Exploration Algorithm for a Mobile Robot. An Experiment

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***Abstract*— Exploring an unknown space it is one of the most well-known tasks to be performed by mobile robots. Among the most used sensors for obstacle detection there are ultrasonic sensors that have the advantage of simplicity in implementation as well as the possibility of obtaining a fast response time from the robot control system.**

Keywords—exploration algorithm, mobile robot, Raspberry PI platform, ultrasonic sensors, camera

I. Introduction

One of the essential objectives of robotics is to achieve autonomous mobile robots. Such robots could perform certain tasks without other human intervention. The orders received from the operator will specify what he wants and the execution of the task will depend on the respective program with which the robot is endowed.

In mobile robotics, the exploration problem deals with the use of one or more mobile robots to maximize the knowledge about their work environment. The exploration problem appears in robotic mapping as well as in search and rescue situations where the environment might be dangerous or inaccessible to human beings.

Obviously the mobile robots capable of performing such operations will be equipped with sensors for perceiving the environment, under the control of a computer system. The progress of autonomous mobile robots is of major interest in many application areas, including certain industrial processes, search and rescue operations, waste processing, exploration of space, oceans and hard-to-reach areas, medicine, assistance to people with disabilities, etc.

The development of technologies needed to make mobile robots that contribute to or even replace various man-made operations, especially repetitive operations, involves many areas such as: sensors, artificial intelligence, computing systems, signal processing, trajectory planning, control of DC motors, electronics, etc.

The approach presented in [1] is based on local representations, and all motions are specified regarding visually distinct and recognizable objects referred to as natural landmarks. Is developed a search strategy in order to find a recognizable object in the presence of odometric sensors and sensing uncertainty. To deal with these uncertainties, are presented new algorithms for building representations of the work environment. The basic principle is to divide the world up into a big number of overlapping regions, which can be represented by a local map and to take into account the relationships between these regions.

In [2] techniques for coordinating multiple robots in their task of exploring and mapping, indoor environments are presented. The authors consider two coordination problems - realization a single global map from the sensor information of the robots, and deciding where each robot should go in order to create the most efficient map. Unfortunately, solving the latter problem optimally is difficult and even unsolvable in most cases, they present a greedy approach that performs quite well, in practical situations.

In [3] a novel algorithm for indoor environment exploration, is introduced. The authors consider robot sensory perception constraints as well as indoor spaces predictable structure. Their method is compared with a standard greedy approach that uses optimization with respect to information gain regions. The two algorithms were tested in simulation as well as in real world environment experiments with Servosila Engineer robot [4].

In our paper an algorithm for navigating a mobile robot in an unknown space is implemented and tested. If no obstacles in front, mobile robot will move with relatively high speed in front. If it encounters an obstacle in: its front, left or right, then the robot's control system will reduce travel speed and control the robot's rotation to avoid that obstacle or obstacles. After avoiding the obstacle, the robot will continue to move forward.

II. Movement of Mobile Robots

The orientation of a mobile robot in a totally unknown environment, using sensors to detect obstacles and communicating with a computer or remote operator are the main important aspects that must be taken into account when using a mobile robot [5].

The ability of robots to perceive the shape and structure of the environment, as well as to change their behavior based on information received from sensors is an aspect that makes mobile robots a very interesting field, with unlimited possibilities. If they were not equipped with sensors, mobile robots could only perform tasks imposed by the human operator and in the manner imposed by him.

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But, the mobile robot is a complex system that must include sensors and, in this way, can perform various activities in a multitude of situations specific to the real world. It consists of a combination of devices including servomotors and sensors controlled by a computer system, which operates in a real space, marked by a series of physical constraints (humidity, pressure, surface type, obstacles, etc.).

The control system must plan the movements so that the mobile robot can perform a task according to its condition and devices and according to the information taken from the working environment. Successful completion of tasks depends primarily on the knowledge that the mobile robot has about the initial configuration of the workspace, but also depends a lot on the information obtained during the task.

The most important tasks that the mobile robot must be able to perform successfully are: avoiding impact with objects in the work environment that may be stationary or moving, determining its position and orientation in the environment and planning an optimal trajectory to follow. If the above tasks can be performed, then the robot will be able to automatically decide what movements it will perform to perform a task, depending on the momentary distribution of objects in the workspace. Any change in the position of moving objects in relation to the position of the mobile robot must be taken into account by it, especially if their movement can influence the execution of the task.

Path planning is not a unique and well-defined problem, but it is a set of problems so that, most of the time, the final trajectory can have several variants or can change even during the movement of the mobile robot.

Avoiding collisions with possible fixed or mobile obstacles (there may be other mobile robots) in the robot's working environment can be done by various methods:

- use of a mechanical guard with the help of which even if the robot collides with other objects it will be protected or after its deformation the robot will and that must change its route,
- use of proximity sensors that measure the distance to obstacles in its direction of travel,
- use of information received based on the processing of images acquired during the movement of the robot. In some situations, GPS information can also be used, for example in the outdoor environment.

In certain situations, especially if the speed of movement is low, it is possible to locate objects by physical contact. Physical contact between the robot and any moving objects or with other robots in the environment, generates reaction forces that can affect the state of the robot. If high working speeds are used, which must be achieved for certain tasks, the dynamic effects of physical contact, even with manipulated objects, may be risky (may cause damage to objects or may disable the robot).

Usually, the robot can be navigated without reporting its position and orientation to a fixed coordinate system, but in most cases, this information is useful for the robot's control system. In most cases, the methods of navigating mobile robots are based on: measuring the number of rotations made by the wheels, the use of accelerators and gyroscopes, electromagnetic buoys installed in the field, passive or semi-passive signals of magnetic or optical type.

In most cases, information about the workspace is obtained before the robot actually navigates the workspace in the form of navigation maps. The map provides only a configuration of the initial structure of the work environment. The configuration that the mobile robot must take into account is obtained by updating the initial map with the information obtained in real time from the navigation system.

Based on the initial configuration, a possible trajectory can be established for the accomplishment of the proposed task, a trajectory that may change after processing the information received from the robot sensors that provide a current image of the work environment configuration.

III. THE EXPLORATION ALGORITHM

The paper proposes an algorithm for navigating in an indoor environment of a mobile robot. The robot must avoid obstacles and emit an audio signal when it encounters obstacles. The sound signal is actually the next action that the robot will perform.

The position of the obstacle encountered is also indicated by an audible warning, namely there are three possible variants: obstacle in front, obstacle on the right and obstacle on the left.

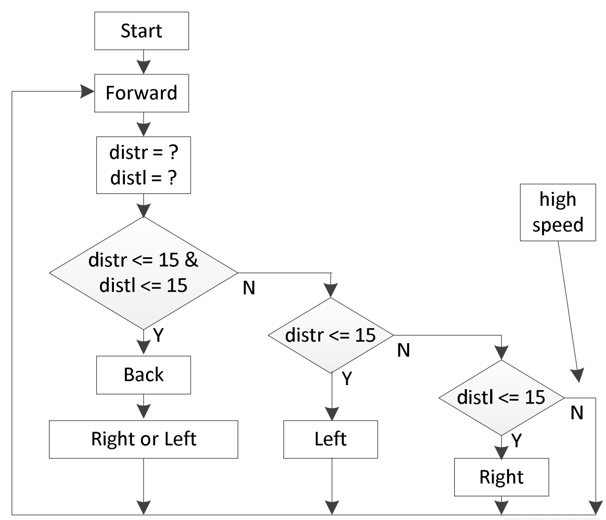


Fig. 1. Organization chart of the algorithm.

The mobile robot moves forward and its control system periodically checks the distance to obstacles based on the ultrasonic sensors, namely **distr** and **distrl**. If these distances are both less than 15 cm, then the control system will control both motors of the robot so that a backward movement will follow. The robot will then rotate 45 degrees or more to the left or right, depending on how the environment is explored.

If one or both distances are greater than 15 cm then it will be tested if the **distr** is less than 15 cm, and if so, then the robot will turn to the left and thus try to avoid the obstacle. If the **distr** is greater than 15 cm, then it will be tested if the **distl** is less than 15 cm, and if so, the robot will turn to the right, then continue moving forward.

If none of the above conditions are met, then the robot will move forward until it encounters an obstacle. Also, the navigation speed in this situation will be set to be high. In any other situation (when the mobile robot detects the presence of an obstacle) it will reduce its speed accordingly, especially if it detects obstacles on both sides (left and right).

IV. THE MOBILE ROBOT

The structure of the mobile robot is shown in Fig. 2.

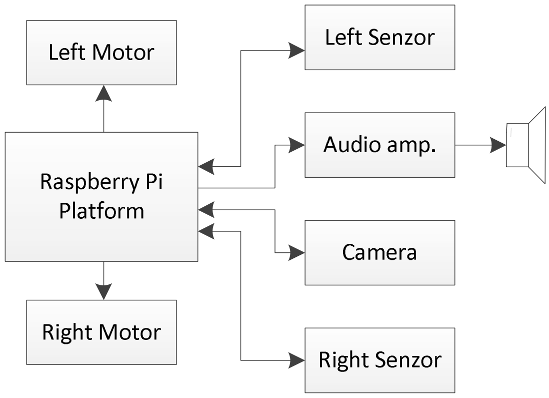


Fig. 2. Mobile robot structure

The mobile robot used for the implementation and testing of the algorithm was made using a chassis with two motors (right and left motor, respectively). A Raspberry PI 4 platform was used for the control part. To determine the distance to obstacles, two ultrasonic sensors type HC-SR04 (right and left sensor, respectively) were used. The distance to the obstacles is obtained if the calculation formula is applied:

distance (cm) = time of flight (us) * 1/1000000 * 340 (m/s) / 2 * 100

The amplification of the audio signals generated by the robot (Raspberry Pi platform), in case of obstacle detection, was done by using a two-channel 3 W miniature class D audio amplifier based on PAM8403 chip. The working environment of the mobile robot for algorithm testing can be seen in Fig. 3.

Fig. 3. The mobile robot and its workspace.

V. TESTING THE ALGORITHM

The algorithm shown above was tested on a surface having the shape shown in Fig. 4. The mobile robot starts from the START point and continues moving forward until the ultrasonic sensor on the right detects the edge of the surface. In this situation, the robot's control system decides to turn left, then the robot continues to move forward.

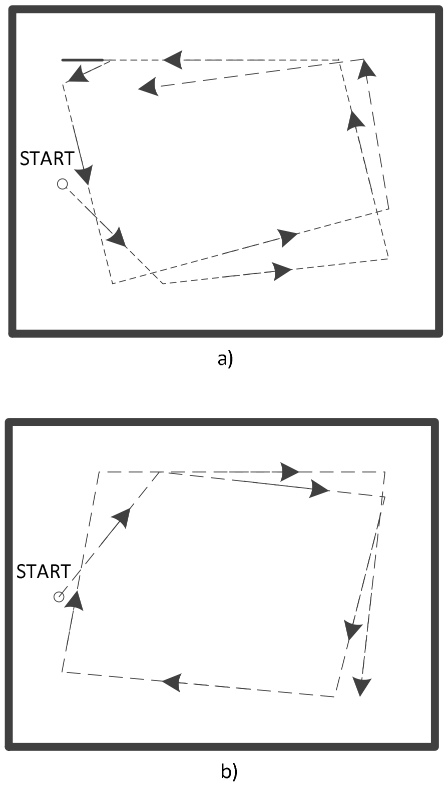


Fig. 4. Algorithm test results.

When the robot reaches the other side of the workspace, then the control system will make a similar decision. The mobile robot will continue to move on the edge of the workspace but keeping a distance from its edges. Of course, this distance can be changed, but it must not be smaller than the physical dimensions of the mobile robot, in order to avoid its collision with the edge, especially at times when cornering is performed.

As can be seen from the figure, due to the imperfections of the locomotor system, the turns are not always made at the same angle of rotation. This can sometimes be a disadvantage, but it can also be an advantage because in this way the mobile robot will not always travel on the same route, and in this way it will cover a larger exploration area.

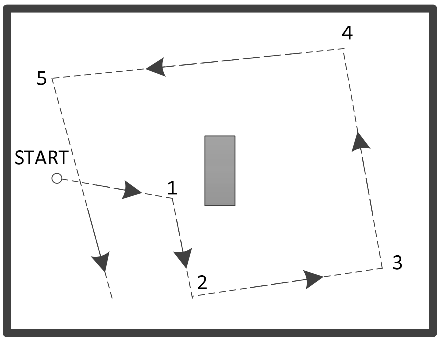
Also important is the initial orientation of the mobile robot for how the robot will move. If it has no obstacles in front of it, the robot will move with relatively high speed in front. If the right ultrasonic sensor first detects the edge of the surface (Fig. 4.a) then the robot will make a left turn and this type of turn will continue to predominate.

In this situation, the sound signals, which are identical with the successive commands executed by the mobile robot, are: GO - LEFT - GO - LEFT - GO - LEFT - GO - BACK - GO - LEFT - GO - LEFT - GO - LEFT - GO - LEFT - GO.

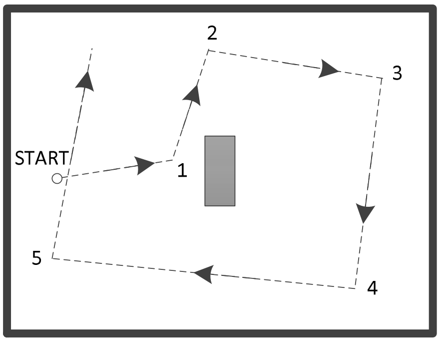
On the other hand, if the mobile robot has the initial orientation as in Fig. 4.b then right turns will predominate. In this configuration, the sound signals, which are identical with successive commands executed by the mobile robot, are: GO - RIGHT - GO - RIGHT - GO - RIGHT - GO - RIGHT - GO - RIGHT - GO - RIGHT - GO - RIGHT - GO.

If the mobile robot encounters an obstacle on their trajectory, it will be avoided by right or left, depending on the angle between the direction of travel with the respective object. In the example shown in Fig. 5a it is seen that the mobile robot will turn right when it encounters an obstacle and will execute the commands successively: GO - RIGHT - GO - LEFT - GO - LEFT - GO - LEFT - GO - LEFT – GO.

In the example shown in Fig. 5b it is seen that the mobile robot will turn left when it encounters an obstacle and will execute the commands successively: GO - LEFT - GO - RIGHT - GO - RIGHT - GO - RIGHT - GO - RIGHT – GO.



a)



b)

Fig. 5. Testing the algorithm with an obstacle.

For the case shown in Fig. 5.a are shown below (Fig. 6) the images captured by the video camera of the mobile robot in the marked positions (where the robot performs the rotation maneuver: 1, 2, ..., 5).

Fig. 6. Images captured by the mobile robot.

VI. CONCLUSIONS

The exploration algorithm can be easily modified so that the mobile robot moves along a wall, namely the well-known wall-following method. In this situation one of the sensors will be mounted in front of the robot and the other on the side. The side sensor will permanently measure the distance to the wall and will cause the movement to be approximately parallel to the wall. Of course, two side sensors can be mounted and then the mobile robot will be able to move with both the wall on the right and the wall on the left.

Such an exploration system can help, for example, visually impaired people because it can indicate the direction of travel so that there are no obstacles in the way. Moreover, by acoustic signaling the intention to move is indicated and the people around can be warned.

There are certain particular situations when the mobile robot may encounter certain obstacles such as thin obstacles (for example, chair legs) on the robot's trajectory or if the obstacles have a sharp edge directed towards the mobile robot (Fig. 7)

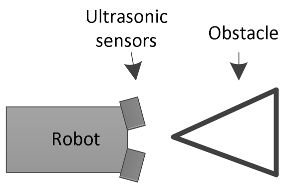


Fig. 7. Example of a possible collision.

In this situation, mounting an additional ultrasonic sensor in front of the robot can be a relatively good solution but the exploration algorithm must be modified accordingly.

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