Low-Cost Support for Search and Rescue Operations Using Off-The-Shelf Sensor Technologies

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Effectiveness of early response is critical to the successful outcome of search-and-rescue operations with the likelihood of survival witnessing a steep decline after 72 hours. Due to the unpredictable and sudden nature of incidents official response is often slow, resulting in people lacking formal training being responsible for early response. To facilitate these people, we introduce low-cost technological solutions for assisting in search-and-rescue missions. We introduce a framework and three prototypes build around our framework and discuss the suitability of different sensing technologies for assisting search-and-rescue missions.

INTRODUCTION

Every year thousands or even millions of people are affected by disasters that cause ruptures, collapsed structures, or other types of incidents that result in people getting trapped or missing. The key to human survival during these events is the time that a person is trapped or missing, with survival rates declining steeply after 72 hours [4]. The unpredictable and sudden nature of these events combined with their large-scale impact on infrastructure often makes official response slow or even lacking. Consequently, people who lack formal training are forced to take the main responsibility of the search and rescue efforts, especially early on [12]. Two of the key challenges facing these people are identifying survivors among the rubble while at the same time avoiding dangerous situations, and maintaining awareness of locations that are important (e.g., where survivors are trapped). Technological means that facilitate these tasks could significantly improve the effectiveness of these operations while at the same time helping to ensure the safety of the people carrying out them.

In this paper, we develop low-cost technological solutions for assisting in (urban) search-and-rescue tasks. Our solutions take advantage of emerging sensing technologies available on off-the-shelf smart devices. Specifically, we combine depth (or heat) cameras with image processing technologies to support identification of obstacles and to assist in the detection of survivors. We combine vision algorithms with audio sensing to localize sounds of importance, including dangerous sounds likely to correspond to falling debris and voice detection to localize people calling for help. To facilitate situational and location awareness, we use motion sensors (accelerometers and gyroscopes) to track the motion paths of the user relative to locations of importance over time. This can be used, for example, to lead additional rescue personnel to locations of trapped survivors and to maximize coverage of search operations by ensuring people do not visit same locations over and over again. Finally, short-range local connectivity technologies can be used to share information between other users, facilitating collaborative search effort and enabling means of ad-hoc team communication.

TECHNOLOGICAL SUPPORT FOR SEARCH-AND-RESCUE MISSIONS

The focus of our work is on supporting key tasks in search-and-rescue missions carried out in urban environments. We first detail the tasks that can be supported through low-cost off-the-shelf technologies, after which we briefly introduce three prototypes that assist in these tasks. We also discuss the sensing modalities and form-factor of devices that can be used to develop support for these tasks.

Finding Survivors

Locating people that are trapped or otherwise in need of help is critical task for search-and-rescue operations. Low-cost sensing technologies can significantly assist in this task, particularly in environments with low visibility. A potential solution is to rely on depth (or combined depth and colour) sensing which is increasingly being integrated into consumer grade electronics (Microsoft Kinect) and high-end smartphones. The depth image provided by such sensors can then be analysed to identify humans, e.g., using Skeletal tracking [15]. The main drawbacks of depth sensing are that the required vision algorithms require extensive processing, and that depth sensors are power hungry.

Consequently, systems relying on depth sensing can operate only for short periods and potentially require additional computing units to be carried along. An alternative to depth sensors is to use forward looking infrared cameras (FLIR). Some high-end smartphones already integrate FLIR sensors and relatively inexpensive FLIR attachments can be purchased for higher end smartphone models. In addition to visual sensing, audio sensing can be used to assist in finding survivors with a simple dual-microphone setup combined with speech detection being able to provide cues about the locations of people calling for help. Two of our prototypes rely of depth sensors, whereas our third prototype is based on a FLIR thermal camera.

Avoiding Danger

Search-and-rescue missions are often carried out in hazardous environments. Examples of hazards facing rescue personnel include poor visibility, rubble, falling debris, and presence of sharp objects. To ensure the safety of the rescue personnel, potential threats can be automatically identified and a warning can be triggered whenever they are detected. Sharp and otherwise dangerous objects can be detected from the output of the visual sensor by applying common image processing techniques (edge and corner detection), whereas other environmental hazards, such as falling rubble, can be identified using audio sensing. A simple mechanism is to monitor the level of audio activity [9], e.g., using energy of selected audio frequencies, and to trigger warnings whenever activity with high intensity is observed. By using microphone arrays, such as those found in a Kinect, or a dual microphone setup, the (coarse) direction of audio can also be estimated. For providing warnings, a combination of tactile and visual feedback is the preferred option as they maximize the likelihood of the feedback being noticed.

Maintaining Location-Awareness

Rescuing survivors that are found often requires additional help, e.g., for moving rubble or providing immediate medical care. Often such help cannot be provided by the first response team, but additional personnel need to be directed to the location of the survivor. To ensure the survivors can be effectively located later on, the rescue personnel need to be aware of the path that they have traversed as well as the location of the survivor relative to the rescue team. Off-the-shelf smartphones, as well as wearable trackers, including smartwatches and fitness trackers, contain motion sensors which can be used for pedestrian dead reckoning which allows identifying the path that the person has taken [2]. Alternatively, the combination of depth and motion sensors can be used to construct floor plans on-the-fly, enabling more fine-grained localization.

Team Communication

When multiple persons are carrying out search-and-rescue missions, coordination between the rescue personnel is paramount to the effectiveness of the mission. In many cases, such as building collapses, earthquakes, and other related incidents, communication infrastructure can become damaged or otherwise ineffective. Off-the-shelf consumer electronics are increasingly equipped with technologies for wireless local area connectivity (such as WiFi direct, Bluetooth Low Energy, and 5G) which can be used to form ad hoc connections between rescue personnel.

PROTOTYPES

We have constructed three prototypes for supporting search-and-rescue missions. Each prototype uses the same basic framework, relying on a head-mounted display (Sony HMZ-T2) for visualizing information to the user. We chose the Sony HMZ-T2 for visual interface as it supports high definition video output, has sufficiently wide field-of-view, and has a casing that covers the user's eyes entirely, providing users with a single visual reference. As the visual interface we use a live video feed of the respective visual sensor with overlay elements that highlight detected humans and visualize current level of sound activity. In addition to the visual interface, all of our prototypes rely on two smartphones. The smartphones are placed on the user's hip to emulate a tactile belt and are used to provide tactile notifications whenever something important or potentially dangerous is detected. A visual cue is also shown on the HMD screen to indicate possibility of danger.

Our first (and earliest) prototype uses a Kinect depth camera as the visual sensor. The Kinect operates with a horizontal field-of-view of 57° and a vertical field-of-view of 43°. The depth information provided by the Kinect has been shown to be accurate to up to a few centimetres [1], which is sufficient for search-and-rescue missions. The data from the Kinect was processed on a laptop carried in a backpack. The backpack also contains a portable power source (battery pack), which is used to power the Kinect (and potentially other components). The setup can be easily made more lightweight and portable by using an USB powered RGB-D sensor (e.g., ASUS Xtion) and a CPU unit with small form factor, such as a Rasperry PI or a high-end mobile phone. The microphone array of Kinect, on the other hand, can be simply replaced by using the microphones of the mobile phones that provide the tactile guidance. Our other two prototypes are based on a similar setup, but replace the Kinect with a high-end smartphone. Specifically, our second prototype uses a Lenovo Phab2 smartphone which has an integrated depth camera and the Google Tango augmented reality framework for processing the depth sensor images. Instead of using a depth camera, our third prototype relies on a consumer grade thermal camera (Caterpillar CAT S60). While both smartphones have extensive processing power, we stream the images to a laptop for processing using WiFi direct due to better availability of image processing algorithms.

Discussion

Our prototypes have been intended as proof-of-concept implementations which have not been optimized for deployment in emergency situations. Firstly, the form factor of our prototypes should be improved as each prototype requires carrying a separate computing unit (in our case a laptop) and a battery pack that is used as an external power source. Further improvements to our prototypes can be made by improving the sensitivity of notifications by integrating tactile actuators inside a belt or another wearable fabric. The cost of each of our prototypes is around $600 and is likely to decrease in the near future as the corresponding sensor technologies increase in popularity. In particular, depth and heat cameras are currently only available on top-end smartphones, but are likely to be available on more and more devices in the near future. The required processing power and support for local connectivity, on the other hand, is readily available even on low-end smartphones. Further reductions in cost can be achieved by using dedicated components instead of off-the-shelf consumer devices.

Our techniques have been designed for urban search-and-rescue missions where rubble and debris are the main issues. Related works have targeted firefighting operations. While our solutions can benefit such scenarios also, our prototypes are not directly applicable for such scenarios due to lack of thermal insulation.

RELATED RESEARCH

Most of the previous research on urban search and rescue has focused on robot-based solutions [7]. The main advantage of these systems is that robots can enter areas that are impossible or dangerous for humans to investigate. However, deployments in actual disaster situations have shown that the autonomous perception capabilities of robots are not sufficient for identifying people from rubble and that remote human operators are needed in addition to the robots [11]. The effectiveness of remote operators, on the other hand, depends on the level of situational-awareness they can maintain, which in turn can be difficult due to the limited resolution and depth perception provided by the sensor data [8]. An alternative is to consider so-called human-robot swarms where a team of human rescuers is supported by a team of autonomous robots [13]. In swarm-based systems, the remote operators can go close to the actual investigation area, thus improving situation-awareness of the operators. The main limitation of swarm-based systems is that visualizing the information from the robot effectively is challenging as the operator also needs to keep track of his/her surroundings. Also some work on adopting ubiquitous computing technologies as part of emergency response services has been proposed. These have mainly focused on developing sensor network based systems that aim at facilitating coordination between response team members. Most of these works have targeted either firefighting or rescue scenarios in remote areas, with the main goal of providing reliable support for communications and data dissemination in presence of equipment and communication link failures [3], [5].

The main focus of our work is to explore how wearable interactive systems can be used to augment and supplement human capabilities. This has only recently become possible with advancements in wearable sensing and display technologies. Prior work on this topic has mainly been targeted at firefighters, with the aim of providing navigation support and to improve situation-awareness through visualizations incorporating digital building plans, locations of team members, and so forth. Klann and Geissler [6] introduce a system where navigation instructions are presented on micro-displays that are embedded within the mask of a firefighter. Schönauer et al. [14] use a head mounted RGB-D sensor to construct floor plans of buildings. As another example, Mann et al. [10] combine a RGB-D camera with head-mounted vibrotactile actuators to provide support for collision avoidance for visually impaired people. Our work further expands the scope of what can be accomplished using such wearable sensing.

SUMMARY

We have contributed by discussing the suitability of low-cost, off-the-shelf sensor technologies for supporting search-and-rescue missions. In particular, we identified four key tasks where off-the-shelf technologies can be of assist (identification of survivors, danger avoidance, location-awareness, and team communications), and presented three low-cost prototypes that implement support for these tasks. Our research paves the way for the development of low-cost solutions that can be adopted for supporting search-and-rescue operations, particularly early response efforts which often are the responsibility of people that lack formal training.

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