FireEye: Needs and Usability Assessment of a Head-Mounted Display for Firefighters

Jon Snydal
Alan Van Pelt
Joel Wilson

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Professor Nancy Van House

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Introduction

This project explores the needs of firefighters and usability aspects for a prototype designed to increase firefighting safety. Every year, about 100 firefighters die in the line of duty (NFPA, 2005), and 16% of firefighter fatalities in 1999 were due to firefighters being lost or trapped in low visibility conditions (ISL, 1999), as shown in Figure 1. Firefighting can be an extremely demanding, chaotic, and hazardous environment in which one must make quick decisions on little information and divide attention between many immediate events, making it difficult to safely and efficiently execute tasks.

Figure 1: Low visibility conditions of firefighting.

The Fire Information and Rescue Equipment (FIRE) project at UC Berkeley's Mechanical Engineering Department aims to design, prototype, and implement hardware and software tools for firefighters to improve the safety, efficiency, and effectiveness of emergency responses. It is intended for use in large urban, commercial, and industrial buildings. To this end, we are working with the Chicago and Berkeley Fire Departments to create effective and practical designs.

The project is composed of three main subsystems:

- *FireEye*: A head-mounted display (HMD) for firefighters with a GUI that gives useful decision support information.
- *SmokeNet*: A wireless network of environmental sensors and signals for firefighters and occupants.
- *eICS*: A GUI for the Incident Commander to improve command efficiency and knowledge of the incident.

The subsystems must work together to create a helpful FIRE system that will ideally increase firefighter safety and efficiency.

Project Goals

This project focuses on the FireEye HMD. The original idea for the FireEye is to have a display for each firefighter, with a graphical user interface (GUI) that shows the user his or her location on a map of the building, and locations of the fire and other personnel. This GUI will be seen on a small display mounted in the lower right corner of a firefighter's Self Contained Breathing Apparatus (SCBA) facemask (see Figures 2 and 3). The resolution of the display is about that of a 320x240 pixel PDA. Though the screen is much smaller than a PDA screen, the optics make it appear as a 3" x 4" screen at arms length from the eye.

Figure 2: Concept illustration of HMD location in mask.

Figure 3: Exterior and interior of SCBA facemask. The head-mounted display can be seen in the lower left (exterior) and lower right (interior). The interior picture demonstrates how the LCD screen is translucent when turned off.

We started this project with a basic physical prototype FireEye, displaying a mockup graphical user interface (GUI) that depicted the user as a dot moving on a static floor plan map, and the current air temperature around the user. At the beginning of the semester, we did not have a clear idea of what else the firefighters might want to see on the display, what their needs are for such a system, and how to best display this information to them.

Thus, the goals of this project were to determine the highest priority items to display on the GUI, and to improve our understanding of their needs and tasks. This includes hearing their stories, learning of the risks involved, understanding their explicit and tacit knowledge about procedures, tools, and dangers of firefighting, and determining requirements the prototype would need to meet to be usable by firefighters.

Overview of Methods Used

As we began learning about firefighting and the needs of firefighters, our key lines of inquiry were: what information should be gathered, who needs to know about it, and how should it be presented and used? To answer these questions, we read through firefighting manuals, conducted a series of interviews and surveys, performed low fidelity usability testing, and conducted task analysis with local firefighters. We also solicited feedback and conducted heuristic evaluations on several lo-fi paper and flash prototypes. Additionally, we learned a great deal from background research on firefighting literature, some CHI and Optical Engineering (SPIE) HMD papers, a GUI interface design analysis, and a cartographic methods analysis.

We used nonprobability sampling in our ethnographic research due to time and budget constraints. Our interviews were of a snowball sampling and purposive sampling nature (Bloomberg et. al 968). The snowball method was used when we were referred to recommended high ranking officers we did not know through the one fire captain we did know, while purposive methods were used when, due to the inconsistency of firefighter's availabilities, we did not know how many interviewees we would be able to successfully interview. This was true for the survey as well, which was done in person with firefighters. Although our sample size was only four participants, they were chosen carefully through the snowball method and consideration of their positions and experience, and it has been shown that useful data can be obtained from such small groups (Nielsen & Landauer, 1993; Romney et al., 1986).

Firefighter Needs Assessment

The sections below summarize our findings. Of our various studies, interviews proved the most educational; we visited three fire stations and talked to a total of seven firefighters (at one interview, several firefighters came and went during our time there). Appendix 1 contains a copy of our interview guide, which we frequently deviated from as conversations led down interesting and unanticipated paths. We initially found that our interview guide contained questions that were too specific and restrictive, making them difficult to work into interviews. As Weiss suggests, we subsequently broadened questions and listed themes, while keeping in mind specifics, that we were interested in learning about in order to better facilitate interview flow and the discovery process [Weiss 48]. We learned much more and received colorful anecdotes when we allowed interviewees to go in directions they wanted to go in, while still sticking to our themes of interest.

We began with Hackos and Redish's lists of environmental considerations [91] as a starting point, and identified all the possible factors that might influence our design. Physical and psychological considerations were more obvious, but we also sought to understand cultural and organizational issues that may inform our design process.

Organizational structure

Though we had read several papers and manuals on firefighting, we quickly discovered that there were more roles, responsibilities, and structure than we had initially expected. This meant that the first interview consisted of a lengthier fact-collection portion, as we tried to adjust our views to the reality of the organization.

Firefighters are organized in a hierarchical command system, with the basic unit of organization being the company, which is "any piece of equipment having a full complement of personnel" [Jiang 2]. Companies are typically comprised of a captain, a driver or engineer, and one or two firefighters, though this can vary. The captain is the officer in charge of a company. The engineer operates vehicles, pumps, and other equipment.

An incident scene is controlled by the IC, who orchestrates the scene by allocating resources and monitoring officers. The officers, such as captains and lieutenants, in turn monitor and command their firefighters, and give status updates to the IC [FDNY 16]. Because of their supervisory roles, officers have the greatest information needs about the overall incident status. Thus, if not all firefighters can have a FireEye due to cost restrictions, it may be most beneficial to give priority to the officers.

Firefighters rely on a chain of command style communication where each person reports to exactly one supervisor. This ensures no confusion about the flow and dissemination of information. Firefighters liked the idea of having some communication redundancy between them and their supervisors, because, as discussed later, radios can be difficult to use.

When firefighters enter the building, they are always paired with a "buddy," and as with the SCUBA diving buddy system, buddies try as much as possible to stick together so that one can aid the other in the event of a problem. If buddies are separated, they usually exit the building and reunite before re-entering. Firefighters indicated that it can be easy to lose their buddy when in smoky, loud environments, and that showing real-time buddy location on a digital floor plan, as well as other firefighter locations, would be useful.

Physical and Psychological Considerations

The nature of an emergency response is fundamentally different than other information technology compatible environments in terms of psychological states, physical demands, and available attention. A burning building is among the most challenging of environments for which to develop products.

Upon entering a building, firefighters can face extreme heat that can reach in excess of 1000 degrees Fahrenheit and low visibility. Noise intensity is also high:

> *There is a lot of noise on the fire ground. You're inside; the fire is burning; it makes noise; there's breaking glass; there's chain saws above your head where they're cutting a hole in the roof; there's other rigs coming in with sirens blaring; lots of radio traffic; everybody trying to radio at the same time.* [Jiang 5]

Smoke can reduce visibility to no more than a foot and often forces firefighters to crawl on the floor, where visibility may be slightly better and temperatures lower. Moreover, lighting may be pitch-black in one room, but bright in the next. Low visibility combined with complex floor plans makes it easy to get lost. Big open spaces, like warehouses, pose an even bigger threat:

> *"With apartment and office buildings, you can use walls and doorways as bearings; you might be able to follow walls around to find your way out, but if you're in the middle of a giant smoke-filled warehouse with random machinery and crates scattered around you, you're going to just keep running into things and going in circles."*

To combat this, firefighters sometimes drag in rope behind them, or use the fire hose as a tether to the exit. Even this is not foolproof, however, as ropes can burn through and cannot be hung on to at all times.

Firefighters also showed us that dexterity is a problem. Protective suits, and especially gloves, are thick to provide sufficient insulation. A typical firefighter wears 40-60 pounds of equipment, hampering agility (Figure 4). Furthermore, firefighters are frequently carrying heavy things – ropes, hoses, tools, victims, etc., making hands-free, or nearly hands-free operation important.

As one firefighter described to us, a firefighter's mind is often racing in several different directions at once – which way to go? Are there any dangers around me? Which way is the nearest exit? Is anyone talking to me on the radio? Are there any victims inside? How can I control the fire quickly? The implication is that firefighters have little attention bandwidth to spare for interpreting interfaces. The HMD must be extremely simple and intuitive, requiring only a quick look to absorb the information presented.

Figure 4: Firefighter outfit, including gloves, turnout coat, and SCBA equipment.

Assessment

We again turned to Hackos and Redhish for their task analysis insights. We gathered that top-level firefighter goals include:

1) Extinguishing fires
2) Rescuing victims
3) Protecting themselves
4) Preventing further property damage

Now the question was: what tasks do firefighters take and what sub-goals do they have to achieve these top-level goals? A major theme that arose was the application of situational assessment, accomplished through strict procedures, as well as firefighter pattern recognition.

Successful firefighting is built on constant reassessment by personnel both on and off the fire ground, and reallocation of resources based on those assessments. Rarely do firefighters enter a scene where they are already familiar with floor plans and potential hazards. There are exceptions to this; UC Berkeley, for example, provides local stations with floor plans of all UC buildings. Firefighters will also, on occasion, conduct pre-planning visits to larger buildings in their area in an effort to map layouts, hazards, and locations of hydrants before an incident. These pre-planning mapping efforts are discussed in later sections.

Typically though, assessment begins with a "size-up" when firefighters first arrive at an incident. During the size-up, the Incident Commander (IC) will evaluate building construction, weather patterns, water sources, victim reports, and external hazards to make decisions about allocating firefighters and resources within the building. The first arriving units are charged with determining the floor location and severity of the fire and inform other units as they arrive [FDNY 15]. It may therefore be useful for FireEye to show where the fire is located before entering the building, or perhaps even while in transit to the incident scene.

The sides of a building are identified as ABCD clockwise, beginning with the main entrance of the building, and these letters are used to give directions to the firefighters. From interviews we learned that basements are called B1, B2, B3… going down and floors are called division D1, D2, D3 going up. Sometimes there is confusion if a building is oddly shaped or if the building is on the side of a hill and division 1 is at ground level on one side, but division 2 is ground level on the other side. The IC will attempt to clear up any labeling issues before firefighters enter to avoid confusion once engaged. The IC remains outside during an incident, coordinating efforts as updated assessments are reported by firefighters.

Firefighters are remarkably knowledgeable about building construction. Part of the size-up is assessing a building's flammability and structural resistance to heat. Many elements of this are learned during training: firefighter manuals provide descriptions of different types of building construction and discuss the use of building infrastructure, such as heating, ventilation, and air conditioning (HVAC) systems, as well as hard wired communication and public announcement systems [FDNY 4]. This training is helpful, but firefighters related that much of this is absorbed on the job, where they experience it first-hand. They also use exterior cues to identify room layouts: "If smoke is coming out of a window that has an exterior vent near it, or above it on the roof, it's probably the kitchen. If smoke is coming out of a small opaque window, it's probably a bathroom."

Once inside, firefighters continue to assess and update the IC on the severity of the fire, the visibility, the structural integrity, and victim conditions. Firefighters draw heavily on experience in assessing conditions. Dangerous conditions such as backdrafts and flashovers can be difficult to identify for inexperienced firefighters. Backdraft, for example, is a situation in which a fire in a room is starving for oxygen and is pulling air in from outside the room. From the outside of such a room, one sees smoke-filled air slowly puffing out, or sometimes being gradually sucked in through doorway cracks and ventilation openings. The danger is that if a fire that is starving for oxygen suddenly receives an influx of oxygen, such as by opening a door, it will flare up, even explode, putting the door-opener in severe danger. On the other hand, what appears to be backdraft, may just be due to an open window in a room that is serving as an outlet for hot, expanding air in the building.

The difficulty of course is in recognizing the dangerous situations from the relatively benign ones. As one firefighter put it, "You assume the worst…. recognize when you misinterpret a situation, and add it to your memory bank." In another example, interviewees told us how firefighters evaluate structural integrity by testing the "sponginess" of roofs and floors. The more spongy it is, the more likely it is to collapse. These are things that are not easily taught in books or classrooms.

Cognitive scientist Gary Klein conducted long-term ethnographic field studies with firefighters, chronicled in his book *Sources of Power: How People Make Decisions*. Klein confirmed that firefighters rely on experience above everything else. Klein observed that fire commanders make eighty percent of their decisions in less than one minute, often with incomplete information about the situation (4). Klein's most important discovery was that experienced firefighters do not weigh options or compare different courses of action:

> *Even when faced with a complex situation, the commanders could see it as familiar and know how to react. The commanders' secret was that their experience let them see a situation, even a routine one, as an example of a prototype, so they knew the typical course of action right away. Their experience let them identify a reasonable reaction as the first one they considered, so they did not bother thinking of others. They were not being perverse. They were being skillful. (17)*

Thus, expert firefighters do not "make decisions" in the conventional sense of considering options and then choosing the one that sounds best, but rather operate on intuition, based on patterns they have learned to recognize through experience. On the other hand, novice firefighters do have to compare different courses of action because they have not learned to recognize patterns and anomalies (21).

These findings suggest two alternatives for the FireEye prototype:

1) The FireEye could offer more benefit to inexperienced firefighters, who may need more information to determine a course of action than experienced firefighters, who rely more heavily on their senses and intuition to make decisions.
2) The FireEye should not attempt to provide information that is experiential in nature, but rather focus on information that cannot be acquired through experience, such as floor plans, paths traversed, nearest exits, and current victim and personnel location. Several of the firefighters we interviewed related that they would not want experiential information: "Computers are a poor substitute for experience because situations are not always so cut-and-dry, and because computers fail." As one firefighter said, "I don't need [the HMD] to tell me the temperature… I know I need to get out when my ears feel too hot."

Existing Tools Firefighters Use

Firefighters employ several different devices while engaged in firefighting. One such device is an air gauge, which displays the quantity of air remaining in the firefighter's SCBA tank, as well as an estimate of how much longer that air will last based on the firefighter's current consumption rate. Firefighters told us that they do not usually look at the gauge because they are too occupied with firefighting. When air is running low, an audible alert will sound and a small vibrator in the nose piece of the mask will go off.

The PASS device is an emergency audio alarm the firefighters can trigger manually by pressing a button on the air gauge, but that also signals automatically when the firefighter has not moved for 30 seconds. Interviewees related that these alarms frequently activate when they are standing around talking.

Some fire stations are also equipped with a thermal imaging device. These are used to locate victims once inside a burning building, to identify fires hidden behind walls, and to locate exits. The firefighters raved about how useful they were, but their use is limited due to their high $10,000 cost.

Radio communication between ICs and firefighters is imperative for conveying updated information and for directing resources, but as the previous quote on noise intensity points out, there is a lot of traffic and it is hard to hear. Our interviewees also repeatedly commented on how much the mask muffles one's voice and how difficult it can be to communicate. Some firefighters have a built-in voice amplifier within their mask. The amplifier is connected to a large rubber button, typically mounted in a left breast-pocket in the suit, which, when pressed, activates the amp. This helps with audibility, but does little for radio traffic, which suggests that an instant messaging system for communication redundancy might be beneficial.

Rate and rank questionnaire

In an effort to better understand what information firefighters really want and/or need to see on the heads-up display versus what information would be nice to have or is not important at all, we drew up a laundry list of possible information elements and created a rate and rank questionnaire which four firefighters completed during interviews.

We suspected that merely talking about what information a firefighter would like to see would not yield the kind of detailed and prioritized analysis of their information needs that we wanted. We hoped that the survey would provide us with a good set of data on which we could base the decision to show or not show information elements.

To accomplish this, we decided to have respondents first rate each item on a scale of 1 to 3 (1 is most important) and then rank all the 1's so that we could see a ranked list of the most important information elements.

In our analysis of the results, we broke the ranked list into three broad categories:

1. Critical items (ranked 1-5)
    a. overview of floor
    b. location and ID of other firefighters on same floor
    c. escape routes
    d. thermal imager
    e. SCBA air level
    f. windows
    g. location and building
    h. doors
    i. show where firefighter has been
    j. stairs
2. Very important items (ranked 6-10)
    a. standpipes / hose outlets
    b. location of fire (on same floor and floors above and below)
    c. emergency calls like "man down"
    d. division (floor) number
    e. direction North
    f. air temperature
    g. teams labeled by company number

3. Important items (ranked 11-20)
    a. hazardous atmosphere levels
    b. where firefighter entered building
    c. elevators

Surprisingly, some of the information we thought firefighters would want turned out to be less useful and less desired by firefighters:

- room numbers
- A,B,C,D parts of building

There was a fair amount of disagreement among the firefighters regarding what information is most useful. For example, one firefighter felt that doors, windows and stairs were the least important, whereas another ranked them in the top five of their "must have" list. This is a clear indicator that more research is necessary. Specifically, the questionnaire should be simplified and made easier to complete, and then it should be circulated to a large number of firefighters who have experience fighting fires in large or complicated structures. Nevertheless, these preliminary findings provided us with a general idea of what information firefighters want to have the most, from which we could draw in ongoing iterations of the prototype.

Cartographic analysis

Although we had a sense of what information firefighters want to see, we had to determine the most intuitive way to present it to them. Since firefighters already use different kinds of maps for various tasks, we decided to examine them as ethnographic artifacts to discover the grammar and syntax of their visual vocabulary.

Our cartographic analysis included the following documents:

- Preplans of the Sears Tower
- Preplan of Davis Hall, UC Berkeley
- Preplan of Doe Memorial Library, UC Berkeley
- Maps of several Berkeley elementary schools
- Preplan of Channing-Bowditch Apartments
- Standard map symbols from *The Firefighter's Handbook*

The main type of map firefighters use is called a preplan, an architectural diagram that shows the layout of the building and features relevant to firefighters. The incident commander may use preplans to direct firefighters, but during the fire, firefighters never use these maps. Some of the firefighters we interviewed used preplans during fire inspections to acquaint themselves with the location of fire hydrants and emergency exits. UC Berkeley disseminates detailed preplans to local fire departments, but surprisingly, the Berkeley fire department does not have preplans for most local buildings. Several firefighters mentioned that it would be extremely useful to have preplans in the fire engine so that the firefighters could begin to size up a building en route to an incident.

The preplans we examined had far too much detail for our display purposes, and tended to emphasize features located outside of the buildings like fire hydrants and control panels. For example, the preplan of Doe Library shows absolutely no interior architectural features. Meanwhile, the Sears Tower preplan resembles an engineering diagram (it was generated from one), and shows no exterior features.

There was no consistent set of symbols used across the maps. The UC Berkeley maps use a common set of symbols (filled circle for hydrant, hashed rectangle for fire alarm control panel), but the elementary school maps were drawn by hand and did not show any firefighting equipment or access controls. The Sears Tower had entirely different symbols and emphasized very granular interior details such as a fireman's phone and wheelchair waiting areas.

The standard map symbols we found in *The Firefighter's Handbook* are surprisingly similar to one another. For example, an unfilled circle can either be a vertical pipe, a standpipe, a fire department connection, an iron chimney or a gasoline tank depending on what uppercase letters are next to it (VP / HYD / IR.CH. / GT). Of 50 symbols, 20 are circles, 20 are rectangles, and 10 are lines or diamonds. Almost every symbol depends heavily on small text inside or next to it to differentiate it from other, visually identical symbols.

It is incomprehensible why the designers of standard symbols would use the same shape for a water source (standpipe) and a combustible liquid (gasoline tank). We decided that it would be reckless to use such symbols in our interface, even if they are "standards." Displaying small text next to symbols would tend to clutter the interface, but even more importantly it would increase the firefighters' cognitive load and potential for misinterpreting a symbol.

We also found that the standard symbols included very few of the information elements that firefighters had ranked highly. In fact, the only top-ranked items we found symbols for were standpipes and stairs. However, the stairs symbol was simply a rectangle with the word "stairs" in it, and a standpipe was an unfilled circle with "HYD" next to it. There were no standards for showing the location of a fire, other firefighters and all the other top-ranked items. Thus, despite our best intentions to use symbols that would match firefighters' expectations, at the end of our cartographic analysis we discovered that we would need to invent many of our own symbols, keeping two things in mind: (1) we should not use shapes or symbols that resemble extant firefighting symbols; and (2) we should use red for firefighting equipment and blue for water sources (a finding from interviews).

Usability Testing with Paper and Digital Prototypes

We created two rapid prototype GUI's and tested each with firefighters. One prototype was a paper system consisting of different maps with varying levels of information detail, size, and number of rooms shown. The other prototype was a digital mockup GUI, made with Flash MX. We presented these to firefighters during each of the interviews.

The digital GUI prototype was actually two different interfaces. These interfaces were designed to examine user preference for symbol placement, size of font, amount of floor plan shown on the display, and the user's frame of reference. Frame of reference refers to the orientation in which the map is presented to the user. The two types presented were egocentric and exocentric.

The design of the egocentric digital prototype was aided by the following finding: firefighters work on shifts lasting anywhere from 12 to over 24 hours, during which they may have much downtime. Our interviews revealed that firefighters are unionized, and as a perk, unions typically buy entertainment systems for the firefighters to enjoy during downtime. Often the entertainment systems include a videogame system such as PlayStation or X-Box. As we questioned the firefighters to learn more about how they would like to see floor plans displayed, they repeatedly brought up games like Halo, which use a simple interface similar to a radar screen, to show enemy and teammate locations. We then found Halo in a video game store and played it, and saw that in this first person game, the player has a small circular map, in which they are in the center. The map rotates to always orient forward as the user turns, and others are shown as different colored dots.

Figures 5 and 6 show the egocentric and exocentric frames of reference. Both show a bird's eye point of view of the same floor plan. Egocentric means that the world rotates around the user when she turns her head such that the top of the screen always shows what is directly in front of the user. Exocentric refers to a static design, where the map orientation is always fixed, and the user's direction changes on the map, indicated by the black arrow attached to the red circle. In both maps, a zoomed in view is shown through either a circular (egocentric) or square (exocentric) window, and this window pans along the larger underlying floor plan, always keeping the user in the center for easy reference. As mentioned before, the letters ABCD are standard orientation references by firefighters and refer to the sides of the building, where A is the side with the street address and generally the main entrance.

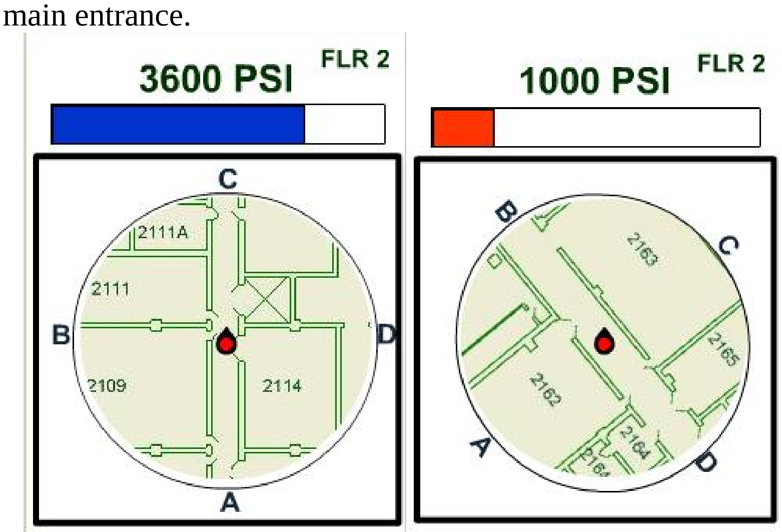

Figure 5: The egocentric digital prototype. Two different views are shown, based on the direction the firefighter is standing or walking. "A" represents the side of the building

from which the firefighters are staging their attack, usually the main entrance to the building.

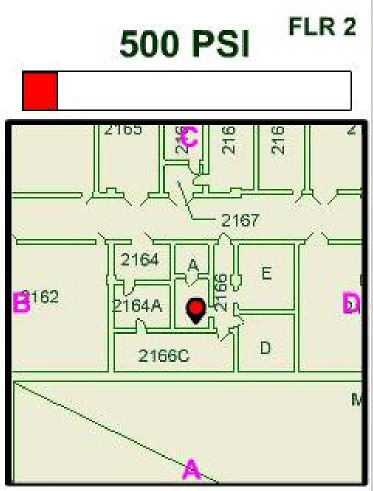

Figure 6: The exocentric digital prototype. The direction the firefighters facing or walking is indicated by the direction of the black arrow attached to the red circle.

During the usability portion of the interviews, we showed these GUIs to the interviewee and asked which one they would prefer, and which they thought might result in more efficient navigation through a building. We had the interviewees think aloud about the prototype. In some cases, we had the interviewee walk around with the paper prototype, alternating between orienting the map in the direction he was walking as in the egocentric design, and keeping the map static as in the exocentric design. Experiments conducted by Kumagai with military personnel showed that the egocentric design is more efficient for outdoor backcountry navigation, and we thought the firefighters might find it more useful as well (252). Ultimately, however, interviewees were split quite evenly on what they preferred, thus the results are inconclusive and further testing must be done in a more realistic setting.

Heuristic Evaluation

A heuristic evaluation of this GUI may be best executed with a combination of Nielsen's 10 heuristics, and those created at UC Berkeley by Mankoff *et al* for ambient displays. The ambient display heuristics were chosen because the FireEye is intended to act as a non-distracting peripheral display during routine incidents where it is of little use, such as a regular residential home response. However, it must also act as a primary information source in complex, high-stress incidents where normal firefighting tactics are inadequate, and more information is needed. An example would be a high-rise building with multiple fire locations, where firefighters must navigate dark, smoke-filled hallways.

Heuristics Used

Appendix 2 includes Nielsen's 10 heuristics and Mankoff's ambient heuristics. Heuristics Mankoff borrowed from Nielsen were removed from the list. The ambient heuristics are ordered in terms of importance, with (1) being most important, as determined experimentally by Mankoff. Mankoff *et al* found that many of Nielsen's usability heuristics do not apply to the domain of ambient displays.

Major Violations

The greatest violations found were a high severity violation of Neilsen's "visibility of system status", a high severity violation of Neilsen's "error prevention", and high and medium severity violations of Mankoff's "peripherality of display."

In the first violation, the FireEye does not indicate whether is or the rest of the FIRE system is working properly, other than if the user is not shown, it is not working. This merits a high severity violation of Neilsen's "visibility of system status." Some kind of error messaging must be created so that the user knows if the system is not functioning. If the system is not operational, the user will no longer see him or herself on the map, or any other dynamic elements such as locations of the fire and other personnel. The fact that no dynamic elements appear on the GUI will be notification to the user of its status, but we should consider creating more explicit error messaging for system failure of events, rather than placing this burden on the user to puzzle out. For example, if data is not available for certain portions of a building, those portions of the map could be marked by a light gray-hashed zone, or by inverted colors. There could also be a text message that would appear in the same area as text messages from the IC that says something to the effect of "FireEye System Failure."

In the second violation, if a firefighter goes outside the boundary of the wireless network or if the system malfunctions, the system will cease to provide accurate information, effectively creating an error. This constitutes a severe violation of Nielsen's "error prevention." Therefore, the system should indicate the boundaries of the network so that the firefighter knows what information is accurate versus unknown. There should be a clear indication that the system is not functioning once the firefighter leaves the wireless network. As before, a message could appear to the effect of "FireEye System Offline," and the color of the map could change to black and white, for example. In this case and in the previous, the map would still be shown, as this could still be useful for navigation.

The third and forth violations concern Mankoff's "peripherality" of the display. The FireEye is mounted low in the user's field of view to minimize obtrusiveness yet allow it to be easily monitored. The GUI is kept simple to minimize distraction. A balance must be found between user intrusion and information awareness. A high severity rating is given because facemasks are known to steam up from time to time and this may prevent users from seeing the display. Furthermore, a medium severity rating is given because firefighters with vision problems have to mount special glasses inside their masks, as contacts are not allowed. The display is mounted such that they may not be able to see it while using these glasses.

The heuristic evaluation was a helpful tool to determine weaknesses in the potential usability of this system. Ultimately, the system must be optimized for emergency response. Thus, only critical items need to be shown, and most systems will be automated with only necessary interactions allowed. The ideas for interactions allowed and items displayed on the GUI are based on interviews with firefighters, but more realistic user experiments with prototypes will occur to determine whether these ideas are correct.

Future Work

This firefighting needs and usability assessment has been very useful for the Fire Information and Rescue Equipment project. We have gathered information from multiple sources, including first hand reactions to the prototype and ideas from experienced firefighters. This information will allow us to improve both the hardware and software prototypes.

We plan to perform a larger scale web based survey with our rate and rank questionnaire in order to obtain a better idea of what information is most important to firefighters for this system. One important factor we realized was that our interviewees were mostly with experienced firefighters who had 15 or more years of experience. These firefighters were suggested to us by our contact within the Berkeley division, but we are interested in also understanding the needs and preferences of less experienced fire fighters, who will be just as likely to use the FireEye, but will likely have different priorities.

We also plan to further test the egocentric and exocentric GUIs for efficiency and user preference in actual navigation experiments. Finally, we are planning to extend our user and task analysis by observing actual incidents and training.

References

(All URLs accessed May 2005)

Blomberg, J., Burrell, M., Guest, G. An ethnographic approach to design. In Jacko J. A., Sears A. (eds.). *The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications.* Lawrence Erlbaum Associates, Inc.: Mahwah, New Jersey, 2003.

FDNY. Firefighting Procedures: High-Rise Office Buildings, Vol. 1, Book 5, 1997.

Hackos, J. and Redish, J. User and Task Analysis for Interface Design, NY: Wiley, 1998.

Information Systems Laboratories, Inc. Wireless Firefighter Lifeline, 1999. http://www.islinc.com/surv_firefighter.asp

Jiang, X., Hong, J., Takayama, L., & Landay, J., Ubiquitous Computing for Firefighters: Field Studies and Prototypes of Large Displays for Incident Command, Proc. of CHI 2004, April 24-29, 2004.

Klein, Gary. Sources of Power: How People Make Decisions, Cambridge, MA: MIT Press, 1999.

Kumagai, J., Allard, F. Effects of frame of reference and point of view on infantry wayfinding, *Proceedings of SPIE Vol. 5079. Helmet- and Head-Mounted Displays VIII* (pp. 242-253). Bellingham, WA: SPIE Press, 2003.

National Fire Protection Association, 2005. <www.nfpa.org>.

Nielsen, J. & Landauer, T. K. A mathematical model of the finding of usability problems, *Proceedings of ACM INTERCHI'93 ConferenceI* (pp. 206-213), Amsterdam, The Netherlands, New York: ACM Press, 1993.

Nielsen, J. Ten usability heuristics, 1999. <http://www.useit.com/papers/heuristic/heuristic_list.html>.

Mankoff, J., Dey, A., Hsieh, G., Kientz, J., Lederer, S., Ames, M. Heuristic Evaluation of Ambient Displays. In *Proc. of CHI 2003*, pp. 313–314. ACM Press, 2002.

Romney, A. K., Batchelder, W. H., & Weller, S. C. Culture as consensus: A theory of culture and informant accuracy, *American Anthropologist*, 88, 313-318, 1986.

Walter, A., Coleman, R., Wutz, T., Carter, W., Miale, F., Dodson, D., Koonce, T.R., Hancock, R., Morris, R., Childress, D., Miller, G., Tully, D., Hawley, C., Rutledge, M. The Firefighter's Handbook: Essentials of Firefighting and Emergency Response, Second Edition, Clifton Park, NY: Thomson Delmar Learning, 2004.

Weiss, Robert. Learning from Strangers - The Art and Method of Qualitative Interview Studies, New York: The Free Press, 1994

Appendix 1: Interview Guide

Head Mounted Display (HMD) User Interface Interview Guide

Thank you for doing this interview with us.

We expect this to take an hour and a half or so.
We're students at Berkeley and we're doing this for a class/research project.
Is it ok to audio record and take pictures of the interview?

((Give a brief background, system capabilities, show the head-mounted display (HMD) in mask, without the map on the screen))
((Purpose of interview: find out what info to display and how to display it))

Do you have any questions before we begin the interview?

General Info:
Name:
Rank/role:

Q: How long have you been a firefighter?

Q: Have you ever fought a fire in a large building?

> (If yes) Tell us what that was like, what challenges did you face?
> Did you ever get lost? How did that happen, and how did you find your way again?

From the moment you got the call for the fire, what did you do, what were your tasks?

Q: Let's say you're back in the middle of that big building incident, what information would have been most useful to you? What information did you not have that would have been useful?

Q: Have you ever lost contact with your buddy during an operation, and what happened?

Q: How are firefighters currently identified over the radio?

Q: Let's say you had the mask display during that big building incident. Could you draw what you would want to see on this display to help you out? Give them a PDA-sized blank box to draw in.

Q: Do you ever use maps for an incident? Are they the ones in the building control room? Are these different from the ones the IC uses?

What from the IC's large floorplan would you want to see on this small screen while you're roaming through the building doing your tasks?
They show us a typical building floorplan- load into their memory their own floorplan vocab- what are most important things on the map for you? Which features are useless?
What do the fire commander's maps look like? What are the important features on them? Which ones do you like the best?

Head-Mounted Display (HMD) User Interface Survey

Please rate the usefulness of seeing the following information on the head mounted display. Imagine that you're using the head-mounted display (HMD) in the middle of a large building/high-rise incident, walking around in dark, smoky corridors. Please keep in mind the limited screen space that would be available on a HMD.

STEP 1: RATE INFO In the **left column**, rate items on this scale: 1 = Very important to see on HMD 2 = Would like to see, but not very important 3 = Least important to see	STEP 2: RANK CRITICAL INFO ***After*** rating ***all*** items, take the items you rated as "1" and in the **right column**, rank them in order of importance from 1, 2, 3, 4. . . as needed.

RATE	**ITEM**	**RANK 1'S**
1 2 3	Your location in building	
1 2 3	Your SCBA air level	
1 2 3	Overview of entire floor (vs. zoomed in detail view)	
1 2 3	Stairs	
1 2 3	Room numbers	
1 2 3	Floor number	
1 2 3	Locations of combustible and hazardous materials	
1 2 3	Locations of standpipes and hose outlets	
1 2 3	Smoke tower	
1 2 3	Fire extinguishers	
1 2 3	Elevator	
1 2 3	Fireman's phone	
1 2 3	Doors	
1 2 3	Windows	
1 2 3	HVAC vent locations	
1 2 3	Handicapped access points	
1 2 3	What direction you're facing in the building	
1 2 3	Indication of where you've been	
1 2 3	Indication of North	
1 2 3	A, B, C, D parts of building	
1 2 3	Indication of where you entered the building	
1 2 3	Locations of only your buddy but no other personnel	
1 2 3	Locations of all personnel on your team only	
1 2 3	Locations of all other personnel on your floor	
1 2 3	Identification of other personnel	
1 2 3	Teams labeled by number	
1 2 3	Locations of fire on your floor	
1 2 3	Locations of fire on floor above you	
1 2 3	Locations of fire on floor below you	
1 2 3	Locations of safe escape routes	
1 2 3	Emergency calls like "evacuate" or "man down"	
1 2 3	Text messages from the Incident Commander.	
1 2 3	Carbon monoxide levels	
1 2 3	Oxygen levels	
1 2 3	Hazardous atmosphere (toxic gasses)	
1 2 3	Air temperature around you	

1	2	3	Physiological Data: Blood Pressure	
1	2	3	Physiological Data: Heart Rate	
1	2	3	Physiological Data: Respiration	
1	2	3	Other:	
1	2	3	Other:	
1	2	3	Other:	

Comments:

Would you please draw symbols of how you would display this, next to they symbols?

((Describe more about how the FIRE system works, what it can and can't do.

((Show paper prototypes of window to larger map, with different scales of maps underneath, same sized window.

Q: Should the map be fixed (showing entrance point or N?) or automatically reorient so that the direction you're facing is the top of the map?

Q: If the map should reorient, how important is it that the map do this? If the map had to be static, what symbols would help for navigation (e.g., arrow showing which direction you were going)?

Q: Would you want a zoom button so that there's a zoom mode where if you hit the button, you would then see an overview of the whole floor, and if you hit it again, you would return to the zoomed-in view?

Ask about manual scrolling, uses of arrows vs dots vs arcs vs border bars?

THANK YOU, THIS HAS BEEN VERY HELPFUL FOR US.

Appendix 2: Heuristics Used

Table 1: Nielsen's Heuristics

1. Visibility of system status The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.
2. Match between system and the real world The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.
3. User control and freedom Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.
4. Consistency and standards Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.
5. Error prevention Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.
6. Recognition rather than recall Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.
7. Flexibility and efficiency of use Accelerators -- unseen by the novice user -- may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.
8. Aesthetic and minimalist design Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.
9. Help users recognize, diagnose, and recover from errors Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
10. Help and documentation Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

Table 2: Mankoff *et al*'s Ambient Heuristics

1. Sufficient information design The display should be designed to convey "just enough" information. Too much information cramps the display, and too little makes the display less useful.
2. Consistent and intuitive mapping Ambient displays should add minimal cognitive load. Cognitive load may be higher when users must remember what states or changes in the display mean. The display should be intuitive.
3. Visibility of state An ambient display should make the states of the system noticeable. The transition from one state to another should be easily perceptible.
4. Aesthetic and pleasing design The display should be pleasing when it is placed in the intended setting.
5. Useful and relevant information The information should be useful and relevant to the users in the intended setting.
6. Easy transition to more in-depth information If the display offers multi-leveled information, the display should make it easy and quick for users to find out more detailed information.
7. "Peripherality" of display The display should be unobtrusive and remain so unless it requires the user's attention. User should be able to easily monitor the display.