the bottom of the screen, where

[1]This component, while not ideal, was necessary with the design of *Icehouse*, no other way to get context information to the system.

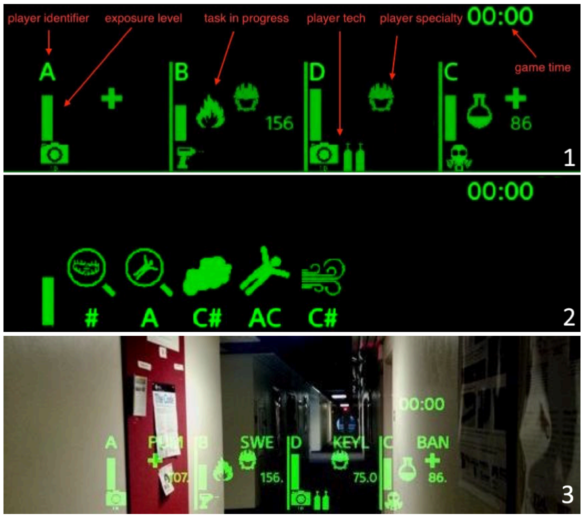

Figure 2: 1. The team status view with player information: identifier, specialty, tech, exposure, task in progress, and game time. 2. The decision-support view shows the optimal order of activities to clear a room, as well as which player should do what. 3. The interface is displayed on top of the transparent lens of the HMD, allowing players to easily split their attention between the interface and the real world.

it minimally interferes with awareness of the nearby environment. Other configurations were tested (e.g., dividing the information between the left and right edges of the screen), however, these interfered with users' awareness of their surroundings. For each player, the interface displays the player's identifier, specialty icon, exposure, room identifier, and activity status. Activity status is represented by an icon for the activity that a player is undertaking (e.g., stabilize victim, fighting fire) and a countdown timer for the estimated completion time.

5.2.2 ***Decision-Support View.*** The decision-support system provides players with recommendations on optimal task ordering, given data about the state of the room and using the activity priority system. These recommendations are displayed to the players through the decision-support view (Figure 2.2). The system provides a sequence of icons that tells the player the recommended ordering.

5.2.3 ***Map View.*** The map view gives a player the digitized version of the paper map provided during loadout. In this view, the system displays a monochrome map of the game world. The map is digitized during the loadout phase, using a camera, and, hence, is static, and is used only to help players do wayfinding.

5.2.4 ***Blank View.*** The HMD did not provide a feature to turn off the display in case the user wanted to focus entirely on the environment. Thus, our design included an additional viewing option that was entirely devoid of digital elements, allowing for an unobstructed view of the the physical world [19].

6 DATA: REVIEWS AND OBSERVATIONS

During the IEEE EMBS 13th Annual International Body Sensor Networks Conference, in San Francisco, California, U.S.A., the *Icehouse* Challenge finalists used members of the U.S. Coast Guard as players to test performance of the wearable interface designs by each competitor. One team of players (responders) ran through multiple *Icehouse* games using each of the competitor-designed interfaces.

The designed systems were judged based on number of victims stabilized, level of exposure, number of mitigated hazards, feedback from the players, and quality of the code and system design. After each play session, the organizers conducted a debrief session, where players provided feedback about each design. In this paper, we only cover the post-game write-ups and observations from the players of our design, since these are the only ones to which we have access.

We originally provided each player with a half-duplex two-way radio to enable voice communication between the players during the live game. This was motivated by the players' familiarity with this equipment and its ubiquitous presence in the disaster response domain. However, interference rendered the radios useless and the organizers allowed shouting as an analog, which is how players communicated during the game. This has the deleterious side-effect of reducing the fidelity of the simulation [22], but, with the small space, players could likely hear one another anyway.

During the run of the live *Icehouse* game, competitors were allowed to observe from inside the physical space while the game was active (without disrupting the players). We paid special attention to how the players used the wearable display to improve their situation awareness and coordination.

First, we observe that the players had no trouble navigating inside the physical space while using the wearables. The smart glass display was active all the time and, hence, we infer that our interfaces are unobtrusive and did not distract the players. Although the players were already trained as coast guard officers with coordination skills, one player mentioned in the post-game debrief session that the system helped enhance coordination with other team members: *"Enhanced team coordination by showing hazards and communicating between members on which direction to go."*

Second, as an informal measure of situation awareness, we interviewed players while they performed physical exercise to increase their heart rate (and gain progress points). Specifically, we asked them to explain the status of their teammates. Since players remained in place during 3–6 minute bouts of exercise, and were physically fit, we were able to interview them without hampering them or affecting game state. Players accessed the status of their team members through the team status view, and later were also able to successfully navigate to the particular room (information which was gained through the interface) in which other players needed help: *"[The team status view] was basically the most useful screen. [The decision-support view] was always prioritizing traps as top priority. [The decision-support view] was not utilized as nearly as often as [the team status view]."*

We expect that players maintained situation awareness of their teammates during play based on the interviews. As the availability of contextual information [11] was frequent, this provided a robust and detailed picture of the situation. As one of the players during the post-game debrief session said: *"[This] system would be more*

Figure 3: During the live *Icehouse* game, players worked together to rescue victims and mitigate hazards. A: Players start by scanning their NFC cards at the eRep in a room to engage with the victims and hazards. B: Players generate progress points by raising their heart rate performing physical exercises. C: After generating enough progress points, players can carry the victim, whose physRep is a weighted balloon, to safety.

useful as command post to be able to update team members of both known hazards and new found hazards."

Last, we infer that effective decisions can be made if information about all team members is made available to everyone unobtrusively. Our observation is in line with Witt et al. [26], who indicated that interaction with information displaying systems should not distract a player from performing the primary tasks (that involve real world physical actions).

7 DISCUSSION

In this section, we provide insight into our experiences of designing and developing wearable collaboration systems for disaster responders.

7.1 Design Challenges for Smart Glasses

We observed that the smart glasses had display visibility issues with bright light and that they provide only a minimal level of expressivity. Although the display on the smart glasses is monochrome and only 80% transmittance is available, this display performs poorly if the background is well-lit or bright. Since the smart glass display was monochrome, interface elements were varied in shape and size in order to differentiate between them. Good differentiation required resolution and space, neither of which are abundant on the smart glasses.

The interface only allowed linear navigation which had the potential for the user to lose context, thus each layer of the navigation has to be designed uniquely. The paradigm is one of swiping through selections, then "pushing down" into a layer or, conversely, moving back up. Sony's design guidelines[2], recommended the depth of interface navigation to be limited to 4 or 5 layers. We realized during prototyping that even with 2 layers of depth it will be difficult to navigate to a particular screen to find information fast.

We initially considered showing individual screens for viewing each player's status. However, that would have necessitated players to scroll through multiple screens. Such status views would clutter the screen less, but would add an additional cognitive load in having to remember the states of multiple players. Hence to avoid layering and extra navigation, we decided to consolidate all the player states to the same screen, even though the interface occupied a larger portion of the display. Hence we decided to take the approach where the screen template is fairly static and interface elements change in particular positions on the screen [19].

7.2 Design Implications for Future Wearables

The purpose of the *Icehouse* Challenge was to understand how the latest technologies can be used to help disaster responders. We derive design implications from the development of our wearable collaboration system and from the mixed reality LARP game to guide the design of future technology for disaster responders.

Our design relied on data entered by users and sensors from the environment, which is not ideal. In the physical world, such data might be generated automatically through sensor data or by analyzing communication. Such sensor data can be used to determine physiological and environmental information. Wireless signals can be used to locate responders in a disaster area [27]. Designers can create algorithms that locate users through accelerometers and digital compass data [27].

Based on the players' reviews, the team status view was found out to be the most useful. The team status view shows a player's identifier, specialty icon, exposure, room identifier, and hazard the player is mitigating (if any). This interface can be easily modified for the physical world to show responders' air pack pressure, heart rate, approximate distance, and distance from a leader, for example. In physical-world scenarios, we expect such systems to be more complex, especially if there are more than four team members and/or a large amount of information needs to be displayed. Embedding all such details into a small HMD would be challenging and may hinder users.

[2] Sony's design guidelines: https://developer.sony.com/develop/wearables/smarteyeglass-sdk/design-guidelines/

7.3 Supporting Team Coordination

Since disaster response is a team activity [2, 21, 23], wearable interfaces need to focus on team status and coordination. Our system provided a way to show each player's status, which enabled team members to maintain a shared situation awareness of the environment and to coordinate their activities to avoid mutual interference and to synchronize effort.

Bretschneider et al. [7] argue that safety of disaster responders can be improved by showing information about the environment and the equipment on the HMD; this aligns with our findings. The team status view of our system, which players found to be the most useful, enhances situation awareness through displaying relevant information on the HMD. Situation awareness can be improved by perceived information from the environment, gathering information from the team members and from remote sensors [8].

Variables change quickly in emergency situations and monitoring them requires a great deal of attention [10, 21]. Our system is designed to provide responders with specific information about what is happening around them, enabling them to focus elsewhere when necessary.

8 CONCLUSION

In this paper, we reported on the process of designing a wearable tactical communication and support system for disaster responders in service to the the *Icehouse* game and the *Icehouse* Challenge. We reflected on our design based on its use in a live mixed reality game, and discussed further challenges and opportunities to designing such systems.

Our design was developed from a grounding in practice and aimed to support team situation awareness and decision making by providing the right amount of information about team status and needs with minimal interferes with awareness of the nearby environment. Based on our process of designing this system, we conclude that one of the primary purposes of such systems is to provide responders with a clear sense of state and of team needs. We expect that developing such a system for the physical world would render disaster response more efficient and safe.

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