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Article

A Concept for Support of Firefighter Frontline Communication

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Abstract: In an indoor firefighter mission, coordination and communication support are of the utmost importance. We present our experience from over five years of research with current firefighter support technology. In contrast to some large scale emergency response research, our work is focused on the frontline interaction between teams of firefighters and the incident commander on a single site. In this paper we investigate the flaws in firefighter communication systems. Frequent technical failures and the high cognitive costs incurred by communicating impede coordination. We then extract a list of requirements for an assistant emergency management technology from expert interviews. Thirdly, we provide a system concept and explore challenges for building a novel firefighter support system based on our previous work. The system has three key features: robust ad-hoc network, telemetry and text messaging, as well as implicit interaction. The result would provide a complementary mode of communication in addition to the current trunked radio.

Keywords: firefighter; communication flaws; communication assistance

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1. Introduction

Despite technical improvements, the work of firefighters still remains dangerous. Research into firefighter support systems is intensely motivated as it has the potential to save lives.

In a reconnaissance mission, a firefighting team must enter the site of the incident, and conduct a systematic inspection under extremely rough physical conditions. Because of the fumes and heat, firefighters have to wear equipment that severely limits their range of motion. Work in such conditions is very complex, during which training and intuition play an important role [1]. Getting lost in a mission inside an unknown building is a common cause of accidents in firefighting [2]. Currently, very limited pervasive technology, if any, comes into play for preventing this kind of accident. Thus, our research into the field began by developing a wireless sensor network (WSN) infrastructure to support way-finding for firefighters performing missions in indoor fires [3].

Our investigation followed a human-centered approach based on leveraging ambient intelligence technologies to develop new practices of navigation [4]. The approach involved a professional fire brigade, a firefighting institute and training center, a leading company for firefighting equipment, two companies focused on the creation of mobile and wearable solutions and three academic research institutes. The goal of this structure was to create an environment to test ideas and establish a dialog around the potential of technology to support navigation [5,6]. As an important result, we showed the feasibility of a deployable ad-hoc wireless sensor system compatible with the complexities of firefighting work [7].

However, this system primarily provides assistance in unexpected emergency situations but falls short in assisting firefighters in typical routine missions. Here we analyze the experience from that work and extract requirements for a system that would assist firefighters in the course of every-day activities as well. Communication technology presents an important aspect of firefighting front-line work and currently has a range of shortcomings. Most importantly these are the high propabality of radio failure and the disruptive nature of communication queries on a firefighters' concentration. Both may lead to reduced efficiency, delayed communication reactions or worse. We present a system sketch that complements the current communication technology by combining ad-hoc networking, implicit interaction and a reduced explicit messaging interface. The system could reduce communication induced stress in the firefighters on-site while at the same time improving the incident commanders' knowledge of the scene.

In this paper, we analyze an approach for automating a large portion of the firefighters' standard communication, making feedback implicit instead of explicit responses. We first present a brief description of current firefighting practice in Germany. We then present and analyze these interviews, which constitute a major contribution of this work, and derive a range of high level requirements for a possible support system. Finally we present and discuss a conceptual sketch of a novel firefighter system based on pervasive computing technology.

2. Firefighting Practice in Germany

The basic tactics of firefighting in Germany are defined by the German firefighting guidelines [8]. In structural fires, indoor reconnaissance missions are fundamental to help reliably assess the incident, find and rescue victims, and control the fire. Because of the fumes and heat, the regulations in Germany prescribe that firefighters engaging in reconnaissance or firefighting should wear a self-contained breathing apparatus (SCBA) and protective clothing. The SCBA provides a limited amount of breathing time and its use is very exhausting. When entering an Immediately Dangerous to Health and Life zone (IDHL), firefighters follow a 2-in, 2-out policy, which mandates that:

- No firefighter enters an IDHL alone.
- For each team entering an IDHL, another team waits outside for support in an emergency.

A fire engine, the smallest firefighting entity to arrive at a scene, transports a crew of firefighters. An engine crew is typically composed of up to nine firemen. Members of a crew include the incident commander (IC) who is responsible for, and in command of, the members of the engine, a dispatcher who performs the radio communication with central command, and an engineer in charge of driving and controlling the equipment. The crew may further consist of two or three teams consisting of two or three firemen each. Upon arrival on site, the IC analyses the situation following a well-defined set of standard steps, collecting as much information as possible from observing the incident and talking to witnesses. Once the IC decides that he has collected enough information to assess the situation, he positions the engine and defines tasks for the teams (*cf.* Figure 1). Following the 2-in, 2-out policy, once one attacking team enters the building, another team assumes the role of the standby search and rescue team or rapid intervention team (RIT). The RIT waits outside, ready to help the attacking team in case of an accident.

Every member of the attacking team has a specific role that defines his function in the team. One individual is the team leader who is also in charge of communication. The IC remains outside of the building at a safe distance, supervising and coordinating the work of the teams. He is responsible for the safety of the attacking team and receives reports from this team over radio. Regulations in Germany require firefighters to work no longer than 20 minutes before taking a break to recover for at least 30 minutes. As a rule of thumb, it is assumed that a firefighter needs double as much air to retreat back than he needs to reach a point. These rules help the IC to define a time threshold after which he pulls the team out of the IDHL.

Figure 1. Before the start of a trial mission, the IC instructs the attacking team with exact details on how to approach the scene.

3. Communication Problems and Issues

In this section we identify problems and the associated issues that frequently occur when working using the SCBA in an indoor reconnaissance mission. These problems and related issues were uncovered during our previous research [3]. In this research effort, fieldwork studies in close cooperation with two user groups were conducted: the Professional Fire Brigade of Cologne (BFK) and the Firefighting Institute of the State of North Rhine-Westphalia (IdF). The BFK is the fourth biggest professional fire brigade in Germany, with more than 800 members. The IdF is responsible for the formation and training of the commanding staff of the non-police state forces. The IdF provided insights into the education process and tactics of firefighters and provided training facilities for conducting the fieldwork.

In total, we conducted more than 15 different workshops that involved several hundreds of hours of cooperative work with firefighters. The work in the field was documented extensively by using video, photography and field notes. All workshops and discussions were audio recorded. In addition, we conducted semi-structured interviews throughout the project to gather impressions from the participants. We asked the firefighters about their overall experience, their actions and decisions. Breakdown situations were discussed in detail with the instructors, incident commanders and the firefighters. To analyze the data captured in the fieldwork, we followed an ethno-methodological approach as outlined in the work of Andy Crabtree [9]. The recordings were afterwards collaboratively transcribed, analyzed and discussed in a multidisciplinary team consisting of an applied linguist, an information systems expert and the system designers in the project. During these workshops, various problems of the front-line communication use in indoor reconnaissance missions became apparent. In the following we describe these problems and the associated issues.

3.1. Robustness of Communication

A firefighting mission always comprises various teams of firefighters engaging in a certain area. Each team plays an important part of the overall intervention even though they do not necessarily have access to all available information. Communication becomes important to exchange information between teams. The communication channel is an element that firefighters take for granted but can also fail. In the following discussion, an experienced firefighter and IC describes problems with current communication technology in daily routine.

> **IC:** "This is something that we openly admit. Wireless communication problems happen to firefighters, and they happen a lot. It does not matter who you ask, professional firefighters, volunteer firefighters, if the crew is well organized or badly organized, the communication equipment dies and leaves us high and dry, or partially gives out. Sometimes it breaks down, or there is interference, or the battery dies, someone keeps on squawking with the talk button, there are countless things which can go wrong."

Communication failures can greatly impact the sequence of events in an intervention. In the following discussion an experienced team leader (FF), an incident commander (IC) and a firefighter instructor (FFI) describe the impact. The discussion is guided by a researcher (R).

FF: "One thing that has to be improved is the communication, or what you said, that happens a lot (sic), a lot of the time the success of the mission can't be guaranteed, because the communication system stops working. (The success of the mission) lives and dies with the communication."
IC: "You can have a totally basic room fire, if the communication system dies everything outside goes crazy. If (the incident commander) can't talk to (the fireman) anymore, he'll send in a rapid intervention team. As soon as he sends in a rapid intervention team, he has to get a second one to have ready. So now he has to restructure everything outside so that he has a second rapid intervention team ready."
FFI: "(Radio failure) starts a huge chain of events. If I am the incident commander standing outside and I have an attacking team inside that's actually using the pressurized breathing apparatus in a fire, and I send in a rapid intervention team, then I make the call to tell the control center, and the control center sends out whatever was already on location. For example, if there are two fire trucks already there, then two more fire trucks are dispatched from some other fire station. A giant juggernaut is put in gear, which might not even be necessary. In Cologne even more [than what is already at the scene] is dispatched."
IC: "If I escalate the situation from a status 1 fire to a status 2 fire [which have different requirements in terms of personnel and vehicle resources which should be on location] then the commissioner has to be told."
R: "Just because communication breaks down?!"
IC: "Yes! Just because one walkie-talkie from one team gives out, which is completely not in a dangerous situation, but doesn't have a radio connection. Now, 6 or 7 fire trucks go racing through the city with their lights and sirens on, and a trip like that is dangerous. Accidents can always happen. When the trucks are moving through the city with their emergency lights on, you can't just stop them. Once the juggernauts get rolling, they keep on rolling."

3.2. Monitoring and Overload

An important role for radio communication is to support coordination mechanisms. The IC and the engineer keep a table with the readings of the remaining air supply for the team, and contact the attacking team at fixed intervals to update the information. The team also contacts the commander to inform him of relevant events, such as entering a room or changing the movement direction. In the following excerpt, an IC and a fire chief (FC), who may also take the role of the IC, report from this practice. The interview is directed by another researcher (R).

IC: "(...) we are the leadership here; our job is to observe from outside, so to say, what the teams are doing inside, and I can't tell what's going on in there because I've lost my sight (radio contact). The only thing I can see is if they are still pulling the hose after themselves, so if the hose is still moving."
R: "Just so that we understand each other: what is the incident commander taught to use as indicators and tools in order to get a picture of what is going on? He can use radio communication and he can use sketches, right?"

> **FC:** “The normal case is really voice communication. He can use his writing pad, but he can only use that to put down what he sees from a building: how many apartments there are per floor, how a house is divided up inside, right apartment, left apartment, front to back. Then he gets the information, ‘we’re going into the apartment on the right.’ And then he doesn’t hear anything for a while. Every once in a while he’ll hear breathing. When he hears ‘we’ve got something’ or something like that, those are things that are communicated, ‘person found,’ that would be a typical point of communication, ‘I found something.’ At that point they give an immediate response ‘I have something, I’m bringing someone out.’ And then he responds ‘yeah, get him out.’ That would be the normal command from the incident commander and I would get everything ready down below, emergency services, getting people in position in the stairwell to be able to start resuscitation as soon as possible.”

The use of radio was often perceived as a disturbance by the members of the searching teams. The flow of information during a reconnaissance was kept small consequently, and was reduced to brief coordination information or requests of reports from the IC on the outside of the building. At some points, for instance in situations such as the one depicted in Figure 2, even this communication can be forgotten or obviated by a searching team, creating diverging perceptions of the situation on both sides:

> **FC:** “There is always what is supposed to happen and what actually happens. Normally, every change in the situation should be communicated, every significant piece of information should be told to the incident commander. Except no fire department actually does that, and the Cologne fire department doesn’t do that either, because it’s just annoying and stressful. He’s got a job to do, he has things to do in front of him. It’s a job on top of his other tasks, he has to push the button, control his breathing to speak, it limits his actions. And his goal is generally like, well, when it’s just a subterranean burn then it doesn’t matter, but when he’s saving somebody, he just doesn’t have the time to talk about what he’s doing. They go in there and look for people who are fighting for their lives right now.”

Figure 2. The various water hoses shown in this image caused confusion in the team during a trial mission with occluded breathing masks. The firefighters did not respond to requests of the IC while trying to find out which of the hoses was the right one to follow.

4. Analysis and Requirements

In today's frontline firefighting practices, voice communication is the most important, and on many occasions the *only* tool for coordination. Voice communication is essential, independent of a mission's nature (*i.e.*, routine or firefighter emergency). For ICs and other personnel outside the IDHL, this type of communication is currently the only possibility to acquire knowledge about the ongoing events and mission process. Other methods such as watching movements of the fire hose only offer limited information.

However, voice communication over radio is far from perfect and suffers from numerous problems. Communication frequently breaks down due to interferences, operating error while working with the SCBA (e.g., pressing the speak button on the radio by mistake) or insufficient maintenance (e.g., dead radio battery). Additionally, using the radio incurs immense cognitive and physical load. Speaking while wearing the SCBA means that the current work has to be paused, the radio has to be grasped, the speak button has to be located and pressed and respiration has to be adapted to talk clearly enough that the receiver can understand. Firefighters rely on that communication. Even though it is known that it may break down, there is no replacement or complementary technology available to provide support in these cases.

A conflict becomes apparent from the discussion: the incident commander requires as much verbal information as possible to complete his task, but the firefighters who provide that information are hindered by the act of provision. This can even come to the point where queries by the incident commander are not answered because the current task is too demanding. The lack of response may be interpreted as an emergency by a commander waiting outside, which can in turn trigger a very complex process that involves new resources and efforts. This in turn causes the superfluous deployment of personnel and vehicles, escalating the situation unnecessarily, incurring significant costs and risk to firefighters and civilians.

The weight of this cascade of events implies that the incident commander needs to be certain that the decision is correct. The incident commanders have experience with communication breakdowns and are aware that queried firemen may be too busy to respond, this decision can be delayed based on the experience of the commander.

The discussed issues show the complexity of firefighting work. They represent an insight into the complex collection of interrelated strategies that firefighters use to deal with their tasks. However, firefighters themselves recognize that the current tools limit their monitoring and therewith also their commanding possibilities. Based on these issues, in the following subsections requirements for the implementation of a pervasive assistance system are discussed.

4.1. Provide Alternative, Reliable Means of Communication

The excerpts in the previous section clearly show that the classical trunked radio communication can be severely impaired for various reasons. Problems regarding the range, *i.e.*, due to interference or/and strong attenuation, could be approached using lower carrier frequencies and higher transmit power or by employing repeaters instead of point-to-point connections. Of these options the latter is probably the most feasible. Higher transmit power typically means larger batteries and lower frequencies typically mean larger antennae. Also, with a repeater-based approach, the topology of the radio link can be adapted to the requirements on site. In fact, the repeater approach is supported to some extent (only one additional hop) by the digital radio communication standard TETRA-25. The downside, however, is that the throughput and latency of data are affected by the number of hops. Thus, a multi-hop approach needs to carefully consider the type of service *i.e.*, speech or data that can be provided over the link.

4.2. Reducing Communication Load and Latency

The presented interviews reveal a conflict between the demands of the firefighters (less communication) and of the incident commanders (as much information as possible). With the currently employed technologies it seems hard to solve this problem. However, monitoring the team's activities and actions could be an approach to avoid this dilemma. In fact, using an approach that acquires information about the actions of the teams inside a building that is then transferred over a robust communication link would deliver the required information to the commander. Within the research communities, various approaches exist to facilitate the monitoring of activities. However, from the requirements of the work environment of the firefighters, these are reduced to a small number of options. Video based systems are not possible due to the limited vision. Thermal camera based systems would suffice but their current physical dimension, weight and price still restricts the integration into firefighter equipment or communication repeaters. Attaching acceleration sensors to firefighter's bodies or clothing could be an approach but must be considered carefully due to the required certification tests.

4.3. General System Requirements

Aside from the novel requirements gathered and presented here, the system also needs to fulfill general requirements of typical firefighter equipment, such as usability with gloves, being easy to maintain and sustaining certain heat and pressure conditions. Especially for the latter the firefighter instructors of the IdF made it clear to us that all modifications to existing equipment will require re-certification. The tests that a firefighter device must pass require a sophisticated setup and depend on the specific part of equipment (Standards for the evaluation of firefighting equipment: DIN EN 136:1998 (Masks), DIN EN 137:2006 (SCBA), DIN EN 420:2003 (Gloves), DIN EN 469:2005 (Clothes)). The system design should also respect the degree of freedom necessary for a firefighter to operate. Another general requirement is that a system cannot rely on existing infrastructure as the current state of technology does not provide economical solutions that could be pre-installed everywhere. The conclusion is that firefighters must bring the tool with them.

5. Related Work

Emergency situations pose a grave danger to human life and well-being. For this reason, developing technology to support responders in these situations has a high priority. In particular, distributed sensor actuator systems with wireless communication technologies have been researched in various modalities for support of first responders [10]. The cumulative result of this research is the discovery that there is a correlation between the ability of emergency responders to achieve their goal and the level of aid provided by the technical systems supporting them.

One approach to evaluating supporting technology is to simulate the emergency situations, the environment, and the response team, and evaluate how certain types of technology would affect the outcome [11]. Here the difficulty is efficiently simulating all parameters, including the interactive human aspects, in such a way as to realistically depict the effect of a novel technological advantage. For example, such simulations have been used to demonstrate the effectiveness of novel communication technologies [12]. In this work opportunistic communication using low-cost 802.15.4 mobile nodes is explored to evacuate individuals safely outside a hazardous zone. The result is that novel robust communication technologies can improve outcomes for emergency situations such as building evacuations, due to the fact that communication is critical for avoiding catastrophic outcomes [12].

While the research previously reviewed is generally applicable for emergency situations and responses, different requirements and goals apply specifically when it comes to the problem of firefighters and related technology. Thus, in the following we restrict our review to publications investigating communication and interaction in frontline firefighting or systems touching especially on the issues described in the previous sections.

Denef *et al*. [13] present an analysis of firefighter work practices isolating three major activity patterns: rigid structures, independent units and monitoring. The authors report from behaviors that match well with our observations, identifying communications as stressful though essential aspect of the work. Yang [14] identifies the accurate and timely monitoring of and feedback to attacking troop as one of the major goals of a firefighter support system [14]. Prasanna *et al*. [15] conducted an HCI-based investigation with firefighter ICs and found that the automation of routine tasks could yield the biggest improvement of firefighter work. As the frequent sending of status information of a firemen to an IC can be seen as such a routine task, this can be seen as in conformity to our analysis.

A well-established tool to support relocation of lost firefighters is the Personal Alert Safety System (PASS) [16]. The PASS monitors the movement of the firefighter and creates a high volume sound signal if no motion is detected after some time (typically in the order of 30 s). Further commercially available systems that focus on (re)localization are the ultrasound-based SummitSafety Pathfinder system [17] and the radio-based Draeger FRS1000 system [18]. Both systems provide a handheld directional tracking device with which a missing firefighter or a beacon can be located.

Other researchers have investigated effects of the IDHL on wireless networks. Hofmann *et al*. studied the performance of various IEEE 802.x wireless technologies under the impact of fire, smoke and vapour [19]. A similar study was conducted by Schubert *et al*. [20], which additionally investigated the influence of firefighter equipment on radio signals. Opposed to Hofmann *et al*., they reported no influence on radio reception due to vapour.

Liu *et al*. [21] investigated the creation of a robust ad-hoc network when the nodes are automatically deployed. They present an algorithm to deploy nodes based on signal strength measurements to ensure a 90% connectivity even if nodes of the consecutive network fail. However, as the system was not evaluated in a mission environment, its performance under these conditions can only be estimated. Rednic *et al*. [22] developed a body area network of 11 accelerometers on various locations for the monitoring of bomb disposal postures. They point out that this information could be used to improve the understanding of the current operational status and physical and psychological state of a subject.

Holistic firefighter support systems provide support to a large number of members of a firefighter crew possibly including the remote control center. A classic holistic system is Siren [23], which supports communication using PDAs and a pre-deployed WiFi infrastructure. The system introduced the idea of sending messages between peers, e.g., “help” or “abandon” messages, a feature that was considered especially helpful by firefighters. The authors further outlined that an application designed for this domain should be designed to support implicit and opportunistic interactions. The vision of an ad-hoc deployed sensor system is also identified by firefighters as a potent approach [23].

Another holistic system FIRE [24] is based on a pre-deployed WSN and a corresponding IC interface. Similar to Siren, this fixed network serves as a communication backbone between teams and the incident commander. Besides communication, the nodes can commit localization, environmental monitoring and emergency communication. The authors conclude that while Ubicomp technology is well received by the firefighters, a gradual introduction of a system is required to allow integration into training and usage practices. Of the above discussed firefighter support systems, to the best of our knowledge, none has been successfully introduced into the practical firefighting work. A system realizing some of the ideas of the community is the Auer Personal Network [25], which features an IC software showing the barometric pressure and the state of the Personal Alert Safety System [16]. As an extension it also includes a head mounted display to inform the SCBA wearer of his own air pressure. While providing useful functionality, discussions with the firefighters revealed that the system is not reliable enough to meet their requirements in terms of connectivity and communication assistance. It also requires a significant amount of maintenance.

6. Concept and First System Sketch

In this section, we present a first system concept based on our previous experience and early outputs from firefighters in a new research effort. Figure 3 shows a sketch of this early system concept. During the course of this paper, it was clearly stated that infrastructure cannot be relied upon in firefighting mission. Thus, we re-use the Landmarke self-deployed ad-hoc infrastructure, which integrates well into firefighting practices [7] to become the reliable basis for novel services that can circumvent the communication problems previously described.

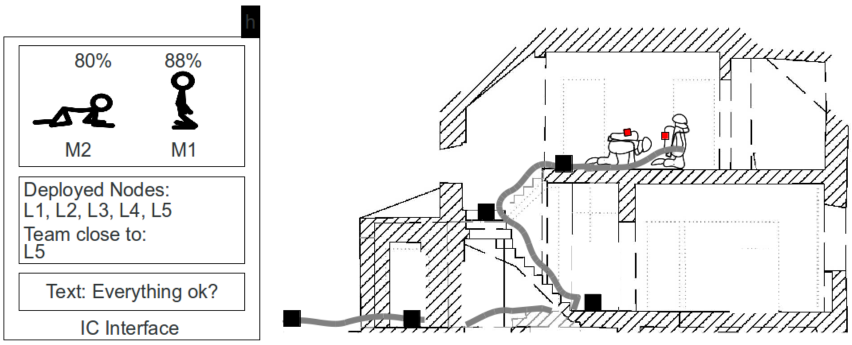
Due to the multi-hop nature of the system, the throughput is limited. In Landmarke trials, hop depths of up to ten were encountered. Thus speech or video will hardly be transferred. Hence, the system is designed as a complementary communication channel that may be used in the case of breakdowns or uncertainties. While the previously developed and investigated system [7] featured a device using which the firefighters could interact with the nodes and other firefighters, the IC was not in the focus of the work. However, in firefighter frontline communication, firemen and the IC are equally important. Our system concept is based on three types of devices: the IC device, the firefighter device and the communication nodes. Using this system, three basic services shall be realized:

Basic telemetry: Using this service, the IC receives continuous information from the deployed nodes (e.g., deployment event, temperature, status) and firefighters (temperature, air pressure), giving him an overview of the team's progress (nodes deployed) and the state of the scene.

Bi-directional text communication: an on-site radio messaging system. Firefighters can answer and request to IC predefined text messages. This gives the ability to communicate without the trunked radio overhead, a more robust communication link and predefind messages that leave no space for ambiguities.

Implicit interaction: Aimed to address the problem of uncertainties and radio-induced distraction by exploring implicit interaction methods for firefighters. Especially tactical relevant firefighter activities and anomalies should be recognized to inform the IC continuously of the mission progress and the state of his teams.

Figure 3. *Right*: Firefighters with a water hose (gray) deploy WSN nodes (large boxes) during reconnaissance. Sensor units (small boxes) are attached to the SCBAs to recognize their activities and provide a simple message interface. *Left*: Activities, probability values, node and firefighter sensor information and messages are relayed to the IC tablet using the ad-hoc network.



In order to spawn a discussion with the experts, especially for the activity recognition, we introduced the concept of implicit activity monitoring/recognition using [26] and described the limits of the system. Firefighters showed a strong interest in the technologies and emphasized that the possibility to continuously monitor the attacking teams' activities would be extremely advantageous. Further interviews based on a thorough mission activity analyses showed that already a relatively restricted set of activities and the detection of accidents could help ICs monitor their teams' status without radio communication.

Based on the nature of services, the device requirements become clear: team members need a system that holds the network nodes to be deployed, provides a UI to use the text communication and runs the sampling and recognition algorithms; ICs will need a device that can query the firemen using simple text messages and visualize the incoming data, possibly with their recognition accuracy in case of the activity information.

7. Discussion

In contrast to the Landmarke system where network nodes could be freely deployed by the firefighters, the novel system must ensure that nodes maintain connectivity. However, the requirements as well as HCI studies [15] clearly state that a dedicated deployment-related activity is out of the question. This indicates that any novel technology should be integrated into processes and equipment that are already implemented and in place. Since additionally every modified piece of equipment must be re-certified and space for sensor locations is very limited, all research will focus on a single device. From our experience, when working with the firefighters, this device could be attached to the SCBA cylinder or the SCBA backplate (see Figure 4). Another option would be to replace the PASS device. As most firefighters nowadays must carry a PASS and the activity/annomaly recognition also provides PASS functionality, this existing and relied on tool would not be lost. At the same time adding another device to the equipment would be avoided. The PASS is typically attached to a chest strap of the SCBA, thus the text interface could be integrated there as well.

Figure 4. Captured from recordings of firefighter activities during a search and rescue mission. Sensor nodes are placed on the Landmarke transport unit on the air cylinder of the SCBA (encircled in red).

Nevertheless, this single point of attachment also presents a challenge for the recognition of activities and movement abnormalities indicating an emergency. Distinguishing multiple activities from one sensing modality and location is not straightforward. Furthermore, researching a system that accurately recognizes activities of several firefighters is difficult, since the same activity can be performed quite differently by individuals trained in different schools and brigades. Independent of possible improvements of the recognition system, the system will make mistakes. Thus, it is required to evaluate if despite these inaccuracies the system could still be helpful to the IC, a question that is also linked to the presentation of activitity information on the IC device interface.

The extracted activity information must also be integrated into the existing information management processes of the IC. To this end, we are researching new interfacing methods that are based on the tactical worksheet (German: "taktisches Arbeitsblatt des IdF"), a special paper worksheet which German incident commanders already use. Research is towards displaying the extracted activity information of the team in an automatic and intuitive way in a digital representation of the worksheet. Furthermore, localizing these activities on a map provides a great increase in utility, but the state-of-the-art is not yet deployable for critical applications [27].

8. Conclusions

In this work, we began by setting the stage for firefighter assistance systems based on wireless sensor networks. The first scientific contribution is a set of requirements from firefighter experts on such a system. These requirements were obtained during research into such a system, designed using participatory design and iterative prototype-feedback rounds involving researchers and firefighter joint exercises. The requirements were gathered in hours of interviews with individual firefighters and their team leaders, over the course of several experiments. The second contribution is a conversion of these requirements from their original domain of firefighter knowledge and experience into the more technical Ubicomp domain. These requirements served as a guideline for creating a system concept for a coordination assistant system for frontline firefighting. This system concept is discussed providing a number of challenges for research in this field and indicating its great support potential not only in emergency situations but also in routine missions. The results indicate that there is still unexplored potential in wireless communication systems, and firefighter activity recognition, with the potential to make firefighter work more effective and less stressful.

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