Landmark Detection and Position Correction of Autonomous Mobile Robots Using a Linear Array of Three Ultrasonic Sensors

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Abstract - This paper presents a methodology to enable a mobile robot to automatically correct its odometry errors while it is navigating and detects landmarks in the environment. Those landmarks are defined a priori to the navigation process, since the map is available beforehand. The robot is able to know whether the detected object is a landmark or not, extracting the necessary information from the range data. The range data is obtained from 3 ultrasonic sensors placed in the right side of the robot. The experiments carried out showed that: the robot was able to detect a landmark on the environment, identify it with regard to the landmark in environmental map and recover its position errors. Furthermore, the robots are able to distinguish a landmark from other object.

Keywords: *Mobile robots, ultrasonic sensors, indoor environment, landmark identification, position correction*

1. Introduction

Odometry is the most widely used navigation method for mobile robot positioning. It is well known that odometry provides good short-term accuracy, is inexpensive, and allows very high sampling rates. However, the fundamental idea of odometry is the integration of incremental motion information over time, which leads inevitably to the accumulation of errors. Particularly, the accumulation of orientation errors will cause large position errors which increase proportionally with the distance traveled by the robot.[2][1][8]. To overcome this problem, a solution to the robot sense its surrounding and detect landmarks for position error correction with its external sensors was proposed by: [10][11][12][13]. For such reason, in our previous researches [3] [4][5] and in the present work our interest of searching for such algorithm. In a previous research a methodology was implemented in a robot's platform that used only one sensor. In this methodology the robot corrected its position at the sensing areas of the landmarks. The sensing areas are determined in advance because the robot couldn't know whether the detected object is a landmark or not.[3] For this reason, in this paper we presented a new methodology, an approach to solve one of the basic problems of accumulate odometry errors that is "Position Correction of Autonomous Mobile Robot". The robot should be able to detect the landmarks with the ultrasonic sensors and then corrects its position. In this methodology the robot senses the environment continuously while is navigating. Since the robot is able to distinguish landmarks and other objects, extracting the necessary information from the reflection of the range data. The range data is obtained from 3 ultrasonic sensors, placed on the right side of the robot. (Figure 1) The straight walls are supposed to be the landmarks in this research.

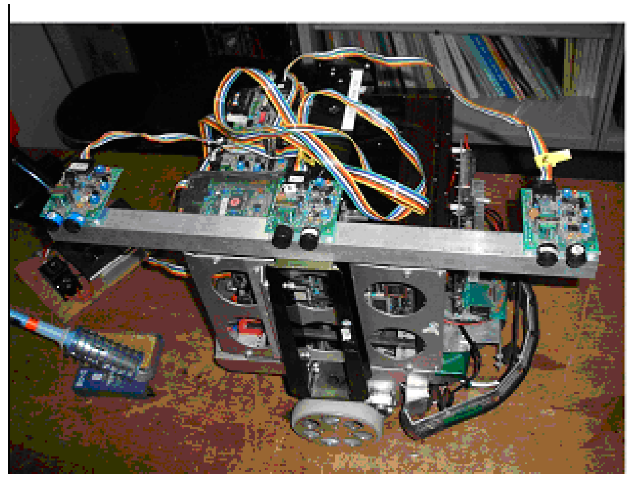

Figure 1: ***"Yamabico" special configuration: three ultrasonic sensors placed on its right side.***

2. Position Correction System using three Ultrasonic Sensors

2.1 Position correction procedures

To enable a mobile robot to know *when* it should correct its position, we propose a method for detection of the landmarks. It consists on reflect the sonar sensor obtained from the three ultrasonic sensors, then is possible to identify whether these data came from a landmark or not. If so, the detected landmark is compare with the environmental map knowing in advance. If the robot detects other kind of object, just ignore it. By other object the authors mean all the objects of the given environment which do not directly affect the algorithm, i.e. not the ones which serve as landmark. As soon as the robot knows that it had detected a landmark and identify which landmark was found, and if is needed correct its position.
The advantage with this method is that since the robot will have three consecutive sensor data it can recognize immediately if it has found a landmark and if it should correct its position.
Using this method the robot should be able to:
• Detect a number of landmarks.
• Distinguish between a landmark and other object.
• Identify which landmark it had found.
• Recover its position errors.

2.1.1 Environment definition

In this method, in order to define the environment to the robot, we represented it by vectors. (Figure 2). These vectors represented the landmark on the environment. Each side of the vector will have a defined area according with its orientation in the x-axis. The right side of a vector represented the emphoccupied area of a landmark. By occupied area the author mean the side of the landmark that will not be used as reference of navigation. The left side represents the *free area* of a landmark, the one that the robot sense and use as a reference of its actual position and if needed correct its position. The path is also specified to the robot a priori of navigation.

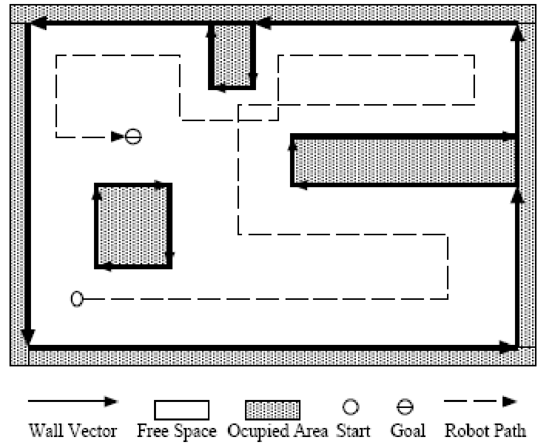

Figure 2: Definition of the map of the environment. The landmarks are defined to the robot as vectors.

2.1.2 Extracting a landmark from others objects on the environment

In order to enable the robot to distinguish a landmark from the other objects in the environment, we developed the next procedure in where the robot has to sense the environment continiuosly while it is navigating through it enviroemnte especify a priori, the robot will get the range data information from three ultrasonic sensors represented by(r1, r2, r3). The three lengths will be subtract as (r1 - r2) and (r2 - r3) then both results are compared, if those are different it mean that the robot has found a object, if the results were the same it mean that the robot had found a landmark.(Figures 3 and 4).

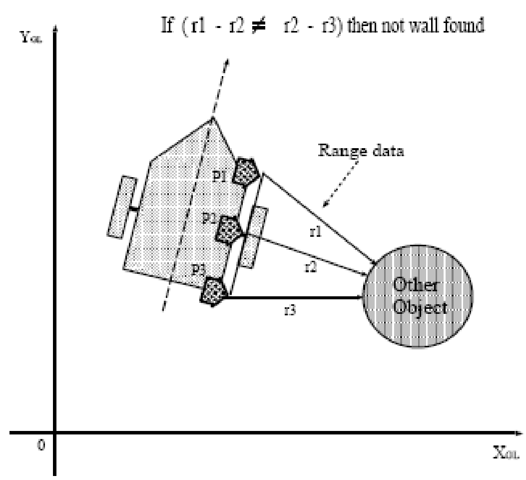

Figure 3: The robot deduces that it did not find a wall when the 2 (length differences) are different.

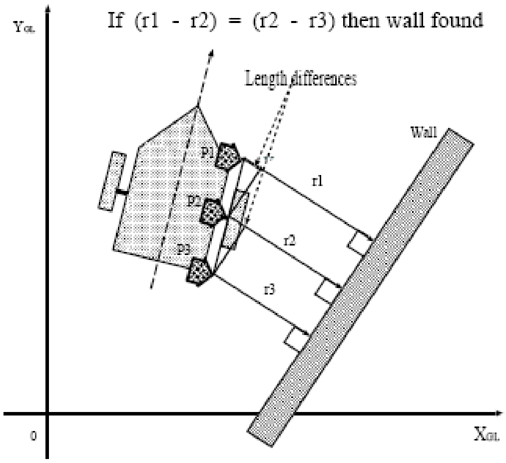

Figure 4: The robot deduces that it found a wall when the 2 (length differences) are igual.

2.1.3 Estimated Reflection Points

The ultrasonic sensor provides useful information for recognizing the environment. One of its characteristics is that its reflection is in vertical direction. It shows, for example, the angle of the landmark.[6][7]. Knowing this information it is possible to estimate the reflection of the points on the environment. In our system, once the robot detects a landmark in the environment it will estimate the reflected points (*R*1,*R*3). (Figure 5).
The procedure for the estimated reflection points will be as follows:
The range data information is obtained from the two ultrasonic sensors (*r*1, *r*3). Supposing that the two ultrasonic sensors of the robot are located on *P*1(*x*1,*y*1),*P*3(*x*3,*y*3) and the position of the robot is(*xabs*, *yabs*,□*abs*). Then is possible to obtain the two reflected points if we estimate the vectors $\overrightarrow{P_1R_1}$ and $\overrightarrow{P_3R_3}$ like this:

$$\overrightarrow{P_nR_n} = \begin{pmatrix} x_n \\ y_n \end{pmatrix} + \begin{pmatrix} r_n \cos\phi \\ r_n \sin\phi \end{pmatrix} \quad (1)$$

Where:
rn: Represent the length obtained for the range data information. *xn*,*yn*: Position of the robot.
Then the direction of the ultrasonic reflection is denotes
by the angle □and 0 degree is set on the direction of xaxis.
Where:

$$\phi = \theta + th \quad (2)$$

□will be estimated as:

$$\cos\phi = \frac{r_1 - r_2}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}} \quad (3)$$

th: Orientation of the robot on x-axis.

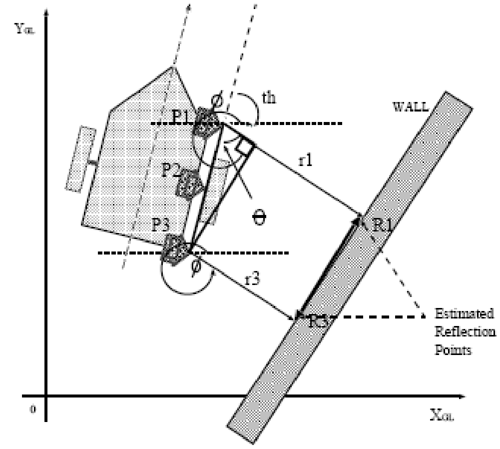

Figure 5: Estimation of the two reflected points (R1,R3).

2.1.4 Selection of a landmark from the environmental map

In order to enable the robot to match the detected landmark with the one in the map, we propose an algorithm in which the robot will compare the orientation on x-axis of the detected landmark with the orientation of each landmark in the map.(Figure 6). When the robot finds that a landmark on the map has the same orientation of the detected landmark, then it estimates *D*1 and *D*2. These are the distances between those two landmarks. If *D*1 and *D*2 are inside of the proposed threshold therefore, the robot knows that it found a landmark and it is able to identify which landmark it has found from the environment.(Figure 7).

2.1.5 Position Correction

In this section we present a specific procedure for reducing the odometry errors. In which the robot will compare the angle of the detected landmark q*calc* with the angle of the landmark on the map □*wall* , in case that those were different a new angle will be estimated like this: □*error* = (□*wall* - □*calc*) that it is the error angle. The robot position using odometry is represented as(*xabs*, *yabs*,□*abs*). Then the robot will rotate it orientation to the new angle obtained from □*new* =(□*abs*+□*error*). (Figure 8).

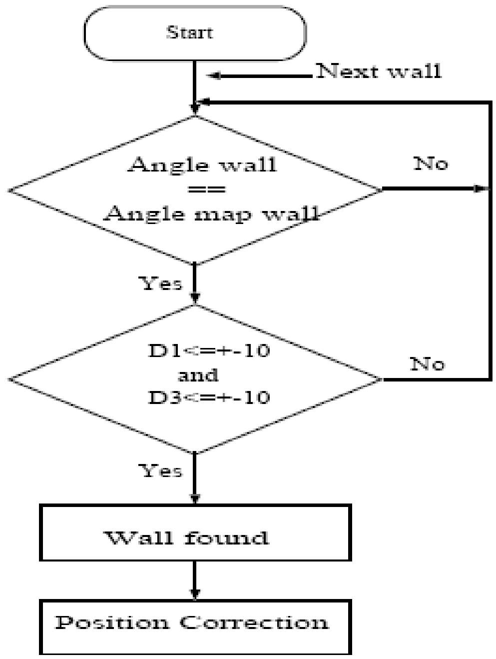

Figure 6: Procedure for landmark detection.

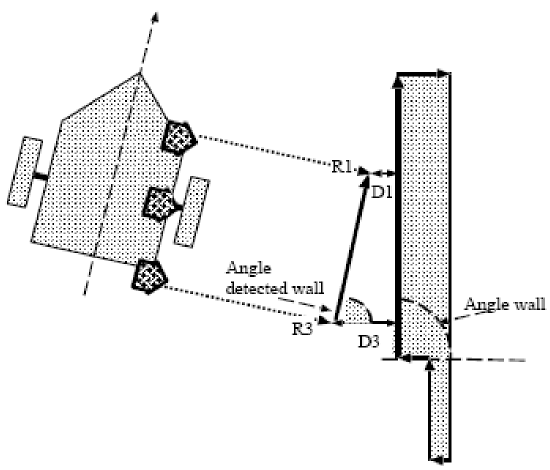

Figure 7: Identifying a landmark on the environment.

Once that, □*new* was obtained, the new position (*xnew*, *ynew*) of the robot will be estimated as:

$$\begin{pmatrix} X_{new} \\ Y_{new} \end{pmatrix} = \begin{pmatrix} x_{abs} \\ y_{abs} \end{pmatrix} + \begin{pmatrix} \cos(\theta_{wall}+90) \\ \sin(\theta_{wall}+90) \end{pmatrix}(D) \quad (4)$$

Where:
D: The standard distance between detected wall and real wall.
*D*1,*D*2: Distance to the wall from the Estimated Reflection Points (*R*1,*R*3).
Then the robot will match its actual position to (x_{new}, y_{new}, θ_{new}).(Figure 9)

3. System Implementation

- The algorithm was implemented on the "Yamabico robot" special platform.
- The robotic platform has a sensor array, consisting of 3 ultrasonic sensors, mounted on the right side of the robot at a distance of 20 cm between them. The range of the sensor is ±15 to 20 degrees within 300 to 500 cm.(Figure 1).

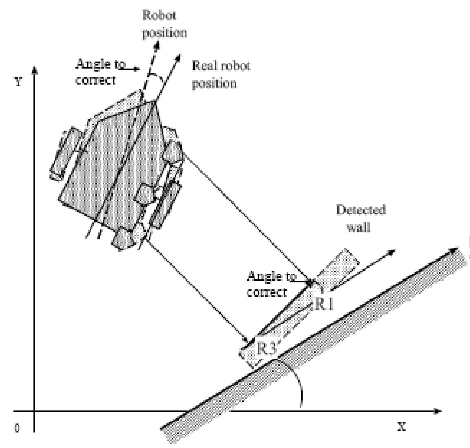

Figure 8: Shows when the robots rotates its orientation tothe correct one

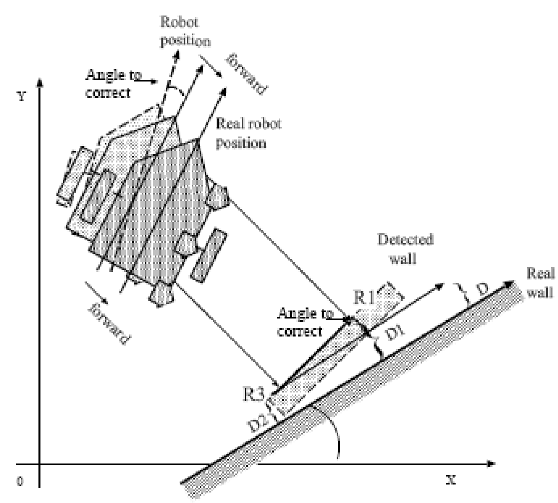

Figure 9: Shows when the robots match its position to the new corrected one.

4. Experiments and Results

A set of experiments were carried out to verify the effectiveness of the implemented algorithms.
The goal of these experiments is to verify if the robot is able to:

- Detects the landmark in the environment while it is navigating
- Correct its odometry errors of navigation,
- Distinguish a landmark from other objects placed in the environment.

4.1 Description of the experiment No. 1

The experiment consisted on run the robot in cw direction following a square path around reference walls. The robot should navigate on this path 10 times.

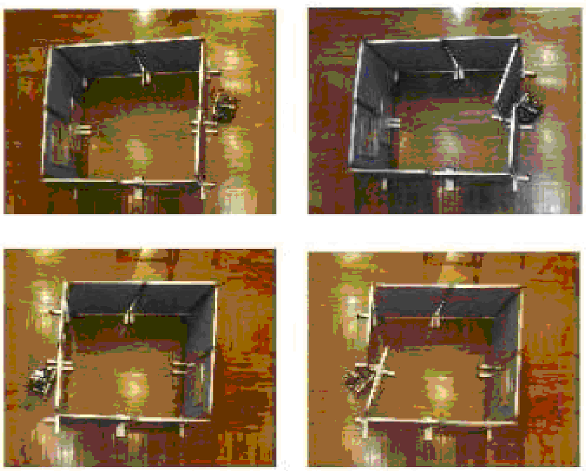

Figure 10: Top view of the experimental environment. Representation of the behavior of the robot when it runs on the square path using only Odometry.

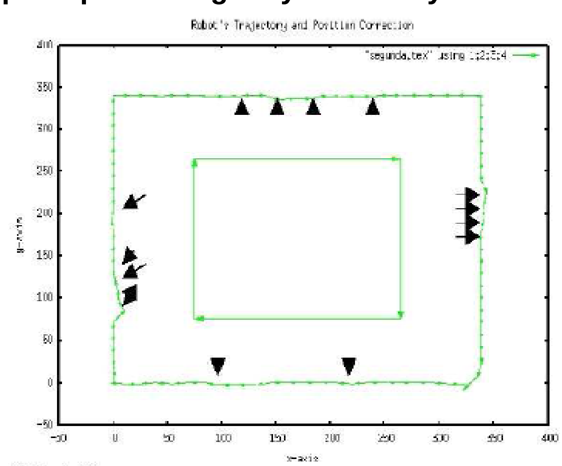

Figure 12: Representation of the behavior of the robot when it runs on the square path and correct is odometry errors.

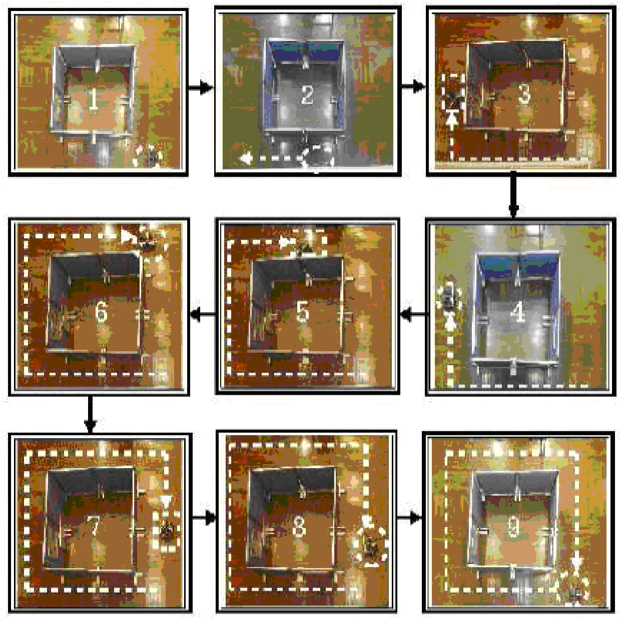

Figure 11: Top view of the experimental environment. Representation of the behavior of the robot when it run on the square path using our system of "Position Correction".

1. The robot runs using only running commands (odometry).
2. The robot runs using our system of "Position Correction".

- The landmarks information is stored in the memory of the robot.
- Experiments were conducted in front of the Intelligent Robot laboratory University of Tsukuba.
- The testing environment for experiment No.1 consisted of 4 artificial walls formed a square with the length of its sides of 2X2m. Figure 10 and 11 show the example of the testing environment.
- The robot path was specified a priori.

4.2 Results of the experiment No. 1

1. As a result of the first part of the experiment, the robot did not succeed in completing the 10 rounds, the robot lost its position and in the 4 round it hits one of the walls. (Figure 10.)
2. As a result of the second part of the experiment, the robot successfully recovered its position, identified correctly several landmarks while navigating through the environment with a map available a priori. It finished 10 complete rounds ending nearly at the same start position.

The representation of the behavior of the robot when it run on the square path using our system of "Position Correction" is presented in (Figure 11). The flow is going from step no.1 to no.9.

- *Dashed lines*: shows the behavior of the robot during the experiment.
- *Dashed circle*: shows the correct position of the robot.
- *Dashed square*: shows when the robot corrects its position.

The start and end robot's position are showed in the steps no.1 and no.9. As these robot's positions are almost the same place, it could be deduced that the robot's trajectory was corrected successfully.
In order to have a real data information of the behavior of the robot when it is navigating around the specified square and correct its position, we obtain the data information of the current position of the robot each 1 sec. The position correction was done by the robot each 2 sec and it was run at a velocity of 15cm/sec. It is shown it in the detailed view in the graphic. (Figure 12)In this graphic the position correction is pointed with the black arrows.

4.3 Description of the experiment No.2

This experimentwas performed in order to test if the robot is able to distinguish a landmark from others objects.

- The robot has information of a wall with a length of 2m before the navigation process. In the environment were placed: One robot.($robot_{ob\,j}$), a wall of 95cm.($wall_{ob\,j}$), a tube of diameter of 21.5cm.($tube_{ob\,j}$).
- The ($robot_{ob\,j}$) and ($tube_{ob\,j}$) represents the other objects on the environment.(Figure 13)
- The robot was run in a straight path of 2m at a velocity of 10cm/s, its start position was at 75cm from the wall.
- • Current information of robot's position each 1 sec and estimate reflected points each 2 sec was obtained.

4.4 Results of the experiment No. 2

The detailed view of the graphic on figure14 shows the results of this experiment.

- The *points* are the robot raveling also the small points on the bigger line are the estimated reflected points.
- The *vectors* are the detected walls.
- The *line* the wall specified to the robot a priori

The results on the graphic show that: when the robot detected other object in the environment it ignores it. In the experiment the robot ignores the first object ($robot_{ob\,j}$) and the second ($tube_{ob\,j}$) but, it successes on detected the($wall_{ob\,j}$). It can be deduced in the graphic for the estimates reflected points and detected wall vectors.
These results show that the robot is able to distinguish a landmark from others objects using the system proposed here.

5. Conclusion

In this paper we presented a strategy for correction the odometrical errors of the autonomous robot navigating in indoor environments with the map available a priori. The robotic platform has a sensor array, consisting of 3 ultrasonic sensors, mounted on the right side of the robot. A set of experiments were carried out to verify the effectiveness of the implemented system. As a result, the robotwas able to detect landmarks, define which landmark was found in the environment, and recover from odometry errors using
an environmental map specified a priori. Further more, the robot was able to distinguish a landmark from other objects.

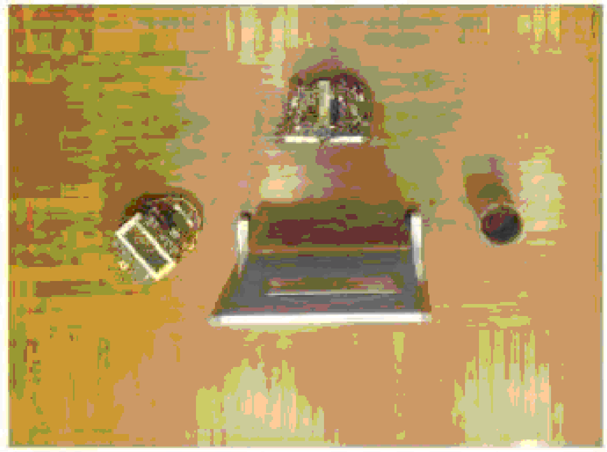

Figure 13: The top view of the experimental environment No.2 using a wall and other objects different than a wall.

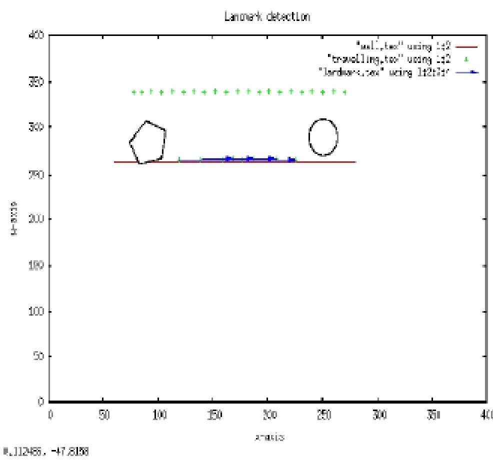

Figure 14: The experimental result after the robot travel in a staight path with a wall and two other objects.

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