Drone-Assisted Disaster Management: Finding Victims via Infrared Camera and Lidar Sensor Fusion

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Abstract— **Robot-assisted natural disaster management is recently employed to aid human rescuers at diverse disaster sites. Due to its compactness and availability, drone has become an effective tool for searching survivors from confined space such as collapsed building or underground area. However, the current scope of research in this field is limited because the research tends to focus on increasing accuracy of 3d mapping, constructed by controlling quadrotor flight at disaster sites. Perceiving disaster environment is necessary for rescue mission, but finding victims at the earliest time is more critical for practical rescue operations. In this work, we propose an overall architecture for drone hardware that enables fast exploration of GPS-denied environment, and practical methods for victim detection are introduced. We employ DJI Matrice 100 and utilize hokuyo lidar for global mapping and Intel RealSense for local mapping. Our results show that fusing these sensors can assist rescuers to find victims of natural disaster in unknown environments, and the detection system is insensitive to illumination change.**

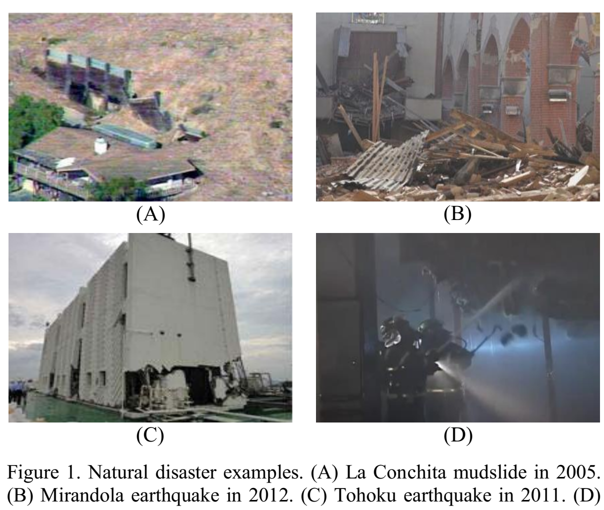
Keywords—unmanned aerial vehicles; disaster management; sensor fusion; lidar; Intel RealSense; Robot Operating System

I. INTRODUCTION

A new trend in managing and accessing natural disaster is to employ robot as the platform for disaster management application. Over the past years, robotic deployment in natural disaster management has been actively performed. In the case of the La Conchita mudslide in 2005, a shoebox-sized wheeled robot was inserted into the damaged house to scan for victims [1]. At the Earthquake-Hit Mirandola in 2012, a team of humans and robots (UGV, UAV) worked together with the Italian National Fire Corps [2]. Recently, a field experiment was also conducted with a team of ground and aerial robots toward the mapping of an earthquake damaged building at 2011 Tohoku earthquake [3]. Fig.1 summarizes these incidents and demonstrates that utilizing robots in such instances is essential for humans to avoid or mitigate further accident.

Among various types of robots, unmanned aerial vehicles, also known as drones, have been extensively developed to monitor and access disaster sites. Drones are cost-effective, compact, and easy to operate in cluttered environment [4], thus become affordable candidates for disaster assistance. As reference, survey of UAV-assisted disaster management is reviewed in [5]. A major application of drone-assisted disaster management is the autonomous navigation through the confined space [6], [7], [8], [9]. In particular, damaged buildings from earthquake are challenging to be explored by human rescuers due to darkness and possible collapse, and drones can be fused with sensors to obtain 3D mapping of the unknown area and prevent human rescuers from additional accident [10], [11], [12]. Although many researchers in this field study on drone's autonomous navigation relying on SLAM, there exist difficulties in implementing their algorithms in real world application. One consideration is GPS-denied environment for disaster site, and another concern arises when there is limited lighting. Current quadcopter-related research tends to focus on increasing the accuracy of drone pose estimation and localization [8], [9], [13]; however, in the field of disaster management, trading off the accuracy with quick tracking of victims is necessary.

The key contribution of this work is the design of drone system architecture focusing on the real world problems that may happen in practical rescue operations. Fig.1 (D) shows the real world challenges that human experiences due to limited lighting and unknown building structure. We propose to develop the drone system that is robust to these problems by utilizing lidar and infrared depth camera. The rest of the paper is structured as follows. Section II reviews the recent works on drone system. Section III addresses our main drone architecture, and experimental sensor output result is presented in Section IV. Concluding remarks are provided in Section V.



(A) (B) (C) (D)

Figure 1. Natural disaster examples. (A) La Conchita mudslide in 2005. (B) Mirandola earthquake in 2012. (C) Tohoku earthquake in 2011. (D) Firefighters at disaster site.

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II. RELATED WORK

In recent years, autonomous quadrotor platform has received increased attention from the research community. Many authors have developed drone architectures capable of simultaneous localization and mapping (SLAM) [6], [7], [8], [9], [10], which becomes the basis for autonomous navigation for indoor flying. In particular, these architectures benefit UAV-assisted natural disaster management.

While some researchers [10], [12] use GPS information for quadrotor navigation, we propose to develop drone architecture that is able to perform SLAM with onboard sensors. In general, there is no available GPS signal at disaster sites, and establishing sensor framework for navigating these unknown areas is crucial. Chen et al. [14] generated collision-free trajectories for quadrotor flight using 3D grids in unknown environments. Camera-based [8], [9], [15] approaches known as visual SLAM also have been extensively studied to aid autonomous navigation. In [15], the author fused laser readings with visual SLAM to robustly track aerial vehicle positions. Saska et al. [16] developed groups of aerial vehicles localizing themselves in GPS-denied environments using visual relative localization.

Although vision-based techniques can help provide pose estimation and 3D reconstruction, these approaches are difficult to implement in the limited lighting condition. Few works [6], [7] present autonomous indoor flying in GPS-denied areas, with a help of laser rangefinder sensor, which can resolve the lighting problems. Our system extends these works and propose to fuse IR depth camera with lidar in order to provide local (nearby victims) and global (overall floor plan) maps of disaster area. This architecture allows fast tracking of survivors and thus effective in practical rescue operations.

III. OVERVIEW OF RESCUE OPERATION

In this section, we introduce our system from the big picture of rescue operation process to the low level of quadrotor hardware setup. We focus on real world application of our architecture and explain the practical use of employed sensors for effective rescue operation.

A. Drone-Assisted Disaster Management

Fig.2 illustrates the overall rescue operation. The rescue center collects necessary information regarding the natural disaster sites and oversees entire rescue procedure. Any image or data obtained by robots throughout the rescue mission can be visualized on the screen of the rescue center. Virtual reality technology enables human to take over the control of rescue robots, and the robotic teleoperation provides 3D scanned environment [17]. As for the robotic deployment scene, all the robots communicate via wireless network with each other to cooperate or complement one another. Since there can be limited lighting condition, sensors such as laser scanner and infrared depth camera, which are insensitive to illumination change, are mounted on the robots for navigation and 3D reconstruction. The robots also guide rescuers and victims to desired places and may carry emergency supplies for survivors.

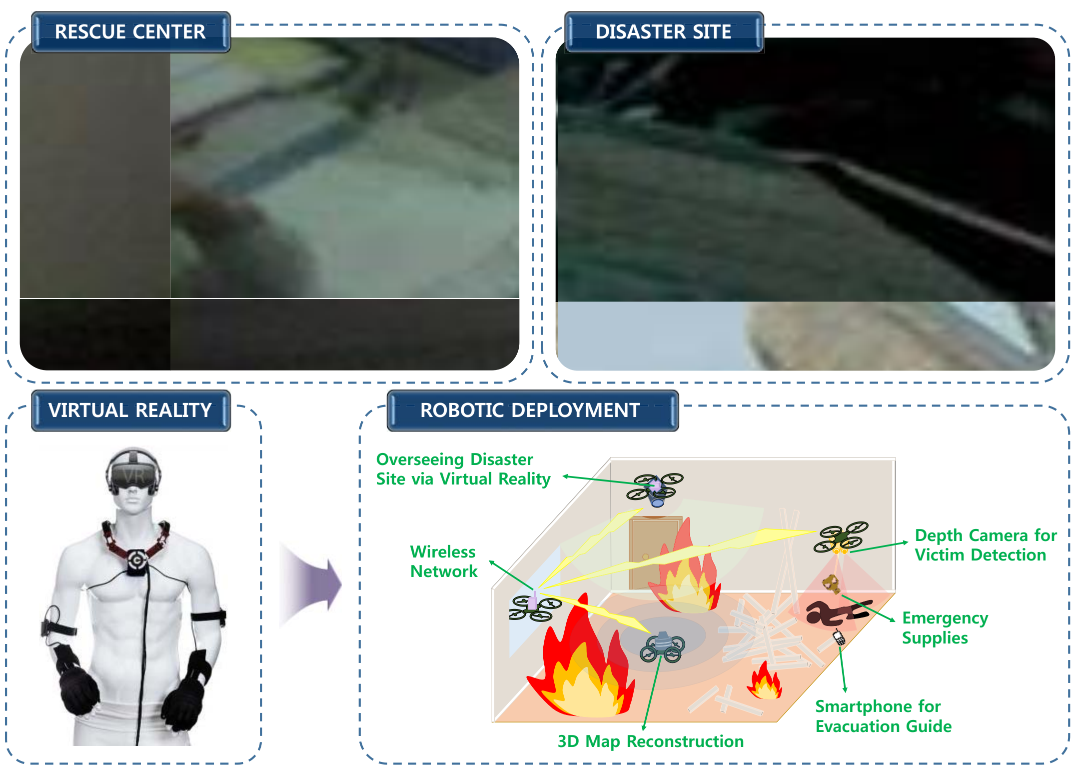

Figure 2. Illustrating the rescue operation overview. Rescue center oversees and controls the overall rescue operation process, and virtual reality allows manual operation of robots by visualizing 3D space of the disaster site.

B. Robot Hardware Architecture

As the platform of robotic deployment in natural disaster, we use DJI Matrice 100 drone. This quadcopter is highly customizable and supports multiple ports for third party components connection. Dual battery components allow up to 40 minutes of hovering time, and rigid lightweight body frame can lift up 1kg of payload. Maximum speed is nearly 20m/s. We argue that these specifications are suitable for disaster management application since its long hovering time and high speed flight with multiple sensors will locate victims at the earliest time.

As for the onboard hardware, we mount a Hokuyo lidar (UTM-30LX scanning laser rangefinder), an Intel RealSense camera (R200), and a drone computer (Manifold) (Fig.3). The lidar measurement is reliable up to 30 meters and available at 25 msec per scan, and the depth camera measurement ranges up to 10m with real-time RGB and stereoscopic IR cameras. The Manifold is a GPU-supported computer featuring an NVIDIA Tegra K1 SOC. Matrice 100 is able to carry these modules, and all sensors and CPU processing are performed on board.

C. Sensor Application for Rescue Operation

The proposed architecture aims to detect survivors of natural disaster, and speedy localization of the victims is the essential motivation of the overall framework. The present drone incorporates built-in IMU, lidar, and IR depth camera to perform the localization and mapping task. When the drone is deployed into the disaster sites, the lidar provides 2D map of surrounding structures. This global map guides the maneuver of the quadrotor by displaying possible flight path and open entrances. The robot then utilizes depth camera to visualize local 3D view. The stereoscopic infrared camera is employed to detect the survivors even in the dark. With the support of IMU, the flying robot achieves the global and local mapping of disaster scenes. In addition, a 360 camera is used to gather visual information from surrounding environment. This sensor works with virtual reality and/or teleoperation for rescue center to manually control the robot. Fig.4 exemplifies the visualization of the 360 camera through smartphone connection. To sum up, the overall sensor setup is able to construct global and local maps via the quadrotor flight at disaster environments and find the victims of natural disaster from unknown building structures with limited lighting condition.

Figure 4. Samsung Gear 360 paired up with a smartphone.

IV. Experiment

Using the aforementioned hardware architecture, we tested the drone system in a confined space. The experiments were performed in bright and dark setting of the same space for comparison purposes.

Fig.5 presents the experimental results with the light on. As the setup, the IR depth camera outputs and the lidar data were processed and visualized in ROS (Robot Operating System) with RVIZ package. Configuration for data visualization is shown in Fig.5 (F), which is equivalent for the two cases of bright and dark environments.

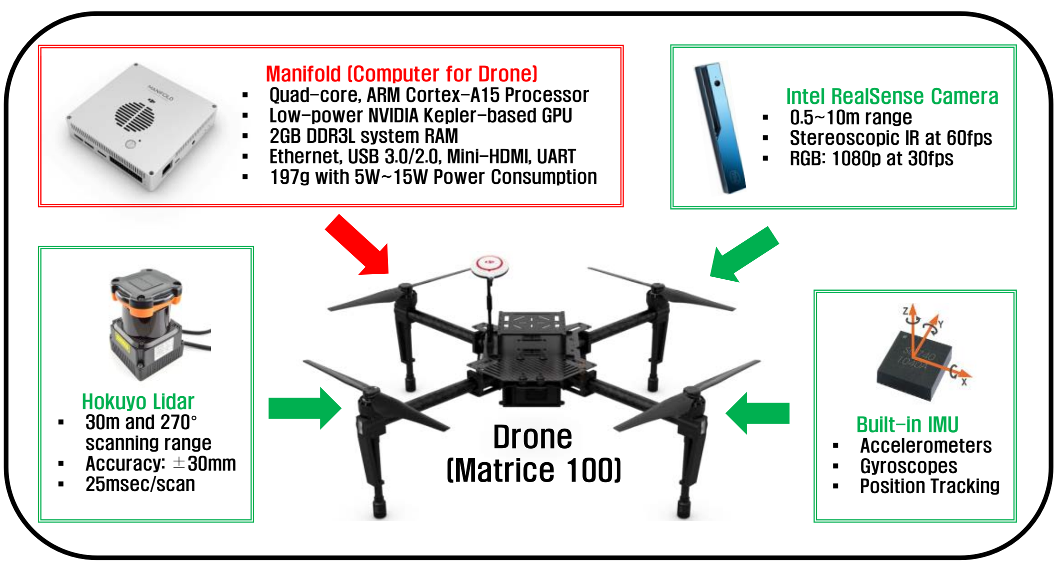

Figure 3. Drone hardware specification. Manifold, marked in red, plays a role in main computer for the drone, and various sensors, marked in green, collect information from surrounding environment.

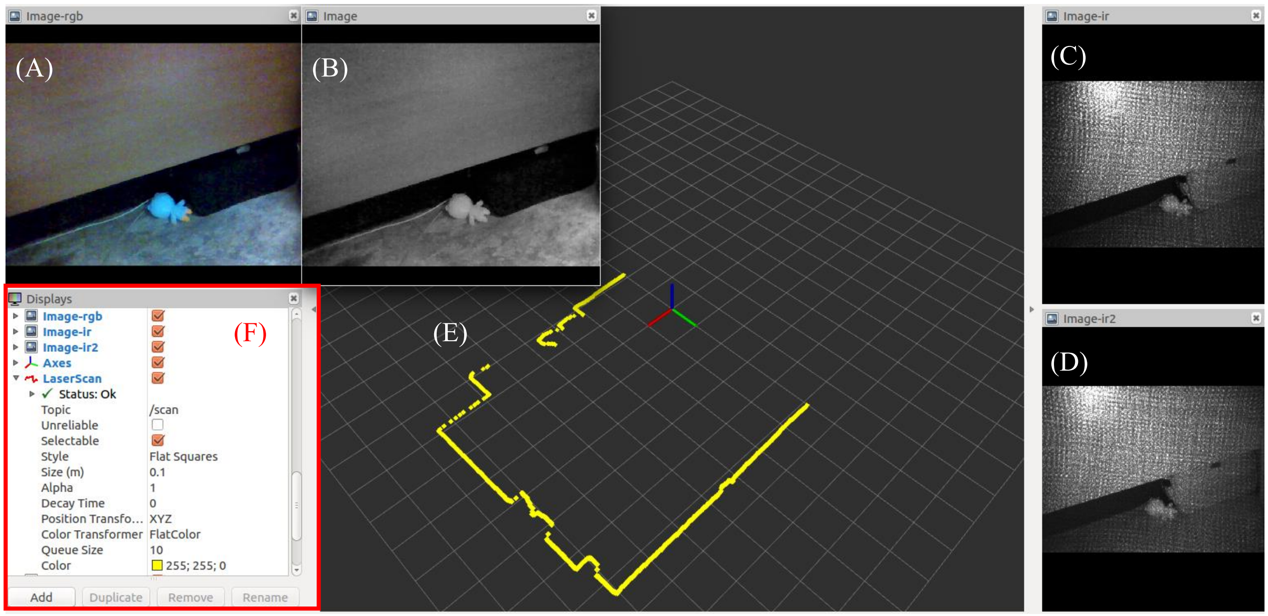

Figure 5. Experimental result from our hardware architecture. The data output is collected from a laser scanner and a depth camera. The visualization is implemented in ROS (Robot Operating System) with RVIZ package. (A) RGB image. (B) Grayscale image. (C) Left infrared sensor image. (D) Right infrared sensor image. (E) Laser scanner point cloud data. (F) Configuration for sensor data visualization.

Fig.5 (A) and Fig.5 (B) show the monocular RGB and grayscale images from Intel RealSense camera. In the bright setting, it is obvious to point out that there exists an object laying on the ground. If the object moves at disaster sites, we consider that the object becomes a candidate for the survivors of natural disaster. The left and right infrared images are illustrated in Fig.5 (C) and Fig.5 (D), respectively. These stereoscopic images also confirm the presence of the object on the ground.

The benefit of activating RVIZ package is the user-friendly customization for data visualization (Fig.5 (F)). For each window opened by RVIZ, users can modify the style and color of the data view, and Fig.5 (E) exemplifies such benefit. The laser scanner sensor returns the yellow point cloud data on a grid map where each grid has a dimension of 1 meter by 1 meter. Therefore, we conclude that the confined space approximately has a dimension of 6 meters by 7 meters.

Fig.6 displays the node graph for the sensor system. A topic marked by an ellipse represents one node and performs specific task. For instance, */camera/depth_points* node works with depth points captured by camera. The graph also demonstrates that there are two nodes (*/camera/driver* and */camera/camera_nodelet_manager*) communicating with each other by transferring messages. The collection of nodes is marked by rectangle and represent distinct sensor data outputs. *hokuyo_node* provides lidar data through one node, and *camera* includes 16 nodes related to the depth camera. This network allows users to modify desired data by executing the node on demand and fuse the sensor data from different sensors.

For the next phase of the experiment, Fig. 7 illustrates the

Figure 6. Node graph for the sensor architecture. The rqt_graph package in ROS provides a GUI for visualizing the ROS nodes and topics. The lidar data is collected by *hokuyo_node*, and the depth camera outputs are stored in *camera*. The presence of lidar and depth camera nodes indicates that both data outputs are accessible and can be fused if necessary.

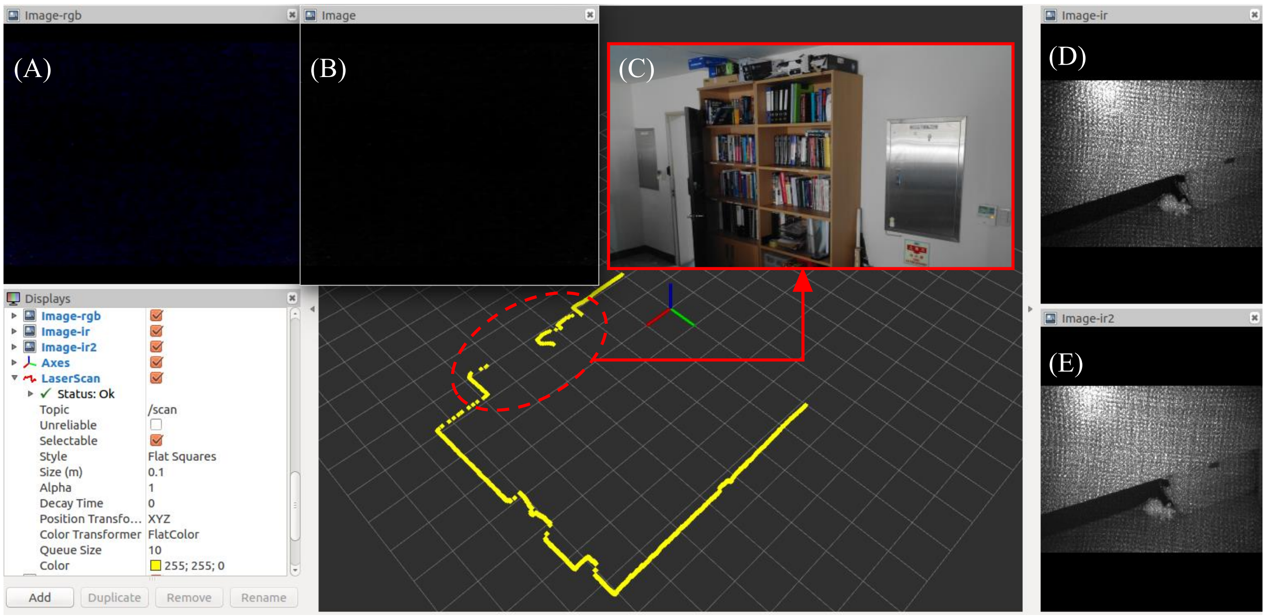

Figure 7. Drone Experimental result in the limited lighting condition. The data output is collected from a laser scanner and a depth camera and visualized in RVIZ with the previously used configuration. (A) RGB image. (B) Grayscale image. (C) Real world view of the selected region. (D) Left infrared sensor image. (E) Right infrared sensor image.

results in the limited lighting condition. Fig.7 (A) and Fig.7 (B) outputs confirm that nothing can be seen with the RGB camera. However, Fig.7 (D) and Fig.7 (E) show that infrared images are insensitive to the lighting because the object still can be found in the dark environment. We also observe that the lidar data in yellow point cloud looks the same as before and conclude that laser scanner sensor helps users perceive the unknown space by providing the point cloud for the boundary of surrounding structures. Fig.7 (C) describes the real world scene of the selected region and validates the entrance location found by lidar. Finally, an example of our drone flight is shown in Fig.8. The quadrotor was manually controlled and flying through a basement room with the limited lighting condition.

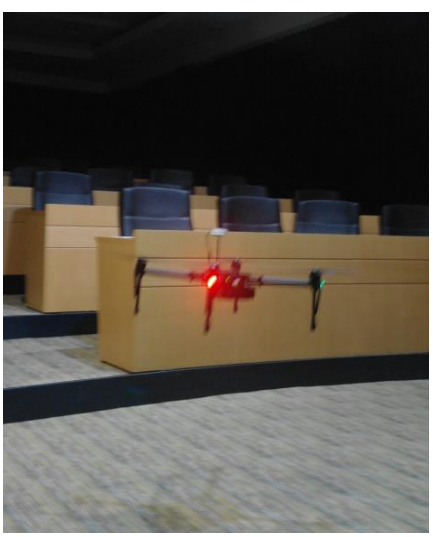

Figure 8. Testing of our drone. The quadrotor is manually controlled and flying in a basement room with the limited lighting condition.

V. Conclusion and Future Work

In this paper, we discuss overall architecture for drone-assisted disaster management and propose the suitable drone hardware with sensors for practical rescue operation. We test our system in the lighted and limited lighting conditions, and the sensor outputs visualized by ROS provide the global and local maps of surrounding unknown environments. We also identify that laser scanner sensor and depth camera are insensitive to illumination change and thus can be fused together to offer meaningful information at natural disaster sites. Successful usage of these sensors enables rescuers to detect significant landmarks such as doors or boundary walls and find survivors from the disaster at the earliest time.

The future work will focus on building a fully autonomous drone that can perform sensing, localization, and trajectory planning on its own. Moreover, sensor fusion of laser scanner and infrared depth camera will be conducted at the lower level in order to provide more accurate mapping information for robot navigation. The autonomous navigation requires path planning algorithms and well-designed controller, and the collective system considering these features will benefit practical rescue operation and save a life.

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