Development of Autonomous Mobile Field Robot
– Accuracy Verification of Self-Localization through Simulation -

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Abstract

In recent years, the increase in marine debris has become a significant challenge in terms of its collection. Costal debris, a type of marine debris, can be collected by human hands, but the variety in shapes, and sizes presents limitations to human-only collection efforts. To address this, I focused on developing an autonomous mobile robot, establishing a simulation environment was considered crucial for facilitating smooth progress. This paper focuses on self-localization, an essential aspect for autonomous movement. We replicated an actual coastal cleaning site within the simulation environment and evaluated the accuracy of self-localization using an EKF (Extended Kalman Filter) with multiple sensors.

Keywords: Field Robot, Self-Localization, Gazebo, Simulation, Extended Kalman Filter (EKF)

1. Introduction

In recent years, the increase in marine debris has become a significant challenge in terms of its collection. Costal debris, a type of marine debris, can be collected by human hands, but the variety in shapes, and sizes presents limitations to human-only collection efforts. To address this, we focused on developing an autonomous mobile robot, establishing a simulation environment was considered crucial for facilitating smooth progress. This paper focuses on self-localization, an essential aspect for autonomous movement. We replicated an actual costal cleaning site within the simulation environment and evaluated the accuracy of self-localization.

2. Autonomous Mobile Field Robot "BUNKER"

In our previous study, we developed an autonomous mobile field robot [1] based on Kawasaki Heavy Industries' KFX®90, an all-terrain vehicle (ATV) powered by a gasoline engine. However, due to the vehicle's structure, the turning radius was large and stable traveling on steep slopes and rocky terrain was difficult, among other problems. To solve these problems, the platform was changed. The new platform uses Agilex's BUNKER [2] as shown in Figure 1. The main changes to the platform are that the traveling mechanism has two opposing wheels and the drive wheels are crawlers. This enables the platform to make super-clever turns, improving maneuverability composed to conventional platforms. In addition, the robot can climb hills with a slope angle of 36°, which is expected to enable it to run at higher speeds. The robot is equipped with an RGB-D sensor and 3D LiDAR as a visual system for autonomy. An encoder is mounted inside the vehicle body to measure the rotation speed of the wheels.

a. KFX®90 b.BUNKER

Fig. 1. Platform Overview

2.1. *Simulation Construction*

In this study, we not only represented the Agilex BUNKER in the simulation environment but also recreated the coast of Hokuto Mizukumi Park in Munakata City, Fukuoka Prefecture, where actual beach cleaning is performed. We used 3D mapping technology developed by prior research using drones. For the simulation environment, we employed Gazebo, a 3D dynamic simulator capable of efficiently and accurately simulating groups of robots in complex indoor and outdoor environments. Gazebo can also be integrated with ROS (Robot Operating System) [3]. The projected BUNKER and the coast on Gazebo are shown in Figure 2.

a. BUNKER b. coast

Fig. 2. Built simulation environment

2.2. *EKF-Based Self-Localization System*

The posture measurement of mobile robots is achieved through various sensors and methods. However, the measurements obtained from these sensors are not true values but are considered to contain errors. In this study, we implemented the integration of odometry using the Extended Kalman Filter (EKF) shown in Figure 3, to achieve robust and low-error self-localization. We used wheel odometry, RGB-D odometry, and LiDAR odometry. The system was designed to accept any of these, individually or in combination, and produce an integrated odometry output.

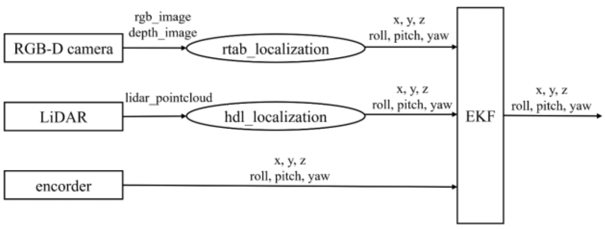


Fig. 3. Input/output data to/from EKF

3. Experiment

In the coastal environments shown in Figure 4 and Figure 5, the initial position of the robot was set as the origin of spatial coordinates, and from there, three destinations were set at (40, -5), (40, 0), (40, 5). The robot was remotely operated to each destination five times to extract the necessary odometry information. For self-localization, both individual odometries and multiple odometries integrated via EKF were implemented, resulting in seven estimation patterns. Mean Absolute Error (MAE) was used for error calculation.

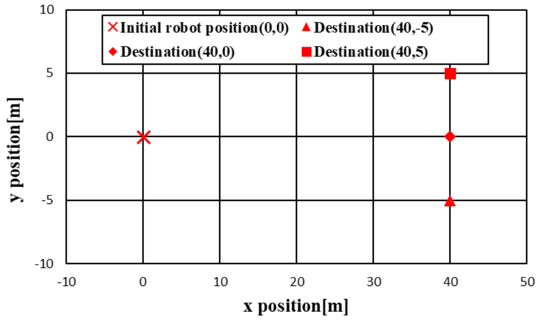
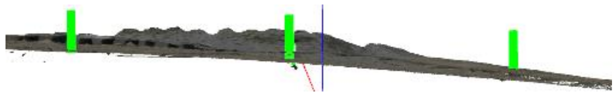
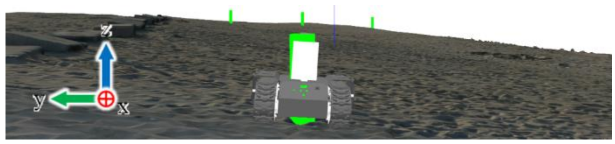


Fig. 4. Test environment



a. Coastal cross section



b. View from initial position

Fig. 5. Experiment in a simulation environment

3.1. *Result*

Table 1 summarizes the errors in self-localization results in the x-axis direction. In Pattern 4, the error was minimal, with the odometry integrating wheel odometry and RGB-D odometry via EKF achieving the highest accuracy in self-localization. Additionally, focusing on Pattern 2, the RGB-D odometry alone also showed generally similar values. From Pattern 3, it was observed that the LiDAR had an error of about 20 m, indicating it was not very useful in the simulated environment replicating an actual beach.

Table 1. Error in Self-Localization along the X-axis [m]

	Wheel	RGB-D	LiDAR	(40,5)	(40,0)	(40,-5)
1	○			11.06	1.22	0.35
2		○		0.08	1.06	1.44
3			○	21.66	25.25	19.50
4	○	○		0.85	0.47	0.86
5	○		○	13.73	5.42	4.47
6		○	○	10.36	10.07	8.27
7	○	○	○	3.20	4.33	5.54

Table 2 summarizes the errors in self-localization results in the y-axis direction. Compared to the results in the x-axis direction, there were significantly larger discrepancies overall. In every pattern, high-accuracy self-localization was not achieved. While some input destinations yielded accurate results, a stable trend was not observed. Among them, the odometry that integrated wheel odometry and RGB-D odometry via EKF had the smallest error.

Table 2. Error in Self-Localization along the X-axis [m]

	Wheel	RGB-D	LiDAR	(40,5)	(40,0)	(40,-5)
1	○			17.90	3.71	1.17
2		○		2.35	12.93	6.09
3			○	15.11	19.68	13.11
4	○	○		2.49	12.68	5.44
5	○		○	14.60	3.14	4.13
6		○	○	7.30	13.64	3.94
7	○	○	○	2.96	12.50	5.28

3.2. *Consideration*

Throughout this experiment, RGB-D odometry was found to have an error and greatly contributed to the improvement of self-localization accuracy. However, the accuracy of LiDAR odometry was considerably low in coastal environments like those in this study, lacking distinct landmarks for reference. The experimental environment featured a slope descending to the right from the travel direction, as depicted in Figure 5, leading to vehicular lateral skidding, which mainly affected y-axis self-localization. The introduction of an Inertial Measurement Unit (IMU) is proposed as a solution for more accurate vehicle posture determination, with prior research suggesting its substantial utility in enhancing results.

4. Conclusion

In this study, we developed a simulation environment for an autonomous mobile field robot and conducted accuracy verification of self-localization. As a result, odometry that integrated wheel odometry and RGB-D odometry using RGB-D and EKF was found to achieve more accurate self-localization. In the future, we aim to improve the accuracy of self-localization by adding an IMU. we will also conduct verification on sandy beaches different from those in this study.

References

1. Ayumu Tominaga, Akihiro Koubara, Ryusuke Fujisawa, Eiji Hayashi, Abbe Mowshowitz. Development of lidar based navigation system for automation of tree harvesting process, Proceedings of International Conference on Artificial Life and Robotics 2021, pp. 469-471
2. BUNKER-Agilex Robotics
3. ROS, Open Robotics

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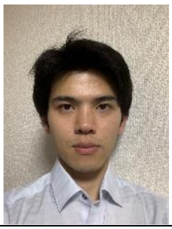

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