Evaluating SLAM 2D and 3D Mappings of Indoor Structures

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Abstract –

This paper introduces a navigation algorithm of mobile indoor unmanned ground vehicle (UGV). The navigation methodology with AR markers is presented and demonstrated in detail. In the navigation algorithm, the mobile indoor UGV can make 2D or 3D map inside the structure. From the driving test, it has seen that the navigation algorithm with AR marker is essential to control the attitude of the UGV and drive autonomously. The proposed navigation algorithm is very important to drive UGV autonomously inside building.

Lastly, for investigating the capability of Simultaneous Localization and Mapping (SLAM) data, the 2D and 3D maps are evaluated by comparing to traditional survey and structure from motion (SfM). In conducting the map, slowing the speed of UGV affects the 2D map negatively, while it has positive impact in 3D mapping. Using visual SLAM with LiDAR makes 3D map very easily and rapidly as compared to SfM.

From these results, the proposed navigation algorithm and manufactured prototype UGV with the mapping device for 2D and 3D are useful for studying the inside buildings even in the developing countries.

Keywords –

SLAM; Visual SLAM; LiDAR; UGV; AR Marker

1 Introduction

Many research topical issues, about technologies in specific, which related to construction industry have only been discussed to some extent in the context of industrialized nations. Usually it is considered that these technologies do not matter the developing countries. This research paper addresses some of the issues about construction technologies from the perspective of developing countries in basic and industrialized countries as well. It starts with some construction and maintenance problems which usually seen as a concern of only developing countries, but also relevant to industrialized nations. It then proceeds to discuss the navigation of unmanned ground vehicle (UGV) and data collection for making 2D and 3D.

Construction problems can be discussed according to the existing situations. In general consideration some construction problems can be financial problems, lack of skilled man power, construction time delay, project management problems, human resource problems, technological problems etc.

The use of technologies has been limited only to the manufacturing industry. Recently the interest of using these technologies in construction industry growing. But this interest is limited to big companies which can afford these technology easily in any cost. Since construction industry is labor-intensive by nature, it is profitable to use technologies like robots [1]-[12].

Similar to the construction problems, there are also common maintenance problems of buildings. Some of these problems include: Lack of proper management, financial problems, lack of engineers or specialists, lack of human resource, lack of technologies etc. These problems can be defined in the same manner of construction problems. Many kinds of building maintenance has been discussed by researchers. This paper is more related to making 2D and 3D for maintenance which consists of elementary tasks (data collection, inspection, surveying, etc.) that needs brief training. So, these tasks can be held by ordinary people in the support of some technologies. Especially historical structures may not have proper design plan and it needs to collect data for preparing 2D or 3D plan.

In an effort to address the need for surveying and data collection, this paper introduces a navigation algorithm of mobile indoor UGV. The navigation methodology with AR markers is also presented and demonstrated. With the navigation algorithm, the mobile indoor UGV can make 2D or 3D map inside the structure. Lastly, for investigating the capability of SLAM data, the 2D and 3D maps will be evaluated by comparing to traditional survey and structure from motion (SfM).

2 Devices for 2D and 3D Mapping

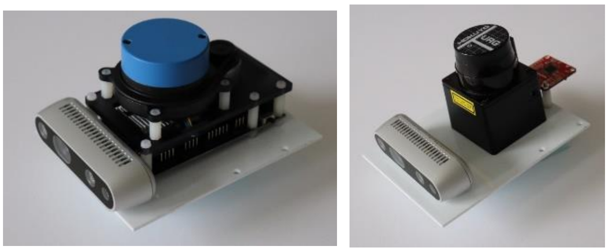
In this research, two types of the mapping device sets shown in Figure 1 are used. Each mapping device set consists of three elements: light detection and ranging (LiDAR), IMU and the depth camera. LiDAR is used for measuring the scale of the structure component and making the map. The IMU device provides the 3-axis accelerations, roll, pith, yaw and 3D orientations form the 3-axis accelerometer, gyro and magnetometer. To use these information, the ROS package estimates the 3D pose of the depth camera and the LiDAR. The mapping device with Slamtec mapper shown in Figure 1(a) utilizes IMU inside Slamtec Mapper [13], [14]. Using URG-04LX shown in Figure 1(b) employs 9DOF Razor IMU. The depth camera is used to obtain 3D information, which are image, distance and point could data. Both devices employ the RealSense Depth Camera D435i. Properties of D435i is shown in Table 1. LiDARs used in this research are Hokuyo URG-04LX UG01 and Slamtec mapper. The characteristics of LiDARs are shown in Table 2.

For making 2D map, Simultaneous Localization and Mapping (SLAM) algorithm is utilized. Many kinds of SLAM algorithms are developed by many robotics researchers. Many of these SLAM algorithms need the wheel odometry information, which means the velocity of wheel, the motor speed and so on. Inside of the building, there are various friction and load conditions on the floor surface. So, it is difficult to implement the wheel odometry information to the SLAM algorithm. Based on this fact, SLAM algorithms which do not require wheel odometry information to conduct map are used in this research paper. For mapping device with Slamtec mapper shown in Figure 1 (a), the 2D SLAM algorithm produced by Slamtec is employed. SLAM algorithm of Slamtec mapper uses IMU information inside the device and not need the wheel odometry. For the other device with URG-04LX, the Hector slam [15], [16] is used with the 9DoF Razor IMU. For conducting map by using Hector slam, the Odometry information is not necessary.

To conduct 3D map of the point cloud data, Rtabmap [17]-[19], which is one of the visual SLAM, is employed for both devices. To make the point cloud data, Rtabmap uses the 3D pose information of the depth camera calculated by 2D SLAM using Slamtec mapper or URG-04LX. For estimating the accuracy and the usefulness, SfM using Agisoft Metashape is also used. For SfM, the photographs are taken with Cannon camera. Its properties are shown in Table 3.

3 Results of 2D and 3D Mapping

To measure and determine the scale and layout of the structural components and openings, demonstration for



(a) With Slamtec Mapper (b) With URG-04LX
Figure 1. Mapping Devices

Table 1. Properties of Depth Camera

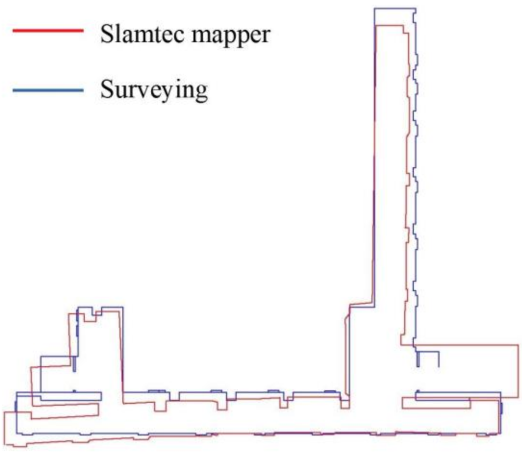
Left/Right Imager Type	Wide
Depth FOV HD (degrees)	H:87±3 / V:58±1 / D:95±3
Depth FOV VGA (degrees)	H:75±3 / V:62±1 / D:89±3
IR Projector	Wide
IR Projector FOV	H:90 /V:63 / D:99
Color Camera FOV	H:69±1 / V:42±1 / D:77±3
IMU	6DoF

Table 2. Characteristics of LiDARs

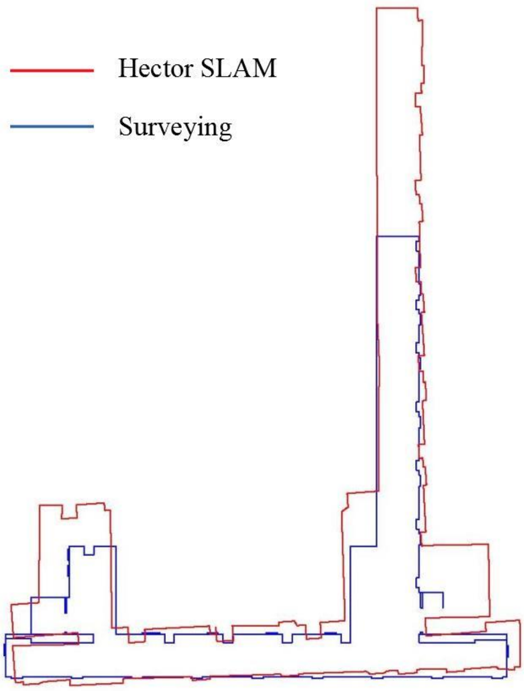
	Slamtec Mapper	URG-04LX-UG01
Distance Range	20m	4m
Smaple Rate	7k Hz	10Hz
Resolution	5cm	1mm
IMU	9DoF	-
Max Mapping Area	300m×300m	-
Re-localization Accuracy	< 0.02m	-

Table. 3

Image quality	Image size in pixel	ISO sensitivity
NEF(RAW) JPGE normal	6000x4000	100



(a) Slamtec Mapper



(b) Hcetor SLAM with IMU

Figure 2. 2D Mapping made by SLAM

2D and 3D mapping were carried out within the buildings of Ashikaga University. The mappings were performed in passer-free environments.

Firstly, 2D maps utilized SLAM are evaluated by comparing to traditional survey results for investigating the accuracy of the 2D mapping. The compared results for Slamtec mapper is shown in Figure 2 (a) and Hector SLAM with URG-04LX and IMU is shown Figure 2(b). Figure 3 shows the result of Slamtec mapper with different moving speeds. From Figure 3 it is clear that the

(a) Slow speed

(b) Suitable Speed

Figure 3. Slamtec Mapper with different speed

Slamtec mapper with slow speed can not specify the location and shape of columns. Throughout the experiment results, the accuracy of 2D mapping depends on moving speed of mapping device. Slow speeds are not good for creating 2D map, but 3D mapping needs slow speed. And the length of the corridor is difficult to measure, because the corridor generally has few features. From Figure 2, Slamtec mapper can estimate the length of corridor and gives more accuracy on 2D mapping compared with Hector SLAM. The length using Slamtec mapper is about 0.96 times of actual, and using Hector SLAM is about 1.51 times.

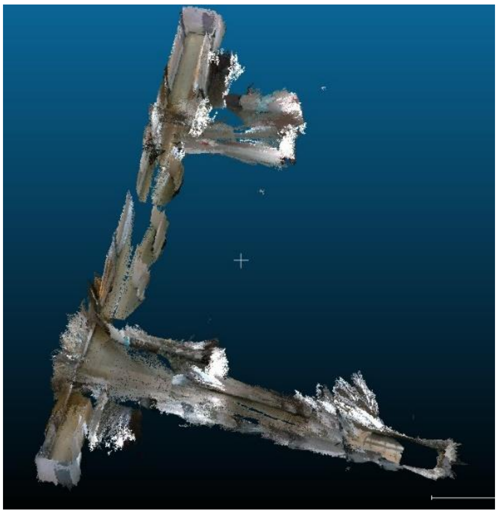
Next, 3D mappings utilized by Rtabmap, which is one of the visual SLAM, are evaluated. The 3D results of Rtabmap are shown in Figure 4. And Figure 5 shows the projection maps of Rtabmap. In Figure 5, the projection maps using Hector SLAM and using the depth camera only estimated the length of corridor in lateral direction longer than actual length. The estimated length using Slamtec mapper is almost same as actual length. From these facts, 3D mapping using SLAM data are more accurate compared with the result using the depth camera only. And scale of 3D mappings using Slamtec mapper creates more accurate than using Hector SLAM. From these results, the pose information of UGV from 2D SLAM is important in making 3D mappings. Comparing to SfM, Rtabmap makes it easy to create an entire 3D layout inside building. But, SfM can provide more detailed 3D mapping.

From these results, SLAM and visual SLAM with mapping devices easily makes 2D and 3D mapping compared with traditional methodologies.

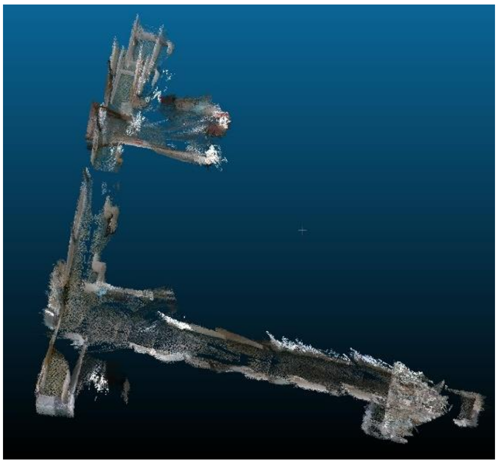
4 Navigation Algorithm

Inside the building, the navigation algorithm can not use the GPS signal. Even it is difficult to use the navigation tool of SLAM as the layout of the building is

(a) RealSense Depth Camera D435i only

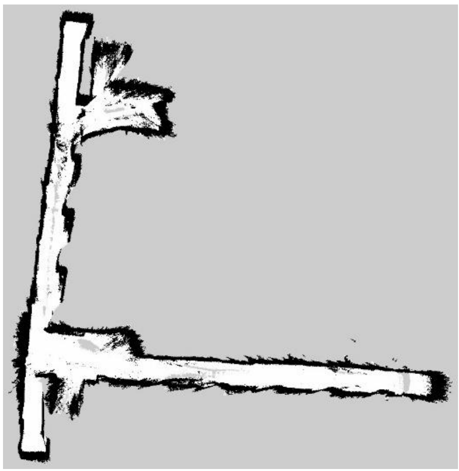


(b) D435i with Slamtec mapper

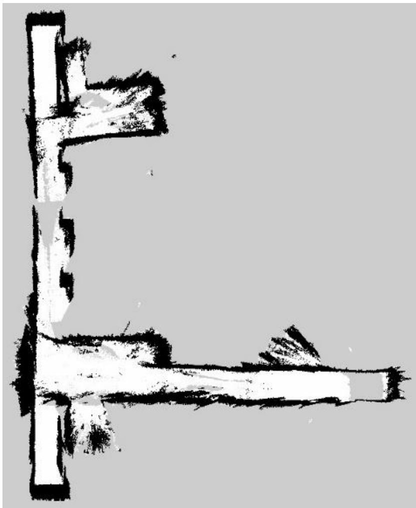


(c) D435i with Hector SLAM

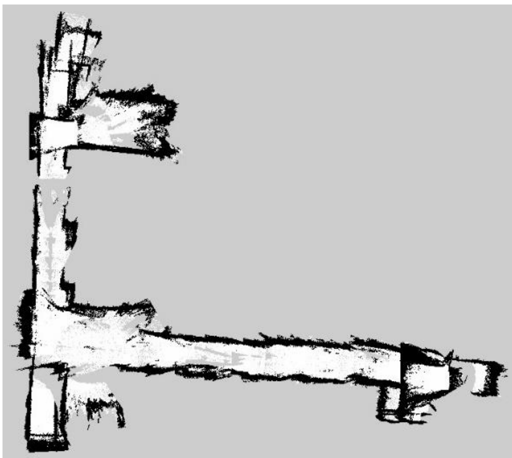
Figure 4. 3D Mapping conducted by Rtabmap



(a) RealSense Depth Camera D435i only



(b) D435i with Slamtec mapper



(c) D435i with Hector SLAM

Figure 5. Projection Mapping of Rtabmap

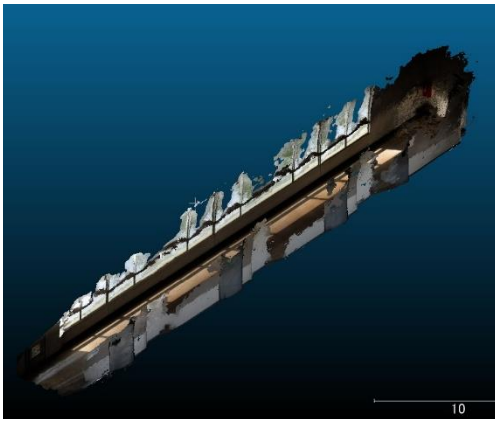


Figure 6. Result of SfM

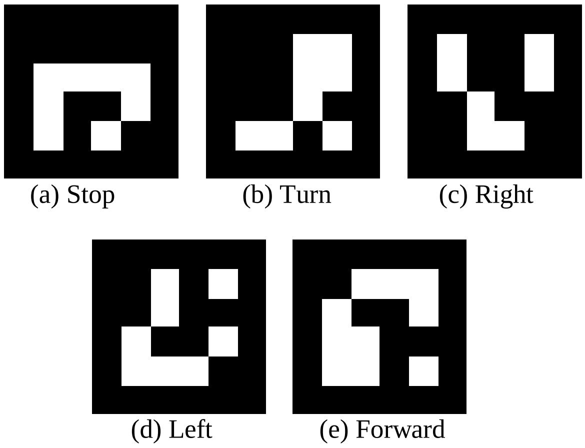


Figure 7. AR Marker

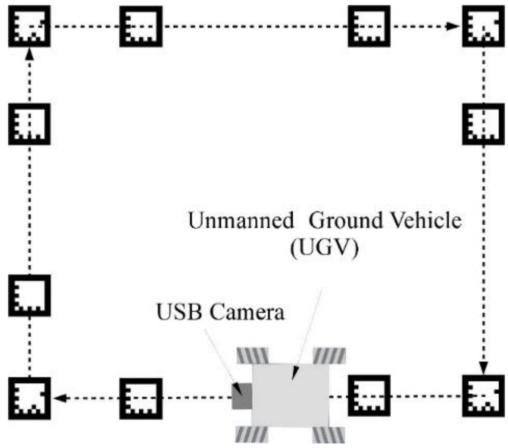


Figure 8. Navigation Algorithm using AR Marker

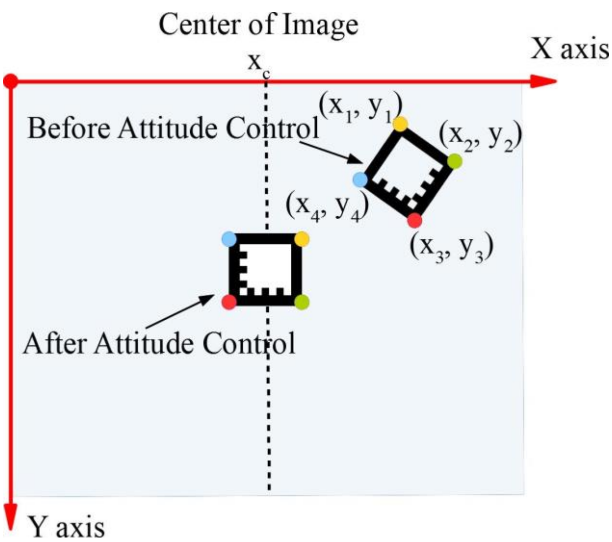


Figure 9. Schematic Figure for Attitude Control

changing frequently. Hence, it can be understood that developing navigation algorithm without the use GPS and the navigation tool of the SLAM is needed [20]-[23]. This paper propose the navigation algorithm that utilizes AR markers on the floor. AR markers are used for two purposes. One is attitude control of UGV and the other is command to the robot, which are “turn” and “stop”. The used AR markers are shown in Figure 7. The schematic figure of navigation algorithm with AR markers is shown in Figure 8. In this proposed navigation algorithm, the size of x axis coordinate and angle of AR marker in the image are important for attitude control and command. The size of AR marker in the image is measured by using Eq.(1).

$$L = 0.5 \times (x_2 - x_1 + x_3 - x_4) \quad (1)$$

in which (x_1, y_1) = coordinates of upper left corner; (x_2, y_2) = coordinates of upper right corner; (x_3, y_3) = coordinates of lower right corner; (x_4, y_4) = coordinates of lower left corner. And the x axis coordinate, x_M, and angle, y_{dif}, of AR maker is detected from Eq.(2).

$$x_M = 0.25 \times (x_1 + x_2 + x_3 + x_4) \quad (2)$$

$$y_{dif} = 0.5 \times (y_1 + y_4) - 0.5 \times (y_2 + y_3) \quad (3)$$

The need of controlling the attitude of the UGV is to keep AR marker at the middle of the camera view and parallel to the X-axis. The concept of the attitude control of UGV is shown schematically in Figure 9 and 10. When Eq.(4) is satisfied,UGV will firstly move in horizontal direction to satisfy Eq.(5). Eq.(4) indicates the range of the control.

$$L > \gamma \quad (4)$$

$$|x_c - x_M| \leq \alpha \quad (5)$$

in which x_c = center X-axis coordinate in the image; γ=threshold value of AR marker size; α = threshold value. If $x_c - x_M$ is the positive value, UGV moves to

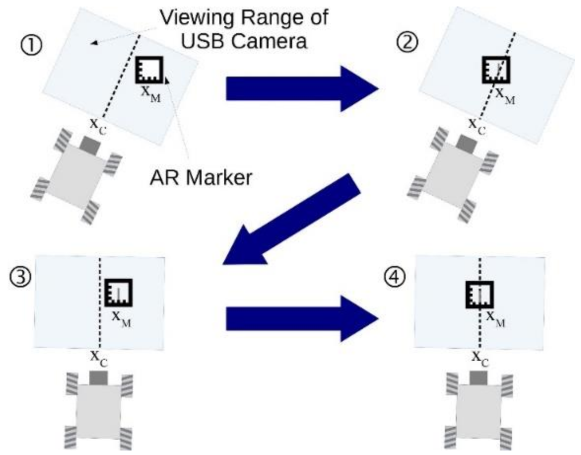


Figure 10. Attitude Control Utilizing AR Marker

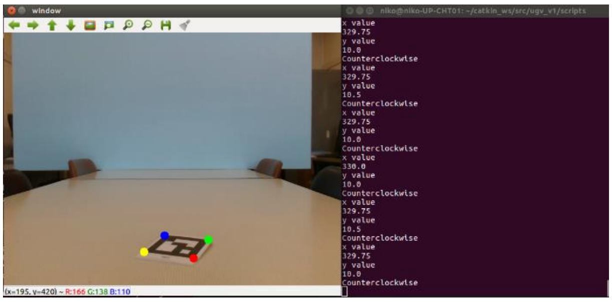
the right direction. If $x_c - x_M$ is the negative value, UGV moves to the left direction. Next, when Eq.(4) is satisfied, UGV will rotates so as to satisfy Eq. (6).

$$|y_{dif}| < \beta \quad (6)$$

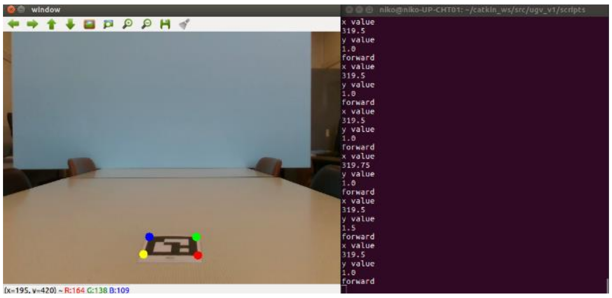
in which β = threshold value. If y_{dif} is the negative value, UGV turns to counter clockwise. If y_{dif} is the positive value, UGV turns to clockwise.

For command control, four different AR markers are used for ordering "Stop", "Right Turn", "Left Turn" and "Turning with 180 degrees". In this control, UGV is commanded when Eq.(4) is satisfied.

To investigate the capability of the proposed navigation algorithm, AR maker detecting tests are conducted. In Figure 11, UGV detects the AR marker and controls the attitude of UGV. After the attitude control, UGV is ordered to move "Forward". In Figure 12, AR maker commands UGV to turn the "Right".

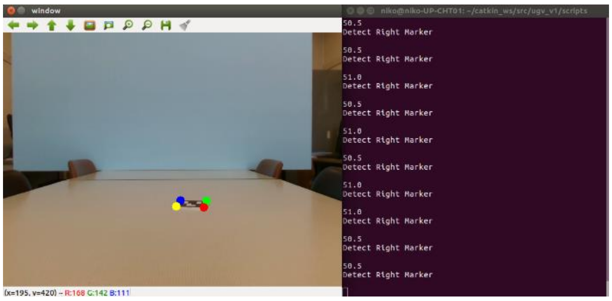


(a) Turning in attitude control

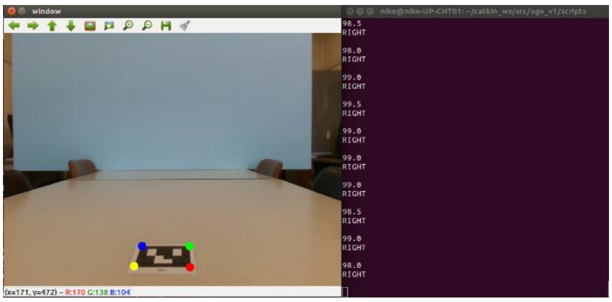


(b) Forward moving

Figure 11. Detecting AR Marker in Attitude Control



(a) Out of Range

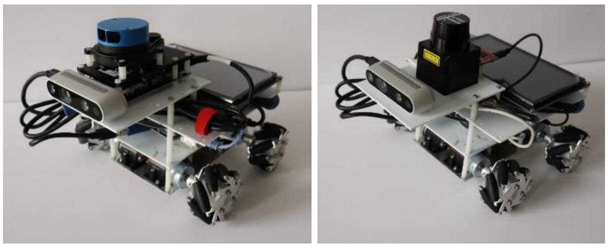


(b) Right Turn

Figure 12. Command Control

5 Prototype of UGV for Mapping

From the results of Section 2 and 3, two prototypes of the small UGV with SLAM function is manufactured for measuring and determining the scale and layout of the inside building components. Manufactured UGVs are shown in Figure 13. The main components of the prototype UGVs are: UP board, Arduino board, the mecanum wheels, Intel Realsense camera D435i, which is depth camera and LCDpanel. UGV shown in Figure 13(a) employs the Slamtec Mapper as LiDAR and IMU device. In Figure 13(b), URG-04LX is used as LiDAR while as 9DOF Razor IMU is used for measuring the pose of the UGV. The UP board with the Intel x86 processor has the higher performance of the calculation than the Raspberry pi, which is one of the famous small Linux computers. The UP board is installed "ROS", that is useful robot OS. On the "ROS", two kinds of program are running. The first one is the proposed navigation algorithm to detect and follow AR markers. The second one is 2D and 3D SLAM algorithm for measuring the scale of the structure components. Arduino board controls the motors of UGV depending on the control signal from the UP board. For moving in any direction,



(a) With Slamtec Mapper (b) With URG-04LX

Figure 13. Two Prototypes of UGV for Mapping

the UGV uses the mecanum wheel. Although, mecanum wheel is better to adjust the attitude of the UGV easily for setting the measured location. The total cost of the UGV components is about $2,500, which can be reasonable for developing countries to afford.

6 Conclusion

To measure and determine the scale and layout of the inside buildings, this paper introduces a navigation algorithm of UGV and manufactures the prototypes UGV for 2D and 3D mapping.

Firstly, to evaluate the accuracy and usefulness of the 2D and 3D mapping conducted by two type of the mapping device, the 2D and 3D mapping results of the mapping devices are compared with traditional surveying and SfM. In conducting the maps, the speed of UGV has significant influence in making 2D and 3D maps. Slamtec mapper can estimate the length of corridor and create more accurate 2D and 3D maps as compared with Hector SLAM. Using Rtabmap with LiDAR is easy way to make 3D map as compared to SfM method.

Secondly, the navigation algorithm utilizing AR markers is proposed. From the demonstration tests, AR markers in the navigation algorithm are used to control the attitude of the UGV and drive autonomously. The proposed navigation algorithm is very useful to drive the UGV autonomously inside the buildings.

Finally, the prototype of UGVs with two kinds of mapping devices are manufactured for measuring and determining the scale and layout of the inside buildings. The approximate cost of the UGV components is around $2,500, which is reasonable cost for developing countries

From the discussion of the research results, it can be conclude that the proposed navigation algorithm and manufactured UGV prototype with the mapping device can be used for studying inside buildings in the developing countries as well.

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