Adapted Sensor Data Visualization on a Smartphone: The Case of a Fire Emergency Rescue Application

Kristine Sundt Lorentzen[1], Siri Fagernes[2] and Tor-Morten Grønli[2]
[1]Evry, Oslo, Norway
[2]Mobile Technology Lab, Faculty of Technology,
Westerdals Oslo School of Arts, Communication and Technology
Oslo, Norway

Abstract

This paper discusses the challenges of visualising sensor data about fire emergencies, aimed for use in rescue operations in fire emergencies. Because of the stress experienced during such situations, it is important to consider human behaviour during emergencies, and the most efficient ways of displaying data. In addition, due to the fact that people generally only have access to their mobile phones during evacuations, this paper focus on developing an emergency aid application for a mobile device. The paper further shows how indoor location data can be utilised efficiently to aid during emergency evacuations, and how list distortion can be used to display info about the floors in a building.

1 Introduction

With recent developments in sensor technology, it has becoming possible to monitor both our environments and assets, as well as the people around us. As these technologies are getting cheaper and more reliable, more and more are being implemented to monitor larger buildings in order to prevent or monitor emergencies. As an example, smoke alarms are required as a minimum in all floors of buildings in Norway. These alarms have saved countless lives, and assist fire departments around the world to quickly and efficiently locate the source of a fire. Understanding how humans actually behave during emergencies is essential when developing an application to aid such situations. In situations where a user may literally be in a life or death scenario, it is crucial to ensure that the design of the application would not worsen the situation.

In this paper, the focus is on how a mobile application could aid during an emergency, possibly saving lives. Technology needed has been researched, and the main focus is on the visual design of such an application. More specifically, the scope is limited to how to display information about a fire emergency in a multi-story building on a mobile surface, in the most efficient manner.

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2 Related Work

In 2004, Santos and Aguiree [1] conducted a critical review of the current emergency situation simulation programs and how well they simulated actual human behaviour during such situations. They found that older studies on emergency situations indicated that such events were heavily influenced by panic, and focused on measures to ensure that people would not get trampled or hurt by other panicking individuals, such as wider doors. This has been best known as the panic model [1]. However, when looking at newer studies, they found that that the levels of panic during emergencies were low, and indicated that rather than creating a chaotic environment, people tended to keep relatively calm and focus on helping others where needed. These findings are backed up by Cocking, Drury and Reicher's 2009 study [2] on psychology of crowd behaviour during emergencies, who argue that the panic model was heavily influenced design choices for emergency plans, and that *[...] rather than being viewed as active, thinking agents, crowd members are considered to flow in the same way unthinking, inanimate objects such as ball bearings* [2]. They also argue that, because of this, little thought and design goes into solutions made to inform evacuees, as there is a fear that the gravity of the situation will make them panic. In fact, they claim that, in many cases, it *"(...)" may not be over-reaction, but rather under-reaction that tends to lead to deaths in emergencies*. This is especially true when the evacuees have formed into groups, as they then spend even more time trying to come to an agreement on how to act [1].

Proulx and Sime [3] conducted an experiment at the Monument train station in Newcastle, where the impact of the alarm system was tested, including the use of Public Announcement (PA) systems and personnel, and the impact of telling the evacuees about the emergency. It was concluded that an alarm alone is not even sufficient enough to get all the passengers to leave the train station, and that people had a tendency to get stuck, or stay idle and wait for help, if the exit they wanted to take was unavailable, and another was not immediately available. Their findings also supported Cocking et al.'s findings [2] on the impact of the panic model on managerial decision making. During an experiment where they announced the location of a fire over the PA system, *"Some concern was expressed in prior discussions with senior management that an explicit P.A. reference to a threat [...] might lead to 'panic'"*. The results of the experiments, however, indicated that this in fact did not encourage panic, but raised the threat level sufficiently for the passengers for them to act rapidly and evacuate efficiently [3]. They concluded that *"In an emergency telling people the truth about an incident appears to be the best way to convince them of the gravity of a situation."* The findings of Jong and Helsloot [4] contradict this however: In their experiment on information management during a Dutch national flooding exercise, they observed that people tend to evacuate earlier and on their own initiative without detailed information, and that how and when the evacuees got the information was more impactful than the information itself. This is however a very different kind of emergency than a fire drill, as a flooding usually is much slower, and people may feel that they have more time to find a suitable solution of their own, rather than wait for help. On the other hand, during an emergency such as a fire, the evacuees may only have a very short period of time to make the right decision, and they may not have the option to go back on that choice once it is made.

Indoor Location Based Services

There has been a demand for using sensors for Location Based Services (LBS) for a long time, and active development of such services have been going on since the Cold

War [5]. The most widely used of these services are *Global Navigation Satellite Systems (GNSS)* like the *American Global Positioning System (GPS)*, providing accurate location data for outside locations with relatively clear *Line Of Sight (LoS)* between the device being located and the satellites from which it is deriving its location. However, GNSS are not suitable for indoor LBS, as the accuracy is too low, and obstacles such as walls block the LoS and creates multi-pathing issues which renders the use of GPS unreliable. With the rapid development of IoT and devices such as smartphones, there is a growing market for services which allows for tracking the location of supplies, devices and even people in an indoor environment. To mitigate the issues faced when using GNSS, most research on indoor LBS utilise wireless sensors with much shorter ranges, such as Wi-Fi, Bluetooth, Radio Frequency Identification (RFID), Near-Field Communication (NFC) or Ultra-Wide Band (UWB). There is an overwhelming consensus among researchers that the field of LBS, especially when applied indoors, is a very popular research field, with both high demand for such services, and new technology which enables precise measurements.

Information Visualization

Because the exact location data about each tracked entity is presented on a floor plan, as previously discussed, the application must be able to present easy access to information about each floor in the building. In addition to this, the data must also as discussed be presented on a mobile surface, the number of floors which can be presented simultaneously is severely limited. As the number of floors of building is ever increasing in big cities, it is therefore important that the developed solution is flexible to accommodate these buildings. The way we solved this issue is by allowing the user to scroll through a list of floors in decreasing order, as to mirror how the floors are placed in the building.

According to Spence [6], implementing the feature of *scrolling* in a user interface allows the user to focus on parts of the information which is being presented, while displaying larger amounts of data than can be visualised at once. However, he also points out that scrolling itself is not innately an organised way of traversing information, as it may be easy to loose overview of where some information is located in context with everything else. This is reflected by Ware [7], who argues that a user is as likely to *"[...] see an interesting detail on detail, zoom out to get an overview, find some related information in a lateral segue, and then zoom in again to get the details of the original object of interest"* as one goes through the process of overview - zoom - detail. The author further claims that a good interactive system should be able to enable both of these forms of traversal.

To mend the issues with scrolling, Spence [6] suggests using *context mapping* to give the user a mental image of their current position in relation to the whole dataset. He presents several methods one can utilise for this purpose. The solutions generally do one of two things: either they trade in having some of the information obfuscated to facilitate showing more context about more relevant information, or they show the highlighted information in its context. In the context of the scenario presented in this paper, this would translate to either showing each floor in succession, with floors not fitting on screen disappearing away from view. To ensure that the user has context about what floor they are on, the number of each floor will be highly visible, and ordered. However, this only allows the user to know what floor he is on, and what direction to go in order to find the floor he is looking for. The user has still no context about where how many floors there are in either direction. This can be obtained by the use of a *scrollbar*, where the space to the

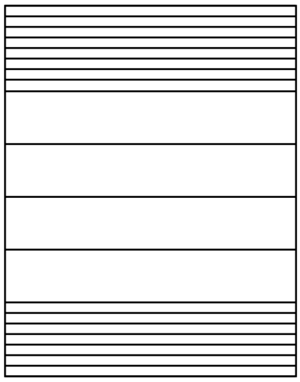

Figure 1: Distortion in the Y-dimension, based on Spence 2001

bottom and top of the bar from the handle is proportional to the distance to the lowest and highest floor. This is the most common way of mapping the context of a list, and should be something that the users are used to. However, because this is only an approximate representation, it may still not be sufficient to communicate the exact number of floors, and will not allow seeing any information about the floors not currently shown on the screen.

Another way to solve the problem is displaying context in a limited screen space is utilising distortion [6]. This method allows the entire context of the selected information to be viewed at all times by distorting the non-selected information into a much simpler form, while showing the selected information in full detail. Spence [6] shows how one common form of distortion of a linear presentation of information is to minimise the height or width of the elements which are currently not in focus. An example of this kind of distortion can be seen in Figure 1

However, according to Ware [7], one issue with this technique is that the method of distortion may make it difficult to identify important parts of the structure. On this basis, he developed the following design guideline, *Design fisheye distortion methods so that meaningful patterns are always recognisable* [7]. This means that the distorted elements must still be partly viewable. The goal of this technique is to give the user the most insight into the entire set of data, without having to use too much screen size. This should therefore be an appropriate method to use when visualising information about a building using a list.

3 Prototype and Experimental Design

The project consisted of several stages. First background research was conducted to determine the requirements for an evacuation app. by interviewing representatives from first responders to an emergency evacuation, such as the police force and fire department. The goal of the interview was to establish what information first responders need from an indoor LBS in order for it to be a helpful tool and identify common challenges. The interview participants explained that, during an emergency, the situation changes rapidly, too quickly for anyone to be able to keep up with the communication and plot that information into a system. This show that the design of an application for first responders needs to be adapted to the pace with which events happen during emergencies, and minimise the need for navigation. The interview data were mapped to a requirement list and iteratively implemented, and later evaluated, in a prototype application. We will next describe the development and evaluation stages.

Development of Prototype

Local university campus building was used as a case in the prototype application, and blueprints of the building were used in the visual layout of the application. The design was done in an iterative manner, beginning with designs closely related to existing prototypes of indoor location systems for emergencies.

After reviewing the data obtained from my interview with the police, we focused scope on floor managers in particular. In the research we noted that, although there are several examples of prototypes visualising one floor at a time using a floor map, we could not find examples showing how this would be incorporated into visualising a multi-story building. We therefore started focusing on the use of lists that give the user some information about all the floors, with expandable list items to display the floor plan for each floor. This allow the user both to use an already familiar type of interface to not only navigate to the floor they wanted, but use the information presented when the list item is not expanded to compare the state of the different floor and evaluate which floor to navigate to.

From the initial designs, we developed a final prototype as a web application with HTML, CSS and JavaScript. This was partly because earlier prototypes, though intractable, sometimes had trouble with the animations required. Neither did it allow much change to be made to the behaviour or look of the components, some of which did not follow the specific specifications of Google Material Design, or allowed any customisation or organisation of data.

We also included a distortion element in the prototype, Figure 2 and Figure 3, were the data, when distorted, loses some detail but the core data remains. This allows the user to not only see that sensors have been triggered and how many, but even do so when the element is minimised.

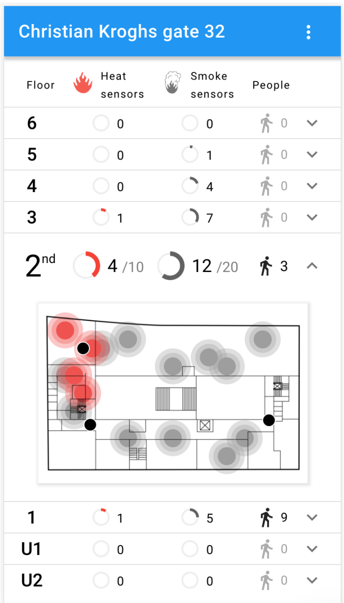

Figure 2: Distortion example 1

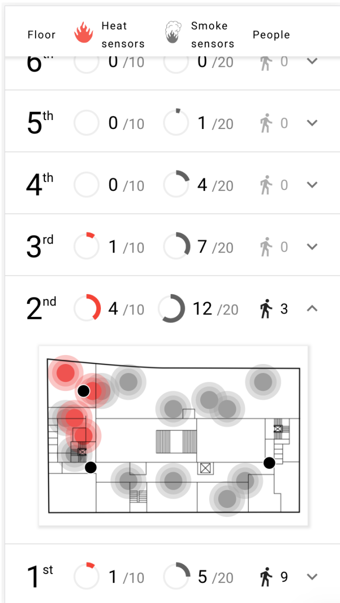

Figure 3: Distortion example 2

A total of four prototype revisions were produced. Three were made with the aid of a high-fidelity prototyping tool, and the last and final prototype was developed as a web application. The changes to the prototypes were made as a result of the initial data obtained from the interviews with the expert users / first responders and in accordance with an iterative approach where the artefact was developed incrementally as new information contributed to the awareness of the problem.

Evaluation of Prototype

Finally, the prototype was evaluated according to the guidelines of Benyon [8]. The prototype was made to be limited in its functionality so that it could be properly evaluated on whether or not its core functionality was appropriate and useful. We designed an experiment to investigate two different yet important aspects of the application under test. Firstly, we wanted to find the real-life business value of the application, and its potential to aid evacuations and save lives. Secondly, we wanted to explore the impact of distorting the list and whether or not the participants saw a notable difference and had any preference. The experiment was therefore designed to encourage the participants to think out loud and give commentary on the application in accordance with the guidelines for cooperative design and evaluation as presented by Benyon [8]. The experiment was divided into two different scenarios, each utilising one form of the list. The distortion of the list is the independent variable, as defined by Oates [9]. The dependent variables are the two sets of data showing an imagined fire emergency, and through commentary and interview, the effectiveness of the distortion was measured in the participants ability to analyse and utilise the data. Since this application was developed for zone managers at businesses, we wanted to test the solution on participants with this kind of experience. The zone managers were contacted by e-mail and asked if they would want to participate in an experiment evaluating an application to be used by zone managers during emergencies, and that it was due to their role as such that they had been asked. A total of 26 people was contacted and the evaluation were performed with six respondents.

4 Results

We will in the following subsections elaborate on the test results from the different user test perspectives of the prototype application.

Order of Information Retrieval

When reporting the status of the floors, a majority of the participants started by reporting the floors with the highest values on the heat sensors. They would start at that floor and comment on how the development was around the supposed source of the emergency. Two of the participants chose to either start at the top of the list and work their way down, or to start at the first floor and work their way out from there. However, after getting to know the application and the data in it, all of the participants were able to quickly find the data they thought was relevant when presented with the second scenario.

Getting Familiar with the Application

A particularly clear example of this is with one participant who at first seemed very unsure as to what the different pieces of information meant. They required some explanation into both what the number of smoke- and fire sensors meant, as well as how the application was able to track the location of the individuals. Following an explanation, the users were able to proficiently use the application. The participant was first showed scenario two, and chose to analyse the situation from the top down. Since the main emergency were in the lowest levels in this scenario, this meant that the user had to go through all the floors to get an overview of what was happening.

However, when the user got more familiar with the application and was presented with a second scenario, they started by looking at the total amount of people shown in the menu, before looking at the list to locate those people. They then assessed how many were left in the top floor on which there still were people, and from there worked down to get an overview of the status of the fire with the heat- and smoke sensors. This show that the user was able to mentally organise the data and later know where to go to find the data that was determined to be most crucial: location of people.

Priority of Information

Several of the participants expressed being torn between smoke and heat and the location of people. One participant explained *"Now the question is whether it's the people or where the fire is , what to prioritize? One would maybe think that for the fire department it would be most important to report where the largest amount of red was [...]. We find it a little difficult to choose what is most important, they are each important in their own right. By for my own sake, it's how many are left inside and that you try to, without causing stress, get those people away from the flames. At least those in my floor. Because, of course, the smoke is dangerous, but you can get through smoke. So, I think it's the red one that is most important, to get people away from it."* Another remarked *"[...] if you are in contact with the fire department, then its first and foremost where smoke and heat has been registered, but as a human, then it's the data about people."*. Others were more secure in their choice, either remarking that the having data about the fire and smoke was most important as to get people away from it, or that the location of people definitely was most important. Several noted that the combination of being able to see both smoke/heat and people ensured that they knew where to prioritise their efforts. It was noted by a couple of people that the smoke was the element that was most harmful for the people, and that it would be good to be able to use the application to prevent smoke inhalation.

The Value of Information in the Menu

One participant, when asked about what they thought was the most valuable, answered the menu and in particular the section *My Tasks* as this was information that could be easy to forget. Although none of the participants explored the menu without being prompted, one remarked that they had been immediately drawn to press the button when first seeing the application. There was a definite difference between how the participants reacted to tasks and building info, several noted that they liked the tasks because that it solidified the fact that this was an application custom made for their role.

However, none of the participants said they thought they would report the building data on their own initiative to the fire department, nor did anyone comment on this information as they were giving information about the incident. Instead, this was noted as something that the participant assumed the fire department knew about, and that, if they would need to know that information, they would know to ask. One participant noted *"This is information that you should get to know beforehand, that you won't start to learn this information. That's not the time to wonder about where the key-box is. It is very useful information, but that should be taught during training."* Despite this, another participant noted that they were unsure about what the information meant, another than this is something that would be familiar for those involved in the administration of the building but may not be as well known by others. Finally, one participant mentioned that they wished the list had been numbered as with my tasks, as that would make it easier to mentally organise and remember the information.

The Map and Visual Preferences

All of the participants noted the value of being able to easily locate dangerous areas and people on the map, and one participant explained *"If someone has used this app a couple of times, or, actually, now, if I was to use this tomorrow, I would probably not read that much, I would just open that map, then you would know what the different things meant. So really, the map [is most important], maybe, because it is kind of a summary of everything, so that you see it very clearly."*.

Several participants noted that they found it difficult to orient themselves on the map and to figure out what direction the map was in. Several noted that the map should contain some sort of compass or indication of north/south, however, those same participants noted that they didn't really know what direction the building was facing. As one participant explained: *"For us who work here, it would be more natural to show the river and the road than north or south, because if I was really stressed out, I would just have though 'but what is south?!'. [...]"*. Another mentioned that most of the floors are divided into the river and road side, and that one zone manager had been assigned to each. Therefore, they said, having that would especially help for those not familiar with the own floor, to ensure that they know that they are emptying the correct section. Another suggestion for showing the orientation was to add the location of the emergency exits, which are all on one side of the building. Several participants noted that this would help them assess the situation and more easily view whether or not people are evacuating on their own.

When asked whether or not the participants had a preference to one type of list or the other, all but one participant answered that they preferred the distorted list. Most of the participants who did prefer the distorted list explained that this was because it allowed them to still view all the information about the other floors without having to scroll through the list to see all the information. Several participants complained that with the regular list, when they expanded one of the list items, 2-3 floors would go out of view and create difficulties in interpreting information.

5 Discussion

The experiment lead to many interesting findings, and in this section, we discuss the findings, their impact and applicability.

Information Retrieval and Application Design

The participants in the experiment would both be able to, and would want to, use such an application during an actual emergency. This was highlighted by the fact that several remarked after the experiment had ended that they wished for such a system to be implemented and even inquired into when it would be implemented. However, this was highly dependent on the data being reliable and accurate, and the participants would need to be introduced to the application beforehand to be able to effectively use it. In their experiment, Poy and Duffy [10] found that, while their application would not distract the zone managers from doing their duties, it probably would not increase the speed and efficiency of their existing routines. Our findings however indicate that the participants saw several ways in which they thought the application could help them be more efficient and thorough. Poy and Duffy [10] conclude their findings by explaining that their test participants found the application too difficult to interact with, and that it contained several distracting or confusing elements. Our findings however indicate that the design of the application is clear and concise, and that several participants found that they did not really need to think or focus too hard to use the application. Based on this, it seems that Material Design is a design specification which can be used to make a highly usable and easy to understand application, and that it may be more suitable than the approach taken by Poy and Duffy [10].

Having the application to be web based poses several challenges surrounding security, first and foremost the security of data. This was highlighted by the police officer as a major challenge, and something that could potentially be very important if the situation involves a perpetrator. One solution may be to generate an unique URL for each incident and then distributing that to the zone managers, but that does not guarantee that he perpetrator is not able to get hold of that communication. Another solution is to either have one global access code or password, or unique ones for each zone manager. However, both the police interview and the results from the experiment indicated that actions like entering a password or having to log in somewhere should be avoided due to the time and mental capacity it takes in an already stressful situation. A final alternative is to have the application only accept requests from computers logged onto the employee network. However, this does not protect against the possibility of the perpetrator being an employee at the school, and is not necessarily as easily implemented somewhere without this kind of network structure. When interviewing their participants, Poy and Duffy [10] found that security was a major concern, but that they had many differing opinions on how to do so. Some of the suggestions included using a password or locking the device in a cabinet. However, both of these approaches would require more work and a higher cognitive load for the zone manager. We can therefore see that the securing of such an application may be the biggest challenge that needs to be solved before an application like this could be used in the real world.

In addition to show that this could be a feasible solution to implement, it indicates that it contains what the zone managers consider to be the most necessary information for their job. In particular, data about smoke, heat and people was highlighted as especially important. Such data allowed the zone managers to both do their job efficiently, while keeping themselves safe. As these are the three main data points of the application, it is not surprising that the participants would consider them the most valuable. However, the participants reflections around how this data would benefit them speaks to its relevance and suitability for this kind of application. We can therefore assume that this data would be a good base to start with when developing applications for aiding fire emergencies. In their findings, Poy and Duffy [10] find that their participants saw the information presented as appropriate and relevant, but that the choice of colour and markers for people in the map should be rethought. In comparison, the participants in our experiment expressed that, once they understood what the colours represented, they thought it was well designed and very useful. However, because of the limitations of the kind of situations which has been tested, we are not able to draw any conclusions on how suitable this kind of application would be for any other kind of emergency.

List Distortion

Our results show that most participants preferred the distorted list because they were able to see all the floors at the same time, and that they felt like this focused their attention on the floor they had selected. From this consensus, we can see that the distorted list is preferred by the participants both because of its efficiency in displaying crucial data, and due to its interactive and flexible nature. However, the fact that the participants were able to see all of the floors at once is contributing to the fact that the building in total consisted of only eight floors. There is some flexibility in fitting more floors in, by making the expanded element take less space, and further minimizing the other elements. However, by doing this, it may limit the amount of interaction that the user is able to have with the map if it gets too small, and it may not be as easy to read the graphs for each floor. Because of the ease of which the user can open and close the different floors, it can be argued that it might be sufficient to show a red or grey dot respectively when minimized. This would be instead of the graph and amount, to simply indicate whether any sensors have been activated or not, and then further to be explored by navigating to that floor or showing the entire list. However, this would need to be further tested to see if it is as efficient in giving the user an overview. In addition, the number of floors that can be displayed on the screen at once, and so it might be advantageous to do more research into how many floors the user needs to see at once to still feel like they have a good overview.

6 Conclusion

We have in this paper investigated visualization of sensor data and aiding zone managers with technology in fire emergency situations. We have answered this by developing a smart phone application prototype that displays information about a fire emergency breakout for zone managers. Our research show that indoor location based systems can be used an aid during fire emergencies, and we have used this data as a starting point for the application. Data from heat- and smoke sensors were also included. We have based the designs both on existing research and existing industry design standards such as material design. Our focus has been on finding a good way to visualise data about multiple floors of a building, and we propose distortion as a successful way doing this efficiently.

Our findings indicate that the application would indeed be suitable for its intended purpose, and that it does display the information in an efficient way. Several of the participants expressed that this was something that they both wanted to use, and thought would aid them in their efforts as zone managers. The main reasons for this was the ability to evaluate the most critical parts of the floor to evacuate, and the option of avoid possible dangers and not disturbing the flow of people already evacuating.

Our results indicate that using distortion is an efficient way of displaying the data, and that it was preferable over a traditional list design. Participants explained that this was because it allowed them to see all the floors at the same time, never losing their overview and in addition, it was mentioned as a feature that eliminated a stress factor - the need for scrolling. Further testing should be done in a large-scale user base to validate and be able to generalize on the results to other scenarios. Other aspects such as sorting of data, cognitive information load and results confirmation through eye tracking and / or galvanic skin response, are all worthy further pursuit.

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