An Automotive Unknown-Environment Explorer Robot Based on Braitenberg Vehicle Four

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Abstract. Environment exploration is an essential task in robotics, but it requires lots of high-tech sensors, which will make the robot very costly. To complete the exploration, a huge number of robots are required. Then, how to explore an unknown environment using simple robots with simple sensors is a significant problem to be studied. In this paper, robots are built based on Braitenberg Vehicle 4 and the robots are made to explore an unknown environment without a human. Braitenberg Vehicles are a series concept created by V. Braitenberg. Braitenberg Vehicle 4, particularly, is a robot that only has reflection level intelligence. The Robot's logic is only four parts, going straight, turning left, turning right, and turning around. The simplicity of the design allows putting the Robot into mass production. MATLAB is used to simulate the working process of the Robot to test the Robot's feasibility. Then, the map drawn by the Robot with the actual environment is compared. The result has shown that the map we got is almost the same as the real surroundings.

1. Introduction

For many tasks assigned to robotic systems, a certain map is necessary. However, in situations such as military tasks, non-automatic warehouses, and disaster victims rescue [1], a well-prepared map hardly exists, thus, to apply a robotic system in these cases, exploring and mapping the unknown environment is of great importance. Due to the necessity, a lot of work has already been done in this field. While a single robot was used in the previous research, multi-robot is a recent study trend because of their strong adaptation, excellent flexibility, and high reliability [2].

To accomplish a given task, a robot collects or receives sensory information concerning its external environment and takes actions within the dynamically changing environment [3]. To achieve navigation in this map, different methods are adopted. For instance, Ioannis M. Rekleitis's team has come up with a multi robots exploration method, in which a set of robots cooperated to reach every part of the map. This method focused on reducing odometry error [2], however, every Robot sacrificed part of its own freedom to cooperate; thus, the efficiency decreased.
Dongsha Wang et al. adopted an algorithm called FORDPSO [1] in their research, which is the advanced version of particle swarm optimization (PSO). Still, the realization of this algorithm required reliable global communication, and the Robot did not obtain the ability to avoid obstacles that may cause severe problems in the real situation. K.S. Senthilkumar et al. utilize an algorithm called ES-MSTC [4], an online multiple ant-type robot coverage algorithms based on an approximate cellular decomposition. However, this method required the Robot to move less efficiently.

Considering the problems mentioned ahead, this paper proposes a new strategy by using Braitenberg Vehicle as a model which has been adopted by a few previous studies [5-7]. First mentioned in "Vehicles: Experiments in Synthetic Psychology," published in 1984, Braitenberg Vehicle has been a classic neuroscience model for a long time. It managed to interpret some of the reflexes of animals using a system consist of a simple vehicle merely equipped with a few sensors and two actuators. Thus, relatively complicated electrical structures and processes can be avoid. Another biology-inspired method has been adapted as well [8]. The mobile robots are equipped with a distance sensor that detects the distance between the obstacles and the robots. The Braitenberg Vehicles in our study are designed to act in the way that they tend to show the behavior of navigating towards a source (the obstacles and other mobile robots) and then turning away when the stimulus becomes strong. In our research, multi robots starting from different points along the boundary of the map are used, which can be defined as Braitenberg Vehicle. They are "attracted" by the obstacles in a certain range of distance and will "escape" from the obstacles while the distance is under limitation. By recording the route of the robots and displaying on a graph, information about the environment can be got. In this way, after one complete process of exploration, a map can be represented on the computer, then the afterwards arrangement can base on the map and increase the efficiency.

2. Method

2.1. The Virtual Hardware Arrangement

2.1.1. Virtual Environment. The map was based on an enclosed 2-dimension rectangle space where the vehicles could theoretically reach every part of it. This area was the simulation of the limited target place under exploration. After setting the basic environment, we defined some parts of the map inaccessible for the vehicles, which act as obstacles. To simplify the obstacles in the 2d map, all the obstacles were defined in the shape of rectangles. The coordinates of their center point and the data of the width and length are determined to set the obstacle; then, the starting point of the vehicles can be defined by users. All the parameters were determined during the initialization process, and none of the information except the starting point was sent to the vehicles. And the vehicles regarded each other as obstacles.

2.1.2 The Vehicles. As mentioned before, all the vehicles adopted the strategy of The Braitenberg Vehicle. Originally used to demonstrate the nervous reflex of creatures in a simple and understandable way, the action of the vehicles is only associated with one parameter, the strength of the signal received. In our experiment, the distance between the vehicles and the obstacles represents this feature. Thus, the sensor system consisted of virtual distance sensors that could return the figure of distance to the processor. To balance the complexity and reliability of the system, we chose to limit the detect range to an area composed of two sectors with part of overlap, which was similar to the detection range of the binocular creatures. The appearance of the vehicles is roughly shown in Figure 1. The distance sensor is defined to be linear, which could only return the length of the line segment between the sensor and the obstacle the sensor facing to. All vehicles carried plural sensors which of them faced different directions, covering the limited range of angels. These sensors were arranged in the orange rectangles in the image. As for the movement of the vehicles, all the movements were motivated by two-DC motors; the function between the rotating speed ω and the return figured can be defined via programming, and differential turn was adopted. The parameters of the vehicles are offered below. The distance between the wheels was D=0.5. The wheel radius r=0.1, every set of visual angles θ=90°, which were divided
equally by three sensors. Distance between two centers of the circle \( d = 0.3 \), the range of the detect is 
\([0.02, 5]\), the resolution is 0.01. In the below image, the blue circle is the body of the vehicle, the green
rectangles are the wheels of the vehicle and the orange rectangles are the sensors.

![Image of the vehicle](image_url)

**Figure 1.** The green blocks represent the wheels of the robot. Where the orange blocks stand for the
sensors, and the blue circle is the main body.

### 2.2. Vehicle moving strategy

What makes the Braitenberg Vehicle distinguish is the simple structure and programming logic. While
first demonstrated in 1984, it was divided into five types, and all of their velocity was determined by
one parameter, or rather,

\[
\nu = f(x), \omega = g(x) \tag{1}
\]

Where \( \nu \) is the position vector of the vehicle, \( \omega \) is the rotating speed of the vehicle.

Due to the structure of the vehicles mentioned before, that differential turning, distance sensing, and
two-wheel vehicles are adopted; thus, the functions above could be interpreted as the form below.

\[
\omega_L = f(d), \omega_R = f(d) \tag{2}
\]

Where, \( \omega_L \) is the rotating speed of the left motor and \( \omega_R \) is the rotating speed of the right motor.

Using some physical calculation, the velocity (\( v \)) and the rotating speed (\( \omega \)) of the vehicle can be
associated with the rotating speed of the left motor (\( \omega_L \)) and right motor (\( \omega_R \)). As a result, this model
could simplify the regular ternary kinematic differential equation to a binary differential equation.

According to the original demonstration of the Braitenberg Vehicle, there are five kinds of it. Though
all of them obtain the basic feature, their kinematic feature will vary because of different functions \( f(x) \).
Aiming to acquire a relatively high efficiency, the vehicle is designed in the way that it will "be attracted"
by the obstacle when the distance was relatively long and will "escape" from the obstacle when the
distance was short. To be specific, the \( f(x) \) meets the conditions below.

\[
\exists x_0 \in [x_{min}, x_{max}] \left[ f(x_0) = 0, f'(x_0) \leq 0 \right] \tag{3}
\]

\[
f(x_{min}) > 0, f(x_{max}) < 0 \tag{4}
\]

The condition above is the mathematic expression of the operation logic of our Braitenberg vehicle,
and other conditions are also necessary for the simulation. First, because the differential turning is
utilized, thus the difference between \( \omega_L \) and \( \omega_R \) It should be significant enough so that the vehicle
would not show massive inertia during turning.

Second, as a set of distance sensors is utilized to simulate a sector range of detecting, for each round
of detecting, several different figures returning by sensors are produced. For each set of figures, the
smallest one is chosen as the input of the system.

In addition, in case an unexpected situation might occur, other functions are defined. The function
was used to prevent the vehicles from hitting the obstacles or getting stuck. If both of the inputs of the
distance sensor were below a certain figure that set, the vehicle would move backwards for a short time
and rotate a certain degree, then continued to run.
2.3 Explore the environment

2.3.1 Single Robot

Using a single vehicle for exploration, sensors attached to the vehicle return the distance from each obstacle in the unknown environment and make the vehicle avoid the obstacle. By returning the coordinates of the vehicle in the environment, the vehicle's path can be plotted. Considering the exact size of the vehicle, the exact size and location of obstacles can be obtained by taking the path that vehicle can travel throughout the overall environment. When increasing the running time of a single robot, a relatively accurate obstacle environment can also be drawn.

However, when a single vehicle is exploring an unknown environment, the information it can get is extremely limited. Due to lack of interaction with other vehicles, in a limited time, the route repetition of a robot with simple reflections will be very high, which affects the determination of the location of the obstacle. Therefore, the best way is to increase the number of vehicles to save time.

2.3.2 Multiple robots

When multiple vehicles are exploring an unknown environment at the same time, the efficiency of exploration will be greatly increased. The Initial Point is set in the center of the

Figure 2. (a) Single Robot runs for only 1 minute 20 seconds; (b) Single Robot runs for 5 minutes

Figure 3. (a) Quadruple Robot Runs for only 1 minute 20 seconds; (b) Preliminary obstacles analysis

2.3.2 Multiple robots When multiple vehicles are exploring an unknown environment at the same time, the efficiency of exploration will be greatly increased. The Initial Point is set in the center of the
experimental site and gave each car a different initial turning angle. By setting the initial running directions of multiple vehicles differently, the repetition of the vehicles' path will be greatly reduced, which allows us to obtain more obstacle information in an extremely limited running time. At the same time, by determining the different sizes of each vehicle, the road map will be further refined. After measuring the size of the site and combine it with the speed of the vehicle itself, the experiment time should be set at least 1 minute to ensure that the car completes at least one circle around the site. Fig. 4 (a) is a 1 minute 20-second simulation by using multiple robots. Fig. 4 (b) represents an estimated distribution of obstacles by analyzing such a road map.

Furthermore, As can be seen from Fig. 4, the cooperation of multiple robots greatly increases the efficiency of exploration, and if the time and number of experiments can be increased, the effect will be better.

3. Results and Discussion

3.1 Data Analysis The method for data analysis is based on the operation logic of the vehicle. From the Stateflow, it is not difficult to see that when the car goes straight, the minimum space distance for both left and right sides of the car is greater than 0.25 meters. Therefore, in the road map obtained later, these straight-line segments can be translated by 0.25 meters to the left and right to obtain a rectangular area. Combined with the operating logic mentioned above, it can be concluded that there are no obstacles in this rectangular area.

For curved paths, in most cases, the vehicle is turning. When the command of going straight become turning in the Stateflow, the required condition is that the minimum space distance of the side that vehicle will turn to is greater than 0.25 meter. So, if the arc is moved 0.25 meters to the recessed side, there are no obstacles in the obtained area. When the Stateflow command transfer into "turn around," the minimum space distance for both the left and right sides of the vehicle is less than 0.25m. Although this data does not seem to be directly converted into results like the previous two cases, it can also play a role in auxiliary analysis and verification when the final data analysis is conducted.

Figure 4. These two figures are given as examples. (a) The left figure shows the robot's track when it is going straight; (b) it shows the condition when the robot is turning right.
Using the above method, an area without obstacles can be drawn roughly based on the road map of the vehicle, and the shadow part outside these areas is where the obstacle may exist. By increasing the number of samples and superimposing these obtained shadow areas, a more accurate map of the unknown environment can be obtained.

By comparing the actual obstacle distribution and the simulated obstacle distribution, the error rate of each vehicle exploration can be calculated, which serves as the basis for the exploration efficiency. In this particular map, the running time is limited to 300 seconds. Then a relationship between the exploration efficiency and the number of vehicles is obtained by increasing the number of vehicles explored many times, as shown in the figure below.

The incremental function of exploration efficiency is obtained by taking the derivative of the function curve once. Although the greater the number of vehicles is, the higher the exploration efficiency we
have, considering the actual time and space conditions, the most cost-effective choice is to simultaneously conduct 5 vehicles to explore for this particular map.

3.2 Discussion Though the result shows that the movement logic of the Robot is functional, there are still some aspects that can be improved. In the design of Stateflow, a "turn around" part is set to avoid the Robot stuck in corners, and it works perfectly. However, as the value is constant rather than a random value, the Robot can only turn along clockwise, which makes it hard for the Robot to detect the obstacles at the upper left corner. In order to solve this problem, the working logic of the Robot can be simply exchanged, from clockwise to counter-clockwise, and use this as another version of the Robot. In this way, all obstacles can be detected.

From the result, the track of our Robot perfectly explains the definition of Braitenberg Vehicle 4, just like how V. Braitenberg defines the concept in his book [2]. About why created a concept as Braitenberg Vehicle, the original idea of V. Braitenberg is to use the Robot as a tool to explore intelligent creatures, start with a low level, and maybe, someday, will end with human, the most intelligent creature on earth. For now, our work still cannot accomplish so much to reveal the "truth" of human intelligence. However, another path is taken to transfer the idea into a practical tool. As the basic logic behind the Robot is simple, the Robot will be extremely easy to produce. That gives us a chance to use a bulk of robots to conduct a relatively complex mission, like drawing the map of an unknown environment.

4. Conclusion

In this paper, possible solutions have been presented by manipulating multiple robots with simple reflexes to explore an unknown environment. Our research suggested that simple reflex robots are motivated to explore the unknown environment by sticking to an obstacle. A typical robot is modeled with simple reflexes and transformed the mapping of its kinematic behaviors into mathematical rules, applying them to the cellular automata. This research identified that the simulation by cellular automata in MATLAB could depict all the road maps of each Robot. In fact, the size of each Robot can be ignored when the unknown environment is large enough so that the road map of multiple robots can roughly depict the size and distribution of obstacles in the unknown environment. According to the relative length of each route and the distribution of path density on the total road map, we finally determine the best plan for exploration and improvement for energy conservation through quantitative analysis. Due to the decreasing technical content and cost of simple reflexes robots, in the future, the cost of people exploring unknown spaces through robots will be greatly reduced. By increasing the number of robots, similar techniques could be used to explore uncharted areas, such as the ground environment of other planets, to produce relatively precise observations for mapping.
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