Team Description Paper: BabyTigers - R 2023

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Abstract. This paper introduces BabyTigers-R, a team from the Uemura Laboratory at Ryukoku University that focuses on research related to autonomous mobile robots and visible light communication. With the increasing importance of collaborative autonomous mobile robots and the shift towards high-mix low-volume production in factories, the team's research is focused on identifying processing machines, measuring the environment, and avoiding collisions. Section 2 discusses the team's research on identifying modular production systems, Section 3 presents research on 3D measurement using 2D range sensors on mobile robots, and Section 4 outlines a study on how autonomous mobile robots can pass each other. This paper concludes with a summary of the team's work.

Keywords: Logistics League, RoboCup, BabyTigers - R, robotino

1 Introduction

This paper describes BabyTigers-R[1, 2], a team composed of members who belong to the Uemura Laboratory in the Department of Electronic Information, Faculty of Science and Technology, Ryukoku University. Our laboratory researches autonomous mobile robots and visible light communication. Collaborative autonomous mobile robots are considered important. In addition, the mode of production in factories is changing from low-mix mass production to high-mix low-volume production. Our research focuses on identifying processing machines, measuring the environment for autonomous mobile robots, and collision avoidance. Section 2 describes research on identifying modular production systems, Section 3 describes research on 3D measurement using 2D range sensors on mobile robots, Section 4 describes a study on how autonomous mobile robots can pass each other, and finally, the conclusion of this paper is presented.

2 Identifying Modular Production Systems

2.1 Introduction

Factories are shifting to high-mix low-volume production, which requires flexible arrangement of processing machines. Autonomous mobile robots transport parts and products between processing machines, requiring accurate identification of the machine type. Processing machines are constructed in units of modules such as belt conveyors and arms, and contain flexible materials such as cables and wires. In order to identify the type of processing machine, there are methods of object detection using a monocular camera and point cloud matching using a stereo camera. Processing machines can be identified by looking at the entire machine captured by a camera, or by detecting each module and identifying the machine where it is located. However, flexible materials like wiring and modules increase the risk of misidentifying the machine type. In this research, we propose to solve this problem by using the number of points in a rectangular parallelepiped that covers the position of the module mounted on the processing machine.

2.2 Proposed method

Flexible materials, such as wiring and other modules mounted on the processing machine, can make it challenging to accurately identify the machine. As a result, misidentification is possible. Even if the same module is used, it may have different wiring patterns. Therefore, if it is identified simply by matching, it may be misidentified as a different module. On the other hand, the wiring in the connector part has a similar shape, providing a high degree of freedom between connectors. However, since the volume of modules does not change significantly, the number of point clouds obtained from measurements is almost the same. Moreover, the appearance and number of point clouds differ depending on the placement of the modules when multiple modules are installed in a processing machine. To prevent misrecognition of modules and misidentification of processing machines, we propose to count the number of points within a rectangular parallelepiped covering the position of the module mounted on the processing machine. During actual identification, the presence or absence of each module is determined by comparing the number of points within the measured position. Subsequently, for each processing machine, the number of modules determined to have a large number of points is counted, and the processing machine is identified.

2.3 Experiment

In order to evaluate whether the proposed method can respond flexibly to changes in the position of flexible materials, we evaluated the accuracy of machine identification and the time required for detection. For comparison, we used point-to-point ICP, which is one of the object detection methods using a stereo camera. However, if the point cloud data is used as it is, it takes a long time to process. We identified a processing machine with a degree of matching of 90% or higher as the correct identification. In addition, it was found that two or more items had a matching degree of 90% or more, making them indistinguishable. For evaluating the proposed method, we took 80 shots of each processing machine using a stereo camera, and used the obtained 3D point cloud data with voxel

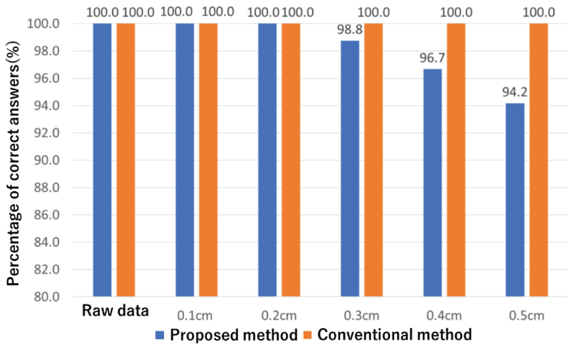

Fig. 1. Accuracy rate of machine identification

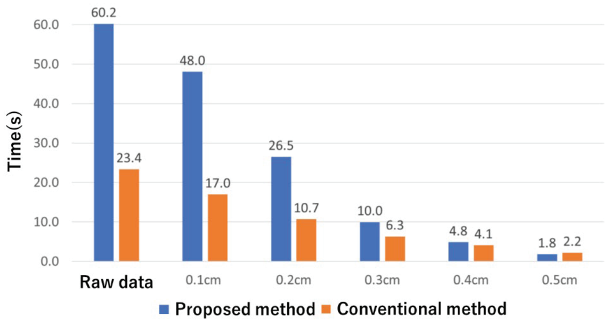

Fig. 2. The time it takes to identify the machining machine

sizes of 0.1 cm, 0.2 cm, 0.3 cm, 0.4 cm, and 0.5 cm. We compared the average rate of correct identification and the average time it took to identify using the proposed method in 1. Figure 1 shows the average rate of correct identification when MPS is used, and Figure 2 shows the average time required for identification. From the experimental results, it was possible to increase the percentage of correct answers using downsampled data with almost the same identification time as the conventional method. We also tried using raw data that had not been downsampled, but found that the proposed method also takes time. However, we found that it takes about one-third of the time of the conventional method.

2.4 Conclusion

This method is useful because it improves the correct answer rate while obtaining the same accuracy, reducing the time required for identification, or achieving the same result.

3 Improving 3D Measurement Accuracy on Mobile Robots using 2D Range Sensors

3.1 Introduction

When a mobile robot performs patrol work, it is necessary to obtain information on surrounding objects for creating a moving route and detecting obstacles. Mobile robots often use the Laser Range Finder (LRF) sensor to detect surrounding objects. LRF uses a laser to measure distance, and by measuring while rotating, the surrounding situation can be obtained in pairs of distance and angle. Conventional mobile robots use an advance map of the location to be traversed. It is common to create a route and avoid obstacles based on the information of the advance map and the information of surrounding objects obtained from the LRF installed in the robot at ground level. However, there is a risk of collision or falling because it cannot detect low obstacles and steps, and there is a risk of false detection of walls when detecting objects that you want to approach, such as work machines when transporting in factories. In this study, we propose a 3D measurement method using a tilted LRF. The 3D coordinates of the measurement point can be calculated from the distance data acquired by the LRF and the inclination of the sensor. Additionally, the robot's self-position information is integrated when obtaining each 3D coordinate. By accumulating 3D coordinates while the robot is moving and synthesizing the difference information, 3D measurements can be performed.

3.2 Proposed method

In this study, we propose a method for measuring in three dimensions by tilting the LRF. Using the distance data obtained from the LRF and the sensor's inclination, the robot can calculate the three-dimensional coordinates relative to the measurement point by computing the rotation matrix. Furthermore, by incorporating the robot's self-position information, it becomes feasible to perform three-dimensional space measurements. Two-dimensional range sensors capture the distance and angle data of surrounding objects, allowing for the calculation of Cartesian coordinates of the measurement point. In Figure 3, the range sensor is installed at the origin O, while the robot's traveling direction represents the x-axis. Let n be the number of measurement points obtained by a single scan at a certain time T, and let the arbitrary measurement points $M(T_n)$ acquired at time T be as shown in the following equation 1.

$$M_{T_n} = \begin{pmatrix} X_{T_n} \\ Y_{T_n} \\ 0 \end{pmatrix} \tag{1}$$

Let θ be the angle at which the range sensor is tilted relative to the robot's traveling direction. If the robot's direction of travel aligns with the x-axis, the rotation matrix about the y-axis can be used to calculate the coordinates of the

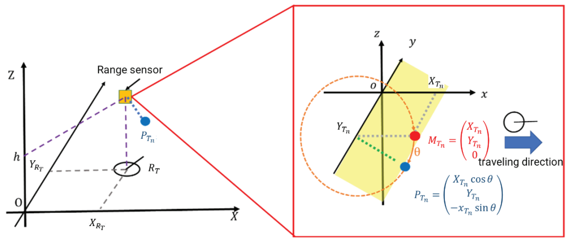

Fig. 3. Positional relationship of 3D coordinates P_{T_n}

measurement point $M_(T_n)$. After rotating the measurement point to $P_(T_n)$, we can calculate the relative three-dimensional coordinates from the sensor's origin using the equation 2 shown below.

$$P_{T_n} = \begin{pmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{pmatrix} \begin{pmatrix} X_{T_n} \\ Y_{T_n} \\ 0 \end{pmatrix} = \begin{pmatrix} X_{T_n}\cos\theta \\ Y_{T_n} \\ -X_{T_n}\sin\theta \end{pmatrix} \tag{2}$$

Let us consider the robot's self-position at time T, denoted by R_T, with the starting point at an arbitrary coordinate O. Suppose the robot is traveling along the X-axis from the starting point O, with X_{R_T}, and Y_{R_T}, representing its X and Y coordinats, respectively. The robot's orientation is given by φ_{R_T}, and its self-position can be expressed by the Equation 3 shown below.

$$(R_T = X_{R_T}, Y_{R_T}, \varphi_{R_T}) \tag{3}$$

If the sensor is installed at a height of H from the origin O, we can obtain the absolute three-dimensional coordinates of the measurement point by using the P_{T_n} calculated from Equation 2 and the robot's self-position coordinate R_T with respect to O. Let the absolute three-dimensional coordinate be denoted by P_{T_n}. To obtain the coordinates of the measurement point with respect to the robot's orientation, we use a rotation matrix with the robot's orientation φ_{R_T} as the y-axis. After the rotation, we add the robot's coordinates X_{R_T} and Y_{R_T} to the x and y components of the measurement point, respectively, and add the sensor's height H to the z component. This yields the three-dimensional coordinates of the measurement point, denoted by P_{T_n}, which can be computed using Equation 4 and illustrated in Figure 3.

$$P_{T_n} = \begin{pmatrix} \cos\varphi_{R_T} & -\sin\varphi_{R_T} & 0 \\ \sin\varphi_{R_T} & \cos\varphi_{R_T} & 0 \\ 0 & 0 & 1 \end{pmatrix} P_{T_n} + \begin{pmatrix} X_{R_T} \\ Y_{R_T} \\ H \end{pmatrix} = \begin{pmatrix} X_{T_n}\cos\theta\cos\varphi_{R_T} - \sin\varphi_{R_T} \\ X_{T_n}\cos\theta\sin\varphi_{R_T} + Y_{R_T}\cos\varphi_{R_T} \\ -X_T\sin\theta \end{pmatrix} \tag{4}$$

3.3 Experiments

The experiment is conducted in the environment shown in Figure 4. For the experiment, two cubes with a side length of 10 cm are used as low obstacles.

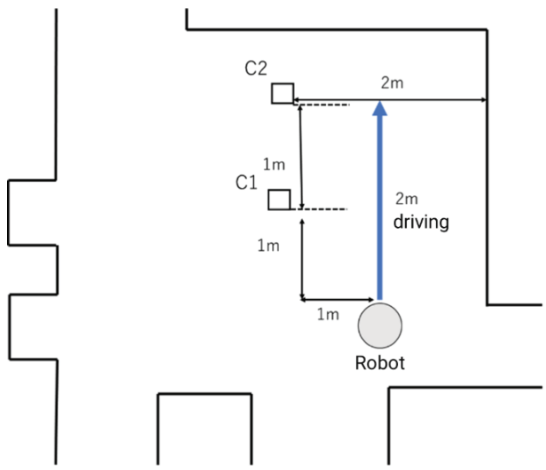

Fig. 4. Outline diagram of the experimental environment and Robotino driving route.

Three-dimensional measurement experiments are performed with the range sensor tilted at angles ranging from 10 to 50 degrees. Figures 5 and 6 summarize the distance from the robot starting point and the height measurement error of the two cubes, C1 and C2. The error ranged from 0.6% to 2.9% with respect to the distance of the cube, which was generally good. However, the height of the cube had an error of up to 14%, which was large compared to the distance error. Additionally, C2 could not be detected twice at 10 degrees. Based on the experimental results, it was confirmed that the height error increased from 10 degrees to 20 degrees, was smallest at 30 degrees, and increased as the angle became larger. These errors are largely attributed to the incident angle of the laser in the range sensor.

3.4 Conclusion

We proposed a method for three-dimensional measurement by tilting the LRF on a mobile robot and conducted an experiment. We experimentally confirmed that it was possible to obtain information on short obstacles that could not be detected by conventional LRF installation methods. In the future, we will work on assessing the impact of the proposed method's errors on actual driving and addressing methods to reduce these errors.

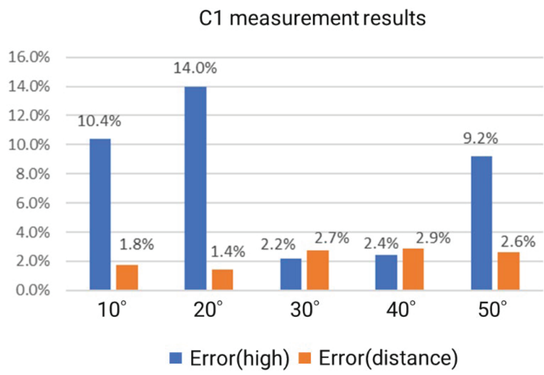

Fig. 5. The average errors in 3D measurement for cube C1

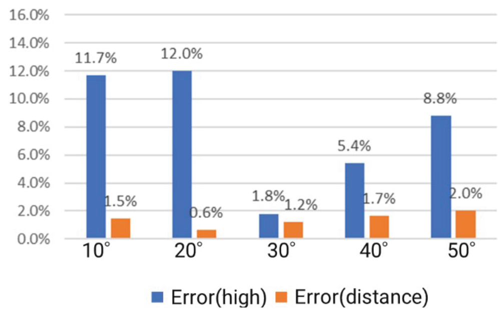

Fig. 6. The average errors in 3D measurement for cube C2

4 Passing a Peer Robot using Autonomous Mobile Robots

4.1 Introduction

In the introduction to autonomous mobile robots, it is important for other robots to move in the same environment. When moving, autonomous mobile robots select a route to the destination, but if the selected route overlaps with the route of another robot, there is a risk of collision. Therefore, it is necessary to detect the other robot and find a safe place to pass without collision. In this study, we propose a method of route search that circumvents the position of the other robot.

4.2 Dynamic Window Approach

The Dynamic Window Approach (DWA)[3] is a method for calculating the trajectory and selecting a route for a robot. It falls under the category of Local

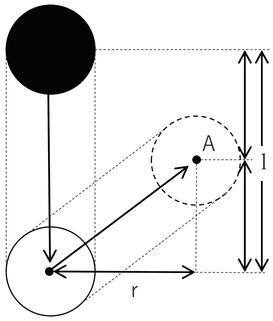

Fig. 7. Points of misunderstanding

Path Planning in path planning. This method selects the path with the maximum evaluation function by considering the robot's motion model, calculating the possible control input (Dynamic Window) based on self-position, obstacles, and destination information, and then computing the robot's trajectory. The evaluation function assesses whether the robot is facing the direction of the destination, far from obstacles, and moving quickly. This method is primarily used for route planning in autonomous mobile robots.

4.3 Proposed method

While DWA is effective for avoiding stationary obstacles, there is a risk of collisions caused by circuitous path planning and sudden stops depending on the parameter settings. To address this issue, we propose a method that uses DWA when no other robots are present and switches to an avoidance path when encountering a partner robot. The avoidance path is determined by finding the difference in position between the two robots.

If the other robot is moving at a constant speed towards the robot, then it is the most dangerous case, and a collision would occur at the midpoint between the two robots. To avoid collision, the robot should aim for a point shifted sideways by a distance of r from the midpoint, where r is the distance required to pass the other robot safely. If the robot's travel direction is along the x-axis and the distance to the other robot is l, the target relay point A would be $(l/2, r)$. When there are multiple counterpart robots, it is important to pass the partner robot with the closest distance, so the passing point A for the robot should be set accordingly. Figure 7 shows a schematic diagram of the passing points.

4.4 Experiments

In the experiment, we conducted route search in an environment with multiple partner robots, and measured and evaluated the distance traveled and time taken to reach the proposed route and destination, respectively. The starting point was (0,0), the destination was (5,0), and the value of r was 0.6m. A collision occurs

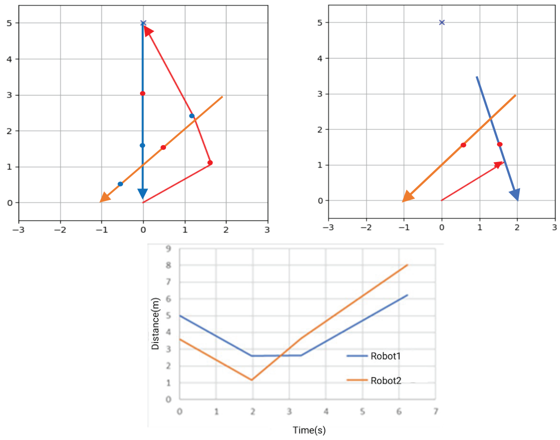

Fig. 8. The experimental results

when the distance between the robot and the other robot is less than 45 cm. The experimental results are presented in Figure 8. The upper left figure shows the successful route, the upper right figure shows the route at the time of collision, and the lower figure shows the relationship between the distance to the other robot and the time taken to successfully reach the destination.

It was possible to reach the destination without colliding with the two opposing robots and keeping a safe distance when successful. The path at the time of collision revealed that the robot advancing towards the passing point was unable to avoid the high-risk opposing robot.

4.5 Conclusion

We proposed an avoidance action for one other robot, tried the proposed method in various environments, and evaluated the performance of the proposed method. In the future, we would like to address the collision problem in real time by calculating the passing point, searching for a new route, and implementing it in the robot.

5 Conclusion

We conducted research on identifying processing machines, measuring the environment for autonomous mobile robots, and avoiding collisions in response to the increasing use of autonomous mobile robots in various settings such as manufacturing and medical sites. With the shift towards high-mix low-volume production, the production landscape in factories is changing, and our research aims to address the challenges that come with this transformation. The proposed method for processing machines is considered useful as it improved the correct answer rate or achieved the same accuracy while reducing the time required for identification or obtaining the same result. The proposed method for environmental measurement of autonomous mobile robots has a small error in the distance to the obstacle, but the height error may be significant due to the influence of the incident angle of the laser of the range sensor. In the proposed method for collision avoidance, it was found that the robot advancing towards the passing point while heading to the passing point could not cope with the high-risk opponent robot from the collision route. However, when successful, it was possible to reach the destination without colliding with the two opposing robots while maintaining a distance.

References

1. BabyTigers DASH, `http://www.kdel.info.eng.osaka-cu.ac.jp/backup/robocup/index-j.html`
2. BabyTigers - R, `https://friede.elec.ryukoku.ac.jp/trac/lab/wiki/BabyTigers-R`
3. Ryosuke KATAOKA, Yonghoon JI, and Kazunori UMEDA, "Smooth Motion Control of Mobile Robot in Human-robot Coexisting Environment", the robotics and mechatronics conference 2019, pp. A13(1) - A13(2).