Full Color 3D Point Clouds from Bird's-eye View Using Multi-view Laser Scanner and Quadcopter

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Abstract - **Bird's-eye views are critical in responding to disasters or accidents. Mobile robots mounted with laser scanners are often used for large-scale spatial remote sensing. We construct a multi-view laser scanning system as a prototype to acquire highly-detailed 3D structures from a bird's-eye viewpoint. We demonstrate the fusion of the 3D point clouds with aerial images captured by a quadcopter. Our experiments show that full color 3D point clouds from bird's-eye view provide an extremely useful approach for organizing disaster response efforts.**

Keywords - 3D laser scanner, 3D point cloud, quadcopter, bird's-eye view, data fusion.

I. INTRODUCTION

Remote sensing by using mobile robots is effective and useful approach to assess hazardous sites that humans cannot enter or rapidly understand the situation after a disaster, particularly a large-scale disaster. To remotely control the movement of mobile robots over the ground and avoid various obstacles, bird's-eye view surveys is the most effective approach to performing 2D path planning for robot navigation [1]. Spatiotemporal bird's-eye views generated from multiple fish-eye images were proposed for survey and rescue efforts in disaster sites [2]. Data fusion approaches based on 3D measurements and bird's-eye view images are useful for 3D scene analysis and obstacle avoidance [3][4]. Moreover, the fusion of fish-eye images and range data has applied to visualize obstacles for remote controlled robots [5]. Operators can find suitable and safe paths for the mobile robot from the visualized information.

In this study, we assume that bird's-eye view surveys are urgently needed to grasp disaster scenes and accident sites. We focus on the fact that quadcopters, which are unmanned aerial vehicles, have excellent 3D remote sensing potential due to their high mobility and plug-and-go integration. Unfortunately, commercially available quadcopters do not currently have built-in highly accurate laser scanners due to weight issues. Small flying robots with ultrasonic range sensors have been used to make 2D or 3D maps from bird's-eye view [6], however, this remote sensing approach does not yield accurate environment maps. We assume that the next generation quadcopters will have both 3D laser scanners and cameras. In the absence of any suitable quadcopter, we developed a multi-view 3D laser scanner system as a prototype. The scanners yield dense 3D point clouds while a quadcopter is used to capture aerial images. We demonstrate full color 3D point clouds by applying data fusion.

This paper is organized as follows: Section II describes our prototype system that generates full color 3D point clouds. Section III examines the performance of our prototype system by testing single- and multi-view scanning schemes. By using the color 3D point clouds, we visualize 3D scenes from arbitrary viewpoints. Finally, Section IV concludes this study and mentions future work.

II. PROTOTYPE SYSTEM

To avoid occlusion in 3D measurement, the prototype handles multi-view laser scanner. Fig. 1 illustrates its configuration. We assume that the next generation quadcopter will be capable of collecting multi-view 3D point groups. We adopt RobotEye RE05-3D units produced by Ocular Robotics. Each can scan the aperture through a full 360 degrees in azimuth relative to the body and ±35 degrees in elevation; see reference [7] for details. We fixed the four 3D laser scanning devices on the ceiling in our laboratory. All scanners were controlled by a personal computer, and the 3D point data acquired from four directions were synchronously transferred to the computer via LAN.

Fig. 2 illustrates the processing flow implemented in the prototype system. We assume that the viewpoint of each scanner is set at the origin of its own local coordinate system. The system derives the rotation matrix and the translation vector between the local coordinate system of each scanner and world coordinate system located on the floor. Given the rigid transformations, the system integrates the 3D point groups by using 3D registration [8]; this yields composite 3D point clouds. The quadcopter was flown at a fixed altitude by a dedicated remote controller and captured aerial image via a bottom camera. Assuming that the measured 3D points are approximately projected onto the camera image by planar projective transformation, our system automatically assigns each 3D point to one pixel in the image by using plane-homography. The above-mentioned procedure yields full color 3D point clouds. Each point consists of 6D information: 3D coordinates and RGB pixel values.

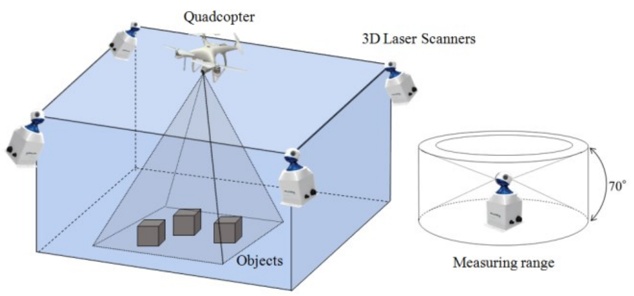

Fig. 1. Configuration of prototype system.

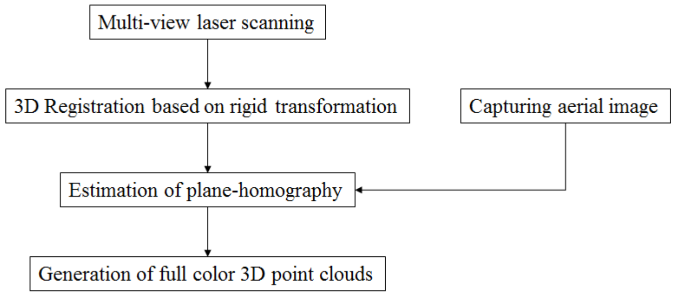

Fig. 2. Processing flow.

III. Performance

Fig. 3 shows our experimental setup. We constructed a physical model of a disaster or accident scene by arranging chairs, desks, foam boards, and wooden wall boards. The empty space formed between the objects represents a safe pathway for a mobile robot. Our prototype system was tested using one (RE1), two (RE1 and RE2), and four scanners.

Fig. 4 provides color 3D point clouds yielded by fusing the composite 3D point clouds with an aerial image. The single-view scanning yielded an incomplete color 3D point cloud; it is unlikely to provide helpful 3D information for planning rescue actions. In contrast, two- and four-view scanning yielded detailed 3D structures with color texture. We demonstrated that the four-view scanning attained fine-grained 3D points and seamless textures. Next, we compared the 3D structures yielded by each scanning scheme in detail. Fig. 5(a) and Fig. 5(b) correspond to close-ups of the 3D point groups shown by the red and blue frames in Fig. 4. As shown in the aerial image, two foam boards were placed beside some wooden wall boards. The single-view scanning scheme failed to acquire the objects due to occlusion caused by the wooden wall board; the two-view scanning scheme extracted the rough 3D shapes. The four-view scanning scheme yielded detailed color 3D points as compared to two-view scanning scheme. In Fig. 4, a green chair is marked the blue frame. Although the single-view scanning scheme failed to capture many 3D points on the chair and floor, the two-view scanning scheme dropped far fewer 3D points. The four-view scanning scheme interpolated the 3D points; its data allowed reconstruction of the dense 3D structure and the texture of the chair.

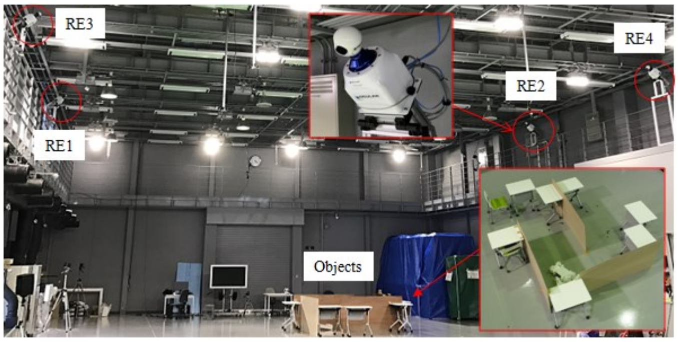

Fig. 3. Experimental setup.

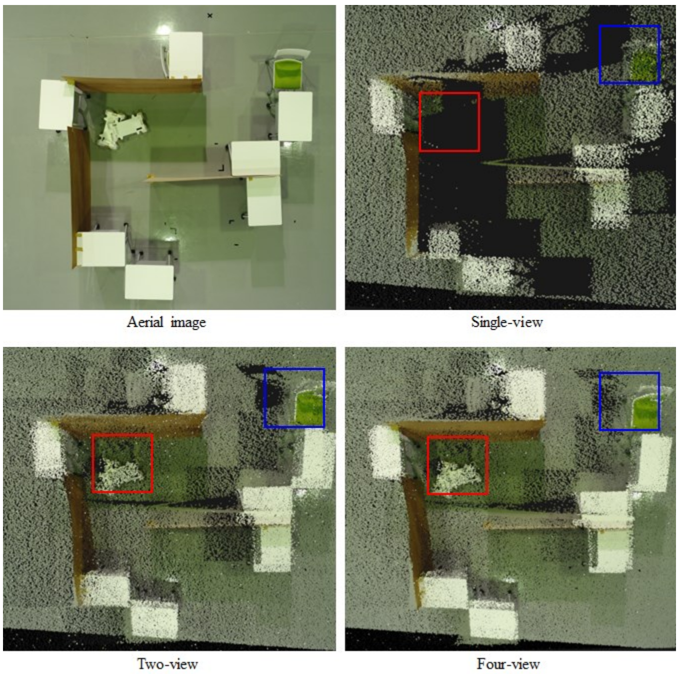

Fig. 4. Full color 3D point clouds from bird's-eye view.

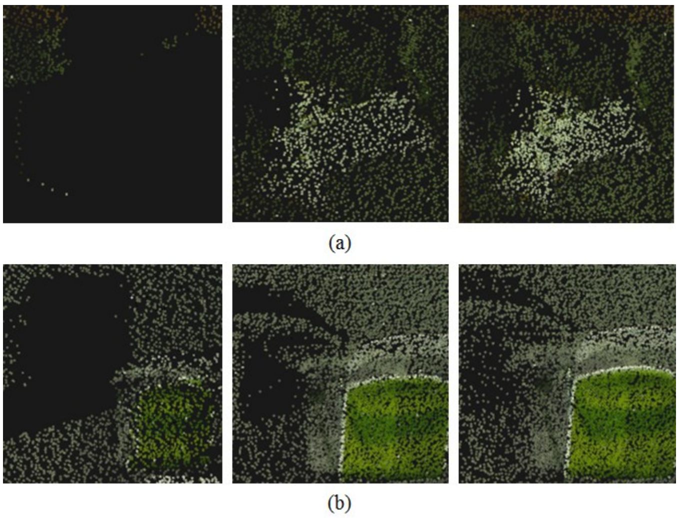

Fig. 5. Close-ups. Left: single-view. Middle: two-view. Right: Four-view. (a) Red frame. (b) Blue frame.

TABLE I. COMPARISON OF THREE LASER SCANNING SCHEMES.

	Single-view	Two-view	Four-view
Number of points	1,079	1,717	3,332
RMS error [cm]	1.1	1.2	1.8

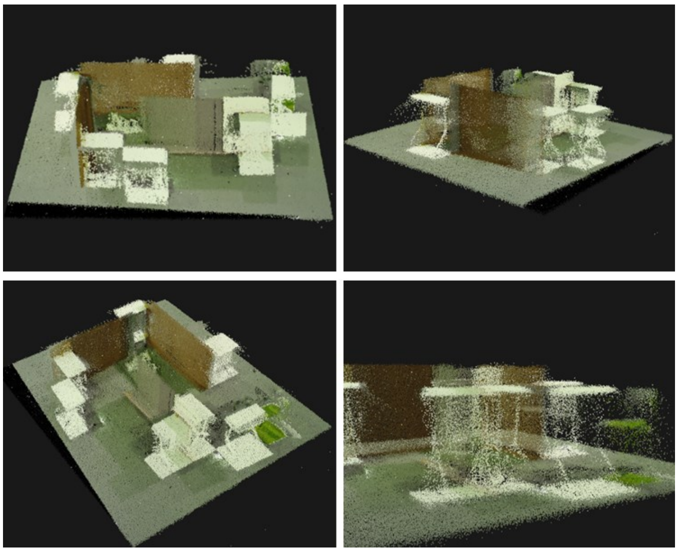

Fig. 6. Full color 3D point clouds from other viewpoints.

Table I shows the point densities and RMS errors yielded by each scanning scheme. We assume that the point density is defined by the number of points within 0.5 meters cube. The point density was approximately linear to the number of viewpoints. RMS errors represent the deviation of 3D points that present planar objects. We calculated the RMS errors from 3D points on the desk shown in Fig. 3. They represent an evaluation of the accuracy of spatial scanning from bird's-eye views. We found that the four-view scanning yielded slightly higher RMS error than the others. Since 3D registration depends on the rigid transformations of the laser coordinate system and world coordinate system, our next work is to acquire accurate 3D point clouds by introducing an innovative calibration technique [9].

Once full color 3D point clouds are generated, we can visualize the real space from arbitrary viewpoints. Fig. 6 shows virtual images recreated from full color 3D point clouds, which were generated from four-view scanning scheme. The side views well recreate the real environment with presence. These demonstrations show that our prototype system is an effective way of acquiring highly-detailed 3D structure. However, RE05-3D cannot acquire 3D points from the surfaces that absorb or diffuse laser beams, e.g. translucent and glossy, curved surfaces, and water surfaces. To handle actual disaster scenes and accidents, we must be able to detect not only these surfaces but also 3D structures with low visibility. We will enhance our system to acquire robust and accurate 3D point clouds by adding the data from other active sensors.

IV. CONCLUSION

In this study, we developed a multi-view 3D laser scanner system as a prototype. We obtained 3D point groups from fixed scanners and aerial image from a quadcopter. The system automatically integrated each 3D point group by utilizing rigid transformations, and then assigned each 3D point to one pixel in the image. Our system can generate full color 3D point clouds from a bird's-eye view through data fusion.

We tested single-, two-, and four-view scanning schemes to examine the effectiveness of multi-view scanning. Four-view scanning scheme yielded dense 3D points that faithfully reproduced the 3D objects. Experiments showed that the RMS error defined by the deviation of these 3D points was less than 2.0 cm. Moreover, we reproduced virtual images from the full color 3D point clouds. We confirmed that the full color 3D point clouds generated from bird's-eye view are helpful in grasping accurate space structures from side-views.

We will improve the accuracy and quality of the full color 3D point clouds by introducing an accurate registration method and using multi-view aerial images. In the future, assuming that the next generation quadcopters will be able to acquire spatio-temporal 3D point groups, we need to realize sequential 3D registration from the measured 3D point groups. Our data acquisition approach needs to be tested in various outdoor scenes with the goal of large-scale 3D surveying. It will be applied to not only path planning for moving robots but also 3D augmented reality displays.

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