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Research Article

Engineering of Autonomous Mobile Field Robot -Validating Precision in Self-Localization via Simulation-

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ABSTRACT

In recent times, the escalation of marine debris has emerged as a formidable challenge, particularly in its retrieval. Among this, coastal debris, which falls under the broader category of marine debris, can indeed be manually picked up, yet the diversity in its forms and sizes limits the efficiency of solely human retrieval efforts. In response to this issue, my research concentrated on the development of an autonomous mobile robot. This study zeroes in on the critical task of self-localization, a fundamental requirement for autonomous navigation. Within our simulation, we meticulously recreated a real-world coastal cleanup site and assessed the self-localization precision utilizing an Extended Kalman Filter (EKF) alongside various sensors.

1. Introduction

In recent years, the amount of marine debris has increased, posing a challenge in terms of its recovery. Coastal drift debris, a type of marine debris, can be picked up by human hands; however, due to the diverse shapes, types, and sizes of the debris, there are limitations to recovery efforts relying solely on human labor. Nevertheless, entrusting the collection of debris entirely to robots presents technical difficulties and incurs significant costs. Therefore, we focused on engineering an autonomous mobile field robot capable of collecting coastal drift debris gathered by humans. In developing the robot, we first created a simulation environment to facilitate smooth progress in the development process. In this study, we concentrated on self-localization, which is crucial for autonomous movement, by replicating an actual beach cleaning site within the simulation environment and evaluating the accuracy of self-localization.

2. Autonomous Mobile Field Robot “BUNKER”

In our earlier research, we engineered an autonomous mobile field robot [1], utilizing the Kawasaki Heavy Industries' KFX®90, a gasoline-powered all-terrain vehicle (ATV), as its base. Nonetheless, the original vehicle's design imposed limitations, including a wide turning radius and challenges in stable maneuverability across steep inclines and rugged terrains, among others. Addressing these issues led to a platform transition. The updated platform incorporates Agilex's BUNKER [2] , as depicted in Fig. 1. Key modifications include a dual-opposite wheel travel mechanism and crawler drive wheels, significantly enhancing its ability to execute extremely tight turns and surpass the maneuverability of traditional platforms. Moreover, the robot is now capable of ascending hills with a 36° incline, potentially allowing for greater speeds. For autonomous navigation, the robot is outfitted with an RGB-D sensor and 3D LiDAR within its visual system, and it houses an encoder in the vehicle's body to track wheel rotation speeds.

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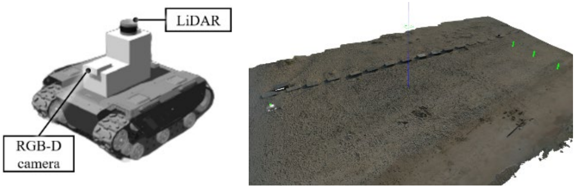
a. KFX®90 b. BUNKER

Fig. 1. Platform Appearance

2.1. *Simulation Environment Construction*

In our research, we successfully simulated the Agilex BUNKER within a virtual environment, alongside an accurate reproduction of Hokuto Mizukumi Park's coastline in Munakata City, Fukuoka Prefecture, a site of actual beach cleanup efforts. This was achieved using advanced 3D mapping technologies from previous studies, which utilized drones. For the simulation platform, we chose Gazebo, a robust 3D dynamic simulator that specializes in the realistic and precise simulation of robot groups in varied settings, both indoor and outdoor. Furthermore, Gazebo offers seamless integration with the Robot Operating System (ROS) [3]. Illustrations of the simulated BUNKER and the coastal area on Gazebo are presented in Fig. 2.



a. BUNKER b. Coast

Fig. 2. Constructed simulation environment

2.2. *Self-Localization System Utilizing EKF*

The measurement of a mobile robot's posture is conducted using a range of sensors and techniques. Nonetheless, the data collected from these sensors is not exact and is believed to include discrepancies. In this research, we utilized the Extended Kalman Filter (EKF), as depicted in Fig. 3, for the integration of odometry data to ensure a sturdy and minimal-error self-localization process. Our system incorporated wheel odometry, RGB-D odometry, and LiDAR odometry, either singularly or in amalgamation, to generate a consolidated odometry output.

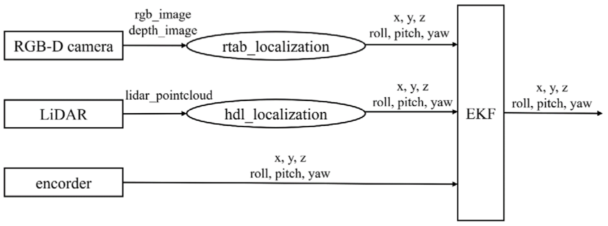


Fig. 3. Data fed into and retrieved from EKF

3. Experiment

In the coastal settings illustrated in Fig. 4 and Fig. 5, we designated the robot's initial location as the coordinate system's origin, setting three target points at coordinates (40, -5), (40, 0), and (40, 5). The robot was remotely guided to each of these points five times to gather essential odometry data. For the purpose of self-localization, we applied both singular odometry techniques and a combination of multiple odometries through the Extended Kalman Filter (EKF), leading to a total of seven distinct estimation approaches. To compute the accuracy of these estimations, we employed the Mean Absolute Error (MAE) metric.

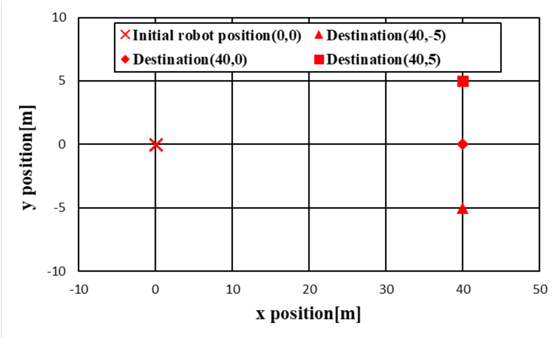
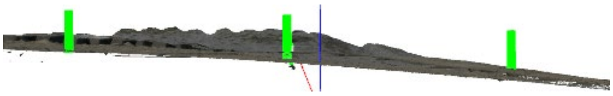
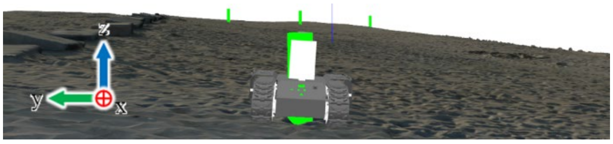


Fig. 4. Testing setup



a. Seashore cross-sectional view



b. Perspective from starting point

Fig. 5. Experiment Environment

3.1. *Result*

Table 1 presents a summary of the self-localization errors along the x-axis. The most accurate results were observed in Pattern 4, where the integration of wheel odometry and RGB-D odometry through the Extended Kalman Filter (EKF) resulted in the lowest error rates for self-localization. Moreover, an analysis of Pattern 2 reveals that using only RGB-D odometry yielded comparably effective values. However, in Pattern 3, it was noted that the LiDAR-based approach experienced an error margin of approximately 20 meters, suggesting its limited utility in the beach simulation environment that mimics a real coastal setting.

Table 1. X-axis Self-Localization Error Analysis[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 outlines the discrepancies found in the self-localization accuracy along the y-axis. These discrepancies were markedly larger than those observed in the x-axis direction, indicating a broader variance in accuracy across all patterns. A consistent high level of self-localization precision was not realized in any of the patterns. Although certain input destinations produced precise outcomes, there was no stable pattern of accuracy. Within these variations, the odometry method combining wheel odometry with RGB-D odometry through the Extended Kalman Filter (EKF) recorded the minimal error.

Table 2. Y-axis Self-Localization Error Analysis[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*

In this study, it was observed that RGB-D odometry exhibited some errors but significantly enhanced the precision of self-localization. Conversely, LiDAR odometry's accuracy was notably poor in coastal settings such as those examined here, primarily due to the absence of clear landmarks for orientation. The experimental setup included a slope that declined towards the right of the travel path, as shown in Fig. 5, causing the vehicle to experience lateral slippage that predominantly impacted the accuracy of self-localization on the y-axis. To address this issue, we suggest the incorporation of an Inertial Measurement Unit (IMU) to improve the determination of the vehicle's posture. Previous studies have indicated the IMU's considerable potential in improving accuracy. It is also necessary to set the friction coefficient to reproduce a more realistic environment in the simulation.

4. Conclusion

In our research, we initially crafted a simulation environment for crafting an autonomous field robot. Within this environment, we evaluated the precision of self-localization techniques. Our findings demonstrated that a combined odometry approach, merging wheel odometry with RGB-D odometry via RGB-D sensors and the Extended Kalman Filter (EKF), facilitated more accurate self-positioning. Conversely, LiDAR-based odometry was found to be less effective in coastal scenarios characterized by a lack of distinct landmarks, such as those examined in our study.

Looking ahead, our strategy includes the integration of an Inertial Measurement Unit (IMU) to further refine self-localization accuracy. Beyond just improving self-localization, we're set to incrementally introduce map creation and route planning capabilities, crucial for autonomous movement. In particular, by predefining waterfronts and rocky areas as non-navigable zones, we believe that efficient route generation can be achieved. Additionally, we aim to extend our testing to encomp ass more demanding settings, like sandy beaches, z towards integrating these advancements with actual robot systems.

References

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2. BUNKER-Agilex Robotics
3. ROS, Open Robotics

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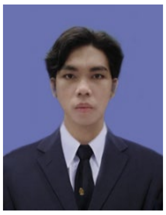

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