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Experiences with USAR Mobile Interfaces: the Need for Persistent Geo-Localized Information

Benoit Larochelle, Geert-Jan M. Kruijff
German Research Center for Artificial Intelligence
DFKI GmbH, Saarbrücken (Germany)

Nanja J.J.M. Smets, Jurriaan van Diggelen
Netherlands Organisation for Applied Scientific Research
TNO, Soesterberg (The Netherlands)

***Abstract*— Urban search and rescue (USAR) missions are unique and unpredictable. Communication and coordination is difficult, with high-level actors (e.g. mission commander) lacking local terrain knowledge while low-level actors (e.g. robot operators, in-field rescuers) lack global situation awareness (SA). In-field actors have high mobility and a direct view of the field, but so far they could communicate this SA almost exclusively through radio. Unfortunately, words are imprecise and unorganized, and thus not easily analyzable and retrievable.**

As part of the NIFTi[1] project, we developed mobile applications to help in-field actors share their SA with the rescue team. We also performed high-fidelity USAR simulations and missions at fire fighting training sites and disaster areas. We discovered a need for persistent geo-localized information and propose a novel system architecture that integrates pictures taken from robots and from in-field rescuers into the existing systems at the command post.

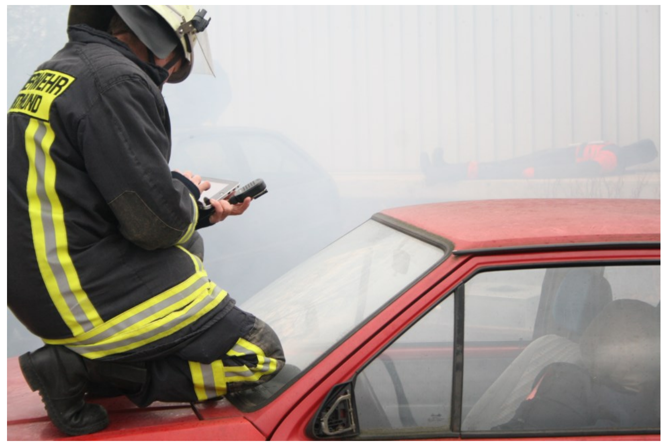

Fig. 1. An in-field rescuer in an end-user evaluation inputs victim information into a tablet integrated with a team awareness system.

I. Introduction

August 2005, hurricane Katrina hits the Gulf of Mexico flooding 80% of the city of New Orleans and bringing water close to 20 km inland along the Mississippi coast line, affecting three million people. March 2011, the east coast of Japan suffers from an earthquake followed by a tsunami, affecting 4.4 million households. The wrath partially destroyed the Fukushima Daiichi nuclear power plants, leading to a 20 km radius evacuation around the plant. May-June 2012, northern Italy is hit by 246 seismic events within a radius of 50 km affecting 900 000 people. In these three events, rescue robots were used to help search for victims or analyze the safety and risks of various areas. However, the areas affected in these events had different scales and dangers; in turn, the robots needed different capabilities. Yet, they all suffered from the same problem: the lack of integration between high-level overview information, required for mission planning, and low-level information, required for robot navigation.

The successful use of robots in Urban Search and Rescue (USAR) missions requires robots and humans to work together as a *human-robot team* [1]. Regardless of the robot's autonomy level, the team members (humans and robots) must dynamically share the tasks at hand and provide one another with the appropriate information without overloading others with irrelevant information. That is, exchanging the **R**ight **M**essage at the **R**ight **M**oment and **R**ight **M**odality $(RM)^3$ [2]. Figure 1 shows an example of such a methodology, where an in-field rescuer inputs victim information into TrexCOP, a team-awareness system described below.

Whereas rescue robots have been improved by leaps and bounds in the past few years (e.g. with respect to 3D mapping using point clouds, autonomous navigation, video capture and post-processing), the envisioned team collaboration is still insufficiently developed. As we bring robots to larger and more difficult environments, the performance of many sub-systems (e.g. mapping, vision, autonomous navigation) quickly degrades. On the other hand, the information provided by in-field rescuers is typically verbal description over walkie-talkies, which robots – and anyone on a different radio channel – cannot use. However, rescue teams could benefit much from richer information, such as photos, sounds, videos, precise locations. For example, robot operators typically spend a lot of time acquiring local situation awareness (SA), because they are often lost and looking for landmarks [3], [4], [5]. In the end, robots and their operators share low-level information while in-field rescuers and mission commanders share high-level information. So far, no system bridges the gap, which is problematic since operators require more than just local SA; they also need an overview of the environment and its dangers [6].

To our knowledge, no exhaustive literature review on mobile USAR platforms has been performed. We present a brief one in §II, which complements our review on desktop

[1] www.nifti.eu

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Operator Control Units (OCUs) in [7]. Based on these two, we prepared three different applications suited to various roles and tasks for in-field rescuers. We then organized a high-fidelity USAR simulation at a fire fighting training center and tested these applications with six fire fighters. §III presents the experiment, the applications, and the lessons learned. Next, §IV proposes a novel system architecture to integrate geo-located pictures (taken from various robots or from in-field rescuers) into existing USAR desktop software used at the command post. Finally, §V discusses outstanding questions that need testing in the field and §VI concludes the paper.

II. Background

Although no restriction exists on the variety of roles and tasks that an in-field rescuer can fulfill, the state-of-the-art mostly equates 'in-field rescuer' with 'mobile robot operator'. Joint exploration in USAR thus often refers to a human in the field controlling a robot also in the field at a relatively close distance. Typically, only this person can control the robot, or receive feedback from it, which does not help team SA much. Because of the narrow focus, the state-of-the-art on mobile OCUs is still quite primitive. In fact, most of the development took place in the early 2000's, and recent versions provide little more than similar applications running on current hardware. Commercial systems are also very basic, although featuring rugged hardware. Most of these applications work with simple wheeled robots that must stay on relatively flat ground. These would not be very useful in the field due to unfavorable environmental factors [8], [9], but they nonetheless provide interesting features.

The first major mobile OCU was developed by Fong and his colleagues [10]. This system, running on a Portable Digital Assistant (PDA), was the most complete OCU for mobile operators, offering map, laser, and camera views and the possibility to control multiple robots. One of the main drawbacks was the necessity to use a stylus, which is highly unpractical in the field, especially with gloves.

To solve this problem, Keskinpala and Adams [11] created a simplified mobile OCU that would attach to the forearm and not require a stylus. This new form of interaction used overlays but the physical screen size could not allow for more than a grid of four by three thumb-sized buttons, limiting the design. Buttons to control the robot were thus made transparent over the video and laser view. More recently, Gutierrez [12] developed a similar application for the iPhone. With the modern screen, he was able to place the control buttons below the video feed, providing an unobstructed view to the operator. Similarly, Yagoda and Hill [13] present an Android-based version that contains additionally a virtual joystick. Finally, Walker and Miller [14] plan to investigate the use of accelerometers rather than on-screen buttons to control the robot's motion. The mobile OCU that we propose in §III uses a tablet instead of a phone and is thus able to show a camera feed and a map simultaneously, which is novel on a mobile device. A virtual joystick, based on [7], [15], is used to control the robot instead of the classical four buttons with arrows.

Christensen and his team took a different direction towards OCUs [16]. Because mobile devices were difficult to see in sunny environments and were unpractical to hold, they developed an OCU to be projected in computer glasses with an integrated screen. The robot's camera feed was shown in the background with sensor information overlayed. Robot control was done through a standard gamepad.

In order to alleviate the operator's task load (and the network bandwidth load), some teams created mobile OCUs that allow for autonomous navigation. For example, Perzanowski and his team [17] developed a multi-modal mobile OCU for indoors robotics. The PDA had a monochrome display and the robot only a laser (no camera). Nevertheless, the pilot could control the robot with a joystick, by clicking on the map, or by speech. Valero and colleagues [18] developed a similar OCU that had a desktop and a mobile version. The mobile version offers only laser and map views (no camera), but allows for four levels of autonomy: tele-operation, tele-operation with collision avoidance, navigation goals, and full autonomy. Similarly Checka and his colleagues [19] developed a more modern version that works on smart phones and provides video feeds.

Unfortunately, none of these systems are designed for rescue teams. One good system to share local situation awareness and pictures is presented in [6], but in this case as in general, little can be found on team or sharing frameworks that involve robotics. Therefore, an initial step forward would be a well-integrated system that shares and adapts the information to the physical requirements and information needs of the various team members [20].

The following section thus presents three mobile applications that we integrated into a team-based system and tested in the field.

III. Experimenting with Three Mobile Applications

Working on complex USAR scenarios, our goal is to integrate the information available from the in-field rescuers and from the robots with the whole rescue team. We thus prepared three different applications suited to a variety of roles and tasks and performed an end-user evaluation (EUE) where we could test these different approaches for integrating a greater variety of information.

The scenario was a low-speed collision between a chemical freight train and cars near a train station. Car occupants might have survived and could require medical attention. However, dangerous chemicals are leaking out and it might be dangerous for humans to approach the spill. The rescue team consisted of one mission commander, one in-field rescuer, one unmanned aerial vehicle (UAV), one UAV operator, one unmanned ground vehicle (UGV) and one UGV operator. Together, they had to build up SA, identify the hazards, and find victims. A command post was set up at a safe distance, from which most actors operated. The UAV could provide a first overview of the scene, showing areas or pathways for the UGV, which would eventually get close enough to cars and chemicals to evaluate the risks for the in-field rescuer to finally step-in.

The three mobile applications are described below.

A. The Mobile OCU

The intent of the NIFTi Mobile OCU was to provide a robot control application for actors in the field. The state-of-the-art, presented in §II, was not a very good starting point because few of the mobile OCUs were designed for USAR environments. Also, all of the mobile OCUs were single-user systems. Therefore, only the in-field rescuer could interact with the robot. Needless to say, such a design does not help team SA much. Our mobile OCU thus departs from the typical mobile OCUs by integrating into a team-based framework. It can display a front camera view and a 2D map, two views that are shown in picture-in-picture style and can be swapped. Such a solution is more versatile than purely map-centric or camera-centric designs, especially in highly varied and unpredictable environments such as USAR scenarios [7], [21]. An on-screen virtual joystick, analogous to the one in the desktop OCU [7], is available to control the UGV. It is also possible for the in-field rescuer to take snapshots that get published to the command post, where team members can analyze the pictures with their existing desktop systems.

A rescuer using such a mobile OCU acts at the operational level, which requires low latency (millisecond range) [8]. Unfortunately, the Wi-Fi network was very problematic at the EUE site. Because we designed a team-integrated mobile OCU, the tablet was connected to an antenna at the command post rather than directly to the robot. In the end, the connection and video delays were so severe that it was not safe to control the robot, which is not unusual in such environments.

B. The GeoCAM Share Project

GeoCAM Mobile for Android is an open-source application developed by the NASA Ames Intelligent Robotics Group (IRG). The application is the Android portion of the GeoCAM Share Project[2]. Providing high-level information for rescue teams, this application allows taking pictures with the tablet's camera and uploads them with geo-location and orientation information to a server that can display them to help disaster management.

The GeoCAM application naturally requires a high-speed internet connection to upload the pictures, which was problematic at the EUE site. Additionally, the GPS reception in our Asus Transformer Prime was insufficient for reliable use. Finally, this application is situated at a very high-level, and given the relatively small size of our experiment site (less than 50m X 50 m), we would have needed a precise mapping between the pictures' GPS coordinates and the robots' generated maps to fully benefit from this application.

[2]The GeoCAM Share Project at NASA Ames: `http://geocamshare.org`

C. The TrexCOP Team-Awareness System

TrexCOP was developed as part of the NIFTi project and allows the in-field rescuer to indicate positions on the local map rather than relying on a GPS localization. Thus, TrexCOP does not require a high-speed or high-bandwidth connection. The intent of TrexCOP is to increase the team SA by providing the **R**ight **M**essage at the **R**ight **M**oment and **R**ight **M**odality (RM)[3]. The in-field rescuer can give an overview of the situation from his perspective and enter detailed information about discovered victims or dangers, as shown in Figure 1. Additionally, each team member can add information and can get notifications from other team members asking for additional information, such as a victim's health status. Figure 4 shows TrexCOP with a localized picture from an in-field rescuer, as well as icons for localized actors and victims.

Lessons Learned

In the EUE, we observed that the communication between the field and the command post was mostly about the layout and content of the scene, or about obstacles around the robot. This information is obviously located in space, but it was communicated mostly by voice. The advantages of this medium are that the fire fighters are already trained to use it, it is efficient, and it keeps their hands free. The disadvantages are that it is difficult to understand or interpret, that it is not persistent, and that it is not precise. The information conveyed is also not shared nor recorded in the computer system, nor does it contain detailed information such as coordinates or pictures.

These observations came up also in July 2012, when the NIFTi team took part in a mission [22] after two major earthquakes occurred in the Italian region of Emilia-Romagna. We deployed a team of humans and robots (UGV, UAV) in the sealed-off area of Mirandola to cooperate with the Italian National Fire Corps. The task was to assess damage to historical buildings and cultural artifacts located therein. We discovered that persistent geo-located information would have been highly useful, for example by using geo-located snapshots from the UAV to guide the UGV in subsequent sorties. Also, "a better situation awareness for the pilot is of high importance, particularly to provide information about close obstacles, and better depth perception." [22]

Similarly, during an exercise where an internet connection was not available, the in-field rescuer often walked back to the command post and browsed the pictures with the mission commander directly on the camera with TrexCOP and the OCUs beside. This observation shows eagerness from fire fighters to get more detailed information from the field. Our goal is thus to integrate these pictures in our software, since they could benefit any team member in a variety of tasks.

Back at the EUE, we observed that mobile devices can fail in the field just as easily as robots do. The main problems were communication: weak connections to the various networks: voice over radio, network over Wi-Fi, internet over cellular phone technology, and GPS over satellites. Because every USAR site is unique and some connections are less stable than others, it might be more appropriate to use applications that require only asynchronous communication, rather than rely on synchronous communication, such as for manually steering a robot. Ashdown and Cummings [8] also came to the same conclusion.

The EUE also showed that typing comments on a tablet, especially with gloves, was not realistic in such environments. It was impractical to carry the tablet, even more to rest it somewhere to type, it took too much time to type, and it was too easy to make typos. Other experiments have shown similar problems as well as difficulties viewing the screen in bright sunlight [6]. The in-field rescuers started using abbreviations in the experiment, and one can imagine that when the stress and time pressure get really high, they will naturally revert to talking.

We thus propose that the in-field rescuer carries a mobile device connected both to a GPS signal and to a fast mobile internet connection. We also suggest a significantly smaller device, ideally keeping at least one hand free. The bulk of the information communicated should be through this device, rather than through the walkie-talkies. Typing is difficult so pictures should convey most of the information. A central application is thus required to act as the gateway between the command post and the field. Our proposal is described below.

IV. The In-Field Pictures Server

The In-Field Pictures Server receives pictures from the in-field rescuers and robots, extracts the relevant information (e.g. location, direction, angle of view), and broadcasts them to all connected actors. Figure 2 represents the architecture of this system. The desktop OCU and desktop TrexCOP at the command post will integrate these pictures and show them as icons on the maps, making the information persistent, retrievable in context, and available to the whole team. The mission commander and UGV pilot would thus be able to ask the in-field rescuers for pictures from specific points of view, or just browse what the rescuers sent based on what they found possibly useful.

For the moment, the pictures are transferred via the commercial application Dropbox[3]. This application synchronizes all pictures and videos taken from a mobile device with the folder where the pictures server runs. We could also synchronize the pictures server with many Dropbox-enabled tablets, telephones, and digital cameras, if a mission called for it. Dropbox is a commercial solution that is free and broadly supported (Android, iPhone, Windows Phone), which allows us to focus our development efforts on the human interaction rather than network communication. Based on our needs, such as speed, security, or privacy, we could change it for another application without affecting the system architecture.

During tests performed on German and Italian 3.5G connections, pictures taken in the field became available at the base station in under a minute. Pictures coming from the UGV or UAV, created when users click the snapshot

[3]The Dropbox application: www.dropbox.com

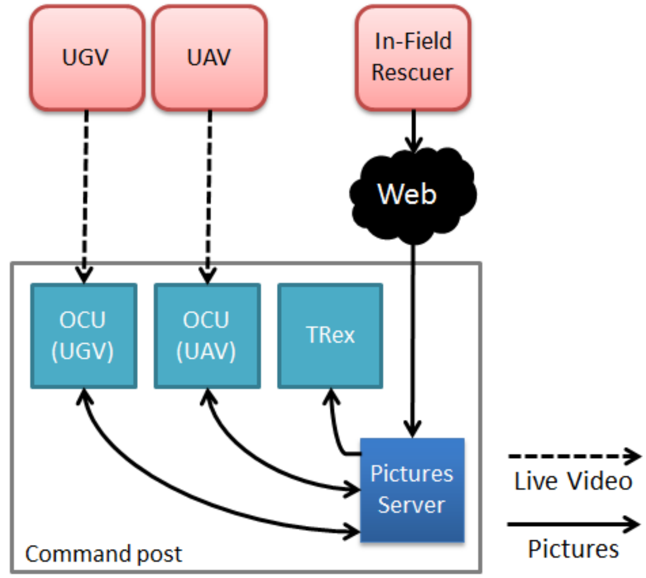

Fig. 2. The system architecture with the In-Field Pictures Server

button in the desktop OCU, do not get sent via Dropbox because they are already on the local network. The delay is thus no more than a few seconds. In any case, this communication is asynchronous and the delays are thus not critical. The tolerance for such information can range from several minutes to several hours or days if the pictures are used as inter-sortie information or for post-mission analysis.

It is, however, very important that users be able to navigate among these pictures and find the relevant information. HCI guidelines from the fields of GIS or shared workspaces will be useful as the system matures, but we are first interested in the content of the pictures and their use in the team rather than specific ways to display them. We are working closely with our end-users (German and Italian fire fighters) to find interaction modes that are as close as possible to their current emergency response systems. Our initial integration is proposed below.

Display in the OCU

The desktop OCU [7] is an application developed mainly to allow a robot operator to control a robot using various degrees of autonomy. The application shows a virtual scene created from the robot's laser to complement the camera feeds. 2D and 3D maps get generated as the robot explores the environment, allowing other team members to use the OCU for other purposes, such as global SA.

Different view types are provided by the OCU, such as top-down view, 3D view, or panoramic camera. Pictures are shown as thumbnails in a filmstrip at the bottom of the application, as illustrated in Figure 3. Pictures coming from the field, whether the in-field rescuer, the UGV, or the UAV, get added in reverse chronological order to the filmstrip. GeoCAM, introduced in §III, uses a similar display of thumbnails. Textual annotations are shown at the right of the filmstrip and are preferable to descriptions over walkie-talkies because they are persistent and geo-localized.

Additionally, pictures are shown in the virtual scene with a blue camera icon, as visible in the top two views of Figure 3. Most current applications also show only picture location, while GeoCAM shows additionally the direction with respect to North. In addition to direction, we plan also to show a cone that represents how wide the field of view is. Displaying the 3D angle of view would be novel for an USAR application. This extra detail might prove important for local SA, such as approaching a large gap while manually controlling the robot, or understanding the point of view when looking at structural damage.

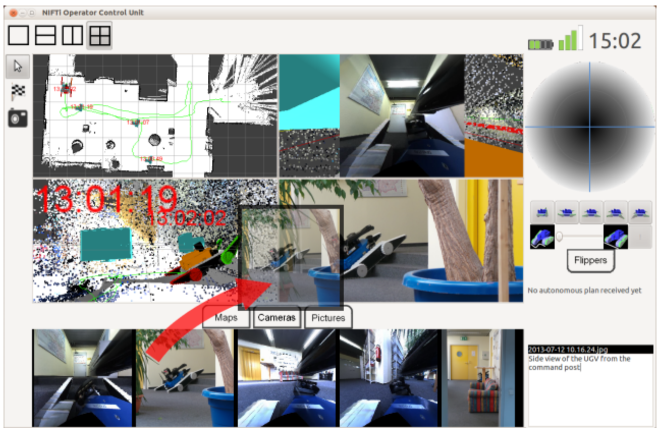

Fig. 3. Dragging a thumbnail loads a picture in a visualization panel. Clockwise from top-left: a 2D top-down view, the robot's front camera, the 3D reconstructed scene, and a picture from a mobile device. Here, the mobile picture helps climbing the stairs more than other views.

The OCU can display between one and four visualization panels at once, each one containing either a picture, a camera feed, or the virtual scene. To take a snapshot, users simply click on the camera icon in the toolbar on the left and then click on the desired camera feed. It is also possible to enter a descriptive comment. To display a picture, users drag its thumbnail (from the filmstrip) into any of the visualization panels, as demonstrated in Figure 3. With pictures displayed side-by-side, rescuers would effectively be looking at 'pre-recorded' feeds beside live feeds. They could compare two pictures, for example to examine a fire at two different time points. Another use could be showing a highly zoomed-in picture of a difficult obstacle while the pilot drives over it with a camera feed beside the picture. With a single visualization panel (instead of four), users could also view a picture in full-screen.

At first, we propose a basic GeoCAM-style interaction that will simply link the icons and the thumbnails: clicking on one will highlight the other. This association should help users quickly see all pictures at a certain location on the map, for example.

Display in TrexCOP

The TrexCOP user interface presents a top-down map of the USAR mission environment with icons where pictures were taken and where cars and victims were found, either

Fig. 4. TrexCOP with a localized picture from an in-field rescuer, as well as icons for localized actors and victims.

autonomously by the UGV or manually by the in-field rescuer who entered the information in the mobile device. An example is shown in Figure 4. These features make information found important by actors in the field available to the whole team, removing the necessity of the mission commander to watch the camera feeds at all times and remember all conversations over the walkie-talkies. Instead, he gets notified on his TrexCOP computer when a new picture appears.

V. Future Works

The accuracy and precision of the embedded GPS coordinates must still be evaluated in the field. Generic studies will unfortunately not help much, because the performance will vary significantly from mission to mission. USAR environments are unique and unpredictable, often composed of partly destroyed buildings and possibly non-functional cellular phone towers. Therefore, the performance could vary even within a site, as signals get blocked or degraded in or around buildings. Preliminary tests with an Asus Transformer Prime tablet (with GPS dongle) and with a Samsung Galaxy Camera were disappointing. The signal strength around our research center in Saarbrücken was weak and the inaccuracies ranged from one to more than ten meters. A Nokia 5800 XpressMusic and an iPhone 5 showed errors under five meters in the same environment. The problem could be related not only to the hardware, but also to the camera application, which does not update its position frequently to save power. Unfortunately, these settings are usually fixed and hidden by the manufacturers.

We must also consider accuracy of the robot's generated map, because it serves as the main point of reference in the OCU for the users – beyond the camera feeds. Due to the terrain difficulty in which we performed our user evaluation, we often noticed errors of a few meters and sometimes much worse. Thus, even with perfect GPS coordinates in the photos, the icons will appear misplaced to the user, with respect to the map. In some cases, the GPS might be more precise than the map. Another possible problem is the inaccuracy in robot location. By integrating pictures from various devices and robots, we inherently mix different levels of inaccuracies.

We must therefore analyze how damaging poorly-localized pictures would be towards the users' trust in the system. We hope that the system will be sufficiently accurate for the users to cope with the errors, without feeling like they need to 'help' the system. If necessary, we might allow the users to adjust picture positions from the command post, which would unfortunately introduce an extra task for them and increase their cognitive load. In any case, we need appropriate techniques for merging and filtering information from various sources.

We will soon evaluate our system at another high-fidelity experiment.

VI. Conclusions

We have shown that successful USAR missions requires high integration of the information gathered by all actors. In particular, information should be persistent, geo-localized, and detailed enough to provide team situation awareness without overloading the walkie-talkie channels. For this purpose, we prepared three mobile applications to be tested by in-field rescuers and organized an end-user evaluation that demonstrated how in-field devices designed for synchronous interaction can severely suffer from technical problems. Based on the lessons learned, we presented a novel architecture that will allow all USAR team members to collaborate more closely by working on the same information. Users can use the existing tools, namely TrexCOP and the desktop OCU, to browse the in-field pictures in context from the command post.

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