Development of a Quadrocoptor Robot with Vision and Ultrasonic Sensors for Distance Sensing and Mapping

Seung-Jae Lee and Jong-Hwan Kim, *Fellow, IEEE*,
Department of Electrical Engineering, KAIST,
335 Gwahangno, Yuseong-gu, Daejeon 305-701, Republic of Korea
E-mail: {sjlee, johkim}@rit.kaist.ac.kr

Abstract The objective of this paper is to build a map using a quadrocopter. To explore the surroundings and build a map, ultrasonic sensors and a camera sensor are used. As ultrasonic and camera sensors get information separately, they have to be synchronized. Through this synchronization, the location of the quadrocopter can be recognized. At that point, the four horizontal distances can be calculated by rotating the quadrocopter. The map is then built through the reconstruction of information using the information from a camera and ultrasonic sensors. The effectiveness of this scheme is demonstrated in a real environment.

Key words: Quadrocopter, Localization, Synchronization

1 Introduction

UAVs have been mainly used in military field for reconnaissance, observation, information gathering and so on. However, they are also used in the private field, such as remote sensing, environmental monitoring, and cartography, because of the development and diffusion of the technology. The fixed-wing UAVs are easy to control compared with rotary-wing UAVs. However, they cannot stay one place for a long period of time. Thus, they have to rotate the same circle continuously. They also cannot quickly change their direction. To solve these problems, many researchers have used the rotary-wing UAVs. A quadrocopter is one of them. It uses four propellers and can quickly change its direction. Until the early 2000s, research papers about quadrocopters were concentrated on the stable control issue like remote control [1]. Since mid-2000s, many research papers about the additional function of a quadrocopter have been published. It can avoid obstacles and film the field safely with safety using infrared and ultrasonic sensors [2]. There is also research about a quadrocopter localization and navigation using sensors [3]. In the recent years, a quadrocopter uses a laser scanner and a camera sensor [4]. It is made for real-time autonomous navigation in multi-floor indoor environments using an aerial vehicle. A laser scanner scans horizontal space and a camera sensor, which is equipped in front side of a quadrocopter, supports positioning. The laser scanner scans the height of the horizontal map according to the change of the height of the quadrocopter and then a computer builds a whole map. In image processing, find a particular object and recognize it as a marker is hard work. There is paper related to find marker [5]. There are also many papers about localization by using specific markers [6] or using many numbers of ultrasonic sensors [7]. But in this experiment, marker is used. The goal of this paper is to build a map using a quadrocopter. For this purpose, a quadrocopter needs to know the horizontal distances around it and its location. The horizontal distance of four directions is obtained from four ultrasonic sensors which are located on the top side of the quadrocopter. The location of the quadrocopter is determined by the camera sensor information about markers. The quadrocopter used in this paper [8] has properties such as 10 minutes of runtime with 2 cell 1000mAh Li-polymer batteries and the weight of 244g including battery and Micro Indoor Hull. Its maximum capacity is 400g when 2 cell batteries are used. In this research, a quadrocopter is equipped with a camera sensor and ultrasonic sensors. By integrating $x$and y positions from a camera and z position from a bottom ultrasonic sensor, it estimates its position. Other ultrasonic sensors are used to avoid obstacles. By using this information from a camera and ultrasonic sensors, it can have some knowledge on its surroundings. Then, the map is built through the reconstruction of information. It carries out map-building quickly in a low price. This scheme can be used for an exploration of place in accident, such as collapsed buildings in which it is too dangerous for humans to enter.

2 The Method for Localization of the Quadrocopter

For localization, a camera sensor is used to detect a marker and measure the location of the quadrocopter in 3D coordinate and the rotation angles of x, y, z axis related to marker axis. Fig. 1 shows the image, which is obtained from a camera. Since it is a 2D-camera which can represent (x', y'), it cannot represent the real world 3D coordinate directly. Therefore, z' is calculated by using proportional expression. In real world, the exact point is located in the direction of vector (x', y', z'). So if z' is decided, the exact one among four markers which are located at each corner can be found by matching the length of the rectangle. By matching the side lengths of a virtual marker and a real marker, the real 3D coordinate of each corner of the marker can be calculated. Then the location of a camera from a marker and the angle of rotation for each axis can be calculated by coordinate transformation from the camera coordinate to the marker one as shown in Fig. 2.

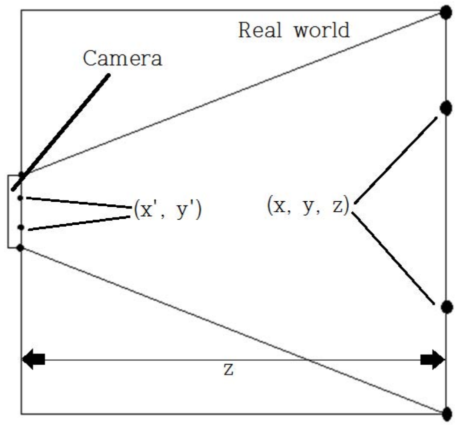


Fig. 1 Camera picture of real world.

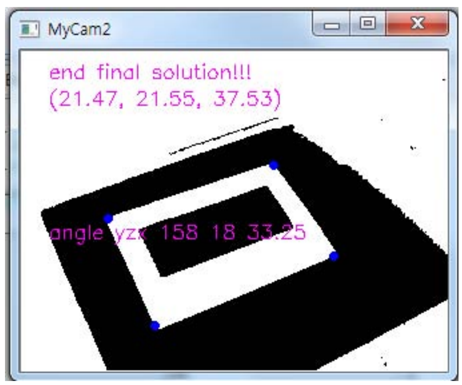


Fig. 2 Location of camera from marker.

3 Experimental Results and Analysis

A global variable was defined and counted every time step when five ultrasonic sensors distance data were received. The data from the ultrasonic sensors and the camera sensor were matched with count number. By using these data, the quadrocopter could build a brief map. When five ultrasonic sensors were used, minimum response time was 20 ms. So 30 ms time delay was defined between distance detection from each sensor. By placing sensors in top of the quadrocopter, it could measure up direction distance. It could avoid upper obstacle when it goes up. Experimental setup for this research was shown in Fig. 3. On the left and the right side, chairs were existed. The desks were in front and back sides. The boxes were bottom of front sides.

Fig. 3 Images of surroundings.

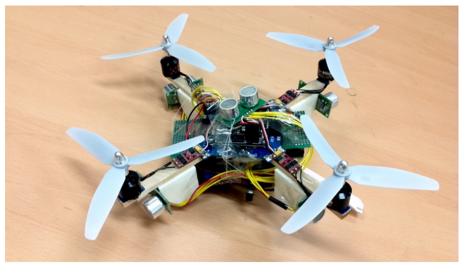
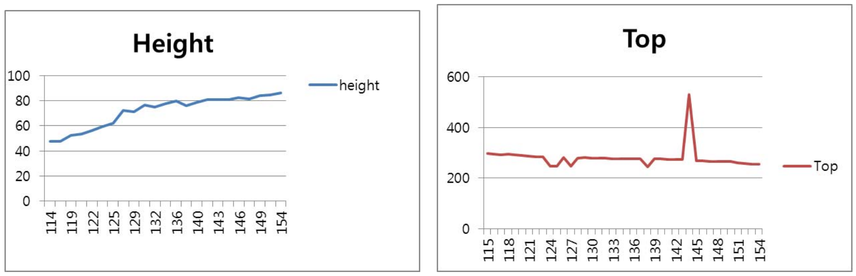


Fig. 4 Quadrocopter with sensors.

3.1 Sensor Information Collection

Fig. 4 shows the complete form of the quadrocopter. The ultrasonic sensors are located in four direction and top of it, and a camera sensor is located on the bottom of the quadrocopter. In this experiment, two types of data were saved. In the first data, five ultrasonic sensors distance were saved. The sequence of the saved data was in order of time, front, left, back, right, and top. In the second data, the camera sensor data were saved. The sequence of the saved data was in order of ultrasonic sensors time, (x, y, z) position, and angle rotation for three axes.

The camera data were saved in every one or two time step. In the first experiment, the process from departure to landing about 80 sec was measured. Overall time from departure, stay about 100 cm height, and landing was 698 time steps for ultrasonic sensor timer. The camera capture time was from 115 to 663 time steps, and 271 pictures were taken. It took two time steps to localization and it was slower than camera capture. It occurred because of not detecting a marker. If a marker was not detected, a camera did not capture a picture in this research. Top direction distance changes from 299 cm to 181 cm. Camera location z height was changed from 47 cm to 153 cm. Top distance was changed about 118 cm and z height was changed about 106 cm. Top distance could have an error because of leaning and sensors detection angle. While departure, there was a little rotation and went up straight. Localization time could be matched with distance data from sensors, and fusion data could produce the information about surroundings. For example, time steps from 115 to 154, the quadrocopter's rotation with y axis was between 6° and 13°, z axis is between -3° and 5°, and x axis was between 177° and 180°. The height was changed from 37 cm to 86 cm (Fig. 3.1). It went up about 48.64 cm. During



(a) (b)

Fig. 5 Height and top distance change according to time.

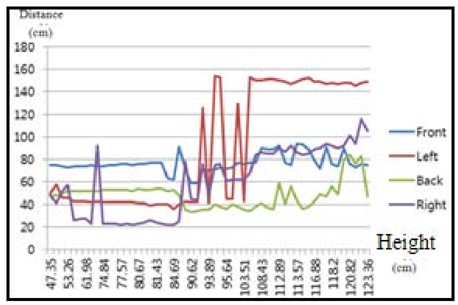


Fig. 6 Distance of horizontal ultrasonic sensors depend on height.

that time, z distance was changed to 44 cm. If height was increased, top sensor distance was decreased. Front sensor distance sustained from 74 cm to 77 cm until 148 time steps, than was changed to 62 cm. Left sensor distance stayed between 36 cm and 43 cm, excluding the early time. Back sensor distance also stayed between 48 cm and 53 cm. Right sensor distance stayed at near 50 cm and was changed to near 23 cm. Rotations for three axes were almost same during the experiment, so it could estimate the shape of four directions according to height (Fig. 6). The quadrocopter's lean angle and position is not considered in Fig. 6. About 90 cm, there was the change of distance. Next chair is far, so left distance increased much. Right chair back is blocked by other things with desk, so its distance increased little. Since lean angle and position of the quadrocopter was not considered in this time, it had huge error and was hard to know map of surroundings.

3.2 Mapping by Fusion

To measure the quadrocopter's location and leaning angle, the data should be filtered. If the rotation angle, x and y coordinate are the same, the distance data is measured from each parallel plane. By command and filter, the quadrocopter went

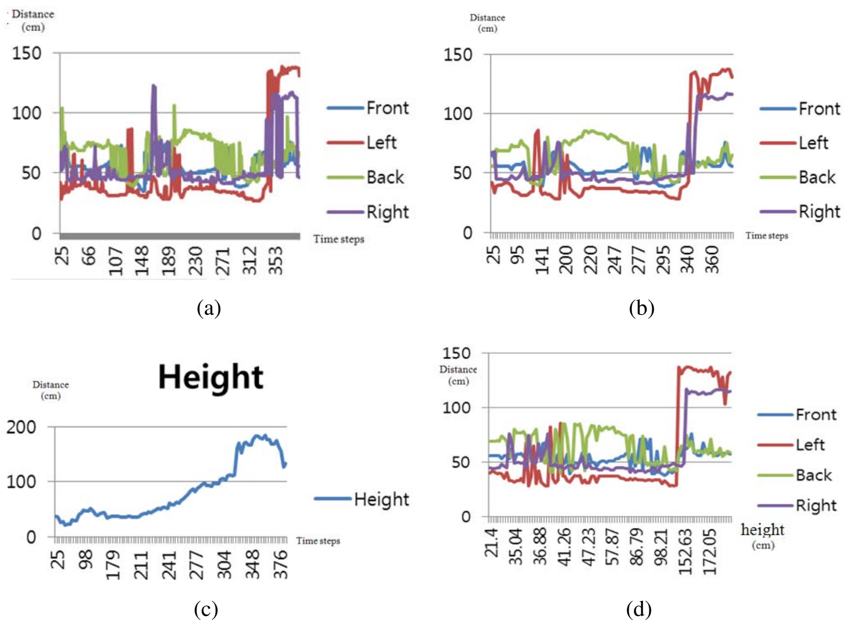


Fig. 7 (a) Distance of horizontal ultrasonic sensors depend on time. (b) Distance of horizontal ultrasonic sensors on time (filtered). (c) Height on time (Filtered). (d) Distance of horizontal ultrasonic sensors depend on height.

upward and downward with minimum rotation. In the second experiment, time step was from 0 to 427 time steps to ultrasonic sensors. The camera was started at 25 time steps, and finished at 391 time steps. 99 pictures were captured. Fig. 7(a) shows all distance of ultrasonic sensors with all time, and Figs. 7(b) and 7(c) show distance and height data depend on filtered time. If the quadrocopter leans too much, ultrasonic sensors data was excluded. Also, if marker was not recognized, that time also filtered. By comparing Figs. 7(c) and 7(d), sudden distance changes were reduced. Its data was depend on time, so it was not able to be used in map building. Fig. 7(d) shows us height changes, it goes up for a long time and go down later. These data and Fig. 7(c) data can be used as map building. This means that each height has four direction distance data, when quadrocopter goes up and down with stable.

Fig. 8 shows each side map according to height. In the front case, boxes and computer were located. Front distance was about 50 cm, and maintained. Height 90 cm to 110 cm was detected as desk, because this part had shorter distance. We can estimate desk is located about 100 cm as middle. In left part, almost data were about 40 cm until 112 cm. After that, book shelf was detected so distance was about 130 cm. Back part distance changed a lot. Its reason was that ultrasonic sensor detected the nearest distance of range, and back part was consisted of many objects. Because of these reasons, distance changed a lot, but we could see about 90 cm to 110 cm, it detected desk. Desk height is same as desk located in front. Right data shows chair

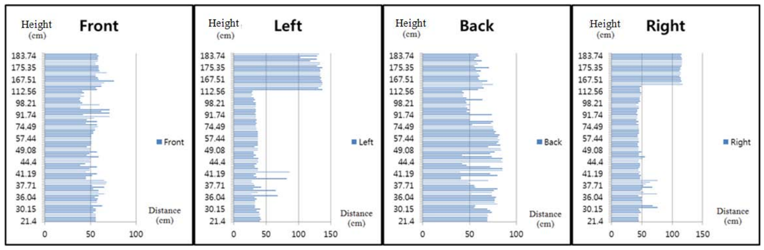


Fig. 8 Distance of horizontal ultrasonic sensors depend on height.

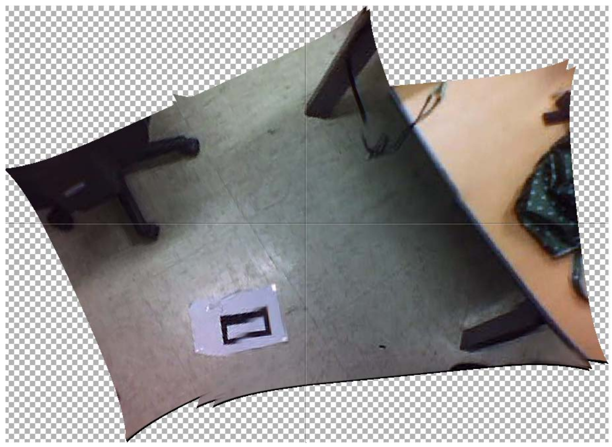


Fig. 9 Bottom image with panorama.

is disappeared range of sensor after height about 130 cm. Sensor detects shortest distance of detection range, so errors occurred like 30 cm to 40 cm shown.

Fig. 9 shows the bottom image such that the camera collected all images and made as one by using panorama. From these data, we could build a map about four directions, bottom and top. Four sides (front, left, back, right) map was made as well with some errors. From this experiment, the quadrocopter could measure all directions of distance including top direction. Computer could make a map of surroundings by these methods. The bottom side picture could be made as one by using panorama.

4 Conclusion

This paper proposed a map building method using a quadrocopter which was operated with additional equipments like an AVR controller, sensors and a zigbee. A hardware and software for controlling the quadrocopter along with localization were developed. In the experiment, a quadrocopter went up and down without rotation.

The bottom map was made by a camera sensor and four direction distance maps depend on heights were made by ultrasonic sensors and a camera sensor. With rotation, the whole map could be built by processing the saved data. If the autonomous movement of a quadrocopter is implemented and the efficient moving algorithm is provided along with this experimental result, a quadrocopter could be used in various fields of society with a cheap price.

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