

Map Building Method Based On Improved D-S Evidence Theory For Mobile Robot

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Abstract. Focusing on the uncertainty of the environment, a grid map building method based on the multi ultrasonic sensors is provided. Firstly, the single ultrasonic sensor grid model is constructed by dividing the detected area into three regions. Then the evidences which are needed to fuse are self-adaptively approximate in order to remove the counter-intuitive behaviors. Finally, the unknown environment map is built by using the D-S evidence theory to fuse the approximate evidence. Aiming at proving the method is right, the simulation is carried out in Matlab. The simulation result shows that the method is valid in unknown environment map building.

Introduction

In order to make the mobile robot go across the environment easily and avoid colliding with the obstacles, the environment map building method is very important. The environment map is the description of the information detected by the robot. A simple and efficient description can help to give a more effective and accurate map building. Now, there are several map building methods, such as the grid method^[1], topology mapping method^[2], the character method^[3] and the hybrid method^[4]. As the above, the grid method is acceptable by many researchers in map building for its simplicity. So we also use it to build the map. Firstly, a grid map building method based on the multi ultrasonic sensors is given. Then the simulation is carried out, and the result shows that the method is good for avoiding the counter-intuitive behavior and can acquire more accurate map.

Ultrasonic sensor model

Reasonable sensor system can provide enough useful information to the robot map building. Because of its low cost and using easily, most mobile robots indoor or outdoor are equipped with the ultrasonic sensor^[5]. But the ultrasonic sensor's shortcomings are also obvious. Firstly, it uses the TOF(Time Of Flight) to measure the distance. This method can be described by Eq. 1:

$$D_{TOF} = V_{sound} T_{tof} / 2 \quad (1)$$

Where D_{TOF} is the distance between the sensor and obstacle, m. V_{sound} is the sound speed in the air, m/s. T_{tof} is the time of flight, s.

The sound speed depends on several elements, and the theoretical value is not the same as the real one, which can make the difference. Furthermore, the T_{tof} also has the quantization error and can't be measured exactly. So it is inevitable to generate the errors using this method to determine the distance.

Secondly, when an echo is received, it is hard to decide by where the echo is generated. Because the obstacles in the arc with the detected radius r can reflect the ultrasound, as is shown in Fig. 1. In conclusion, the low direction accuracy and the physical character of the ultrasound make the measurement uncertain which should be considered in map building.

Given the sensor detected distance is R , the error is ε , the field angle is β . For the above reasons, the detected sector can be divided into three regions, as is shown in Fig. 2 a):

Region I([0, R-ε]): The grids in this region can be empty generally. It is between the sensor and arc 1.
Region II([R-ε, R+ε]): The grids in this region can be full generally. It is between arc 1 and arc 2.
Region III([R-ε, +∞)): The grids state in this region is unknown. It is outside the arc 2.

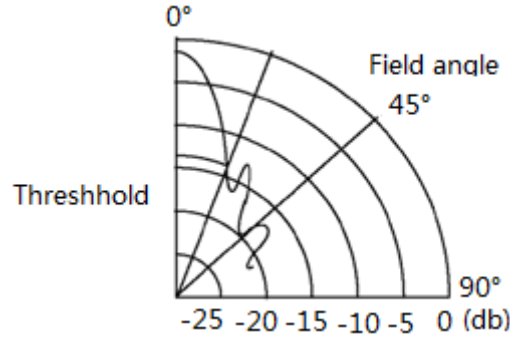


Fig.1 Typical beam pattern showing the threshold level

Then the sensor grid model can be expressed as the following which is shown in Fig. 2 b):

For the grids in region I

$$\begin{cases} P(F) = 0 \\ P(E) = \rho \\ P(\Theta) = 1 - \rho \end{cases} \quad (2)$$

Where $P(F)$ is the probability of the grid is full. $P(E)$ is the probability of the grid is empty. $P(\Theta)$ is the uncertain probability of the grid. ρ is a variable concerned with the grid area.

For the grids in region II

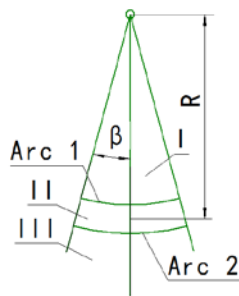
$$\begin{cases} P(F) = 1/n \\ P(E) = 0 \\ P(\Theta) = 1 - 1/n \end{cases} \quad (3)$$

Where n is the quantity of the grids in Region II.

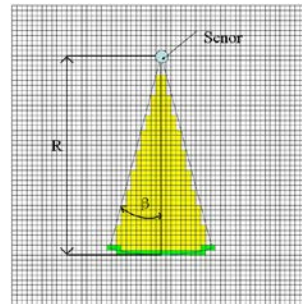
For the grids in region III

$$\begin{cases} P(F) = 0 \\ P(E) = 0 \\ P(\Theta) = 1 \end{cases} \quad (4)$$

The above equations are effective only when the sensor can receive the echo.



a) Ultrasonic sensor model



b) Grid model

Fig.2 The classification of regions in the sensor model

Grid map building method based on improved D-S evidence theory

In fact, the sensor information is always uncertain. Therefore, it is necessary to describe the uncertainty. The researchers have studied the problem, and given several methods, such as the fuzzy sets method [6], the Bayesian probability method [7], Gray uncertain [8], D-S evidence theory [9]. Especially, D-S evidence theory defines an uncertainty measure method which can explain the

possible reason for unknown data. Moreover, it doesn't need to know the priori probability density and conditional probability density which are not easy to acquire in unknown environment.

As we can see, the sensor model probability is similar to the D-S evidence. We can let $m(F)$ and $m(E)$ represent $P(F)$ and $P(E)$, and use the D-S evidence theory to fuse the sensor information.

Because the environment map is built by the grids, and the grid has only two states, full or empty. Let E express empty, and F express full. U is defined as

$$U = \{E, F\} \quad (5)$$

Power set is

$$\Lambda = 2^U = \{\phi, E, F, U\} \quad (6)$$

Each grid state can be expressed by the basic probability of the label in Λ . The basic probability assignment can be calculated by Eq. 2 to Eq. 4

After one sensor measurement, a series of basic probability can be acquired according to the sensor model. Therefore, the detected grids need to fuse the basic probability assignment m_1 and new one m_2 , which the fused basic probability assignment m can be acquired by Eq. 7:

$$\begin{cases} m(\phi) = 0 \\ m(F) = \frac{m_1(F)m_2(F) + m_1(F)m_2(\Theta) + m_1(\Theta)m_2(F)}{1 - m_1(F)m_2(E) + m_1(E)m_2(F)} \\ m(E) = \frac{m_1(E)m_2(E) + m_1(E)m_2(\Theta) + m_1(\Theta)m_2(E)}{1 - m_1(F)m_2(E) + m_1(E)m_2(F)} \\ m(U) = 1 - m(F) - m(E) \end{cases} \quad (7)$$

However, the D-S evidence has the counter-intuitive behaviors. Especially, when the two evidences are contradictory to each other, the behaviors is more obvious. For example, the two evidences m_1 and m_2 are shown in Table 1.

Table 1 The evidence information

	$m(\Phi)$	$m(F)$	$m(E)$	$m(U)$
m_1	0	0	1	0
m_2	0	1/n	0	1-1/n

Fuse m_1 and m_2 based on Eq. 7, and the new evidence m is: $m(\Phi)=0$, $m(F)=0$, $m(E)=1$, $m(U)=0$. No matter what m_2 is, the result m always equals to m_1 . This is the counter-intuitive behaviors. Obviously, when the evidence state is sure, it is never changed after fusion. That means the grid state never update when $m(E)$ or $m(F)$ equals to 1. If the state is wrong, it will make the map building failure.

In order to remove the counter-intuitive behaviors, Cao provides a numerical approximate method to adjust the basic probability assignment. Because of the uncertainty of ultrasonic sensor, the grid state should not be determined by one time which means $m(U)$ should not be set 0^[10]. Although the above method can weaken the counter-intuitive behaviors, the uncertainty of the evidence is bigger. Therefore, a self-adaption numerical approximation method is provided. There are one accumulator to counter how many times the grid is regard as empty and one accumulator to counter how many times the grid is regard as full. These two are called full accumulator and empty accumulator respectively. The Eq. 2 and 3 is transferred as the followings:

For region I the grid evidence can be expressed as Eq. 8

$$\begin{cases} m(\phi) = 0 \\ m(F) = e_2^{(1+k_2+k_1)/(k_2+1)} \\ m(E) = \rho - e_1^{(1+k_2+k_1)/(k_2+1)} - e_2^{(1+k_2+k_1)/(k_2+1)} \\ m(\Theta) = 1 - \rho + e_1^{(1+k_2+k_1)/(k_2+1)} \end{cases} \quad (8)$$

Where e_1 , e_2 are very small positive number, k_1 is the counter number of the full accumulator, k_2 is the counter number of the empty accumulator.

The evidence of the grids in region II can be calculated by Eq. 9

$$\begin{cases} m(\phi) = 0 \\ m(F) = 1/n - e_2^{(1+k_2+k_1)/(k_1+1)} - e_3^{(1+k_2+k_1)/(k_1+1)} \\ m(E) = e_2^{(1+k_2+k_1)/(k_1+1)} \\ m(\Theta) = 1 - 1/n + e_3^{(1+k_2+k_1)/(k_1+1)} \end{cases} \quad (9)$$

Where e_3 is a very small positive number.

Algorithm implementation and simulation

Step 1: Use the multi ultrasonic sensors to detect the environment, and receive each sensor echo.

Step 2: Based on each sensor echo and the sensor model, the grids which are in the sensor beam can be detected. And record the grids status involved and the corresponding status accumulator adds 1.

Step 3: Calculate the grid evidence based on Eq. 8 and Eq. 9.

Step 4: Update the grid map based on the D-S evidence theory.

Step 5: If the map building is over, the grid state can be determined by Eq. 10; if not, go to Step 1.

If $\forall A_1, A_2 \subset \Lambda$, A_I can be regard as the result only when A_I satisfies the following rules :

$$\begin{cases} m(A_1) = \max(m(A_i)) \\ m(A_2) = \max(m(A_i), A_i \neq A_1) \\ m(A_1) - m(A_2) > e_4 \\ m(\Theta) < e_5 \\ m(A_1) > m(\Theta) \end{cases} \quad (10)$$

Where e_4 and e_5 are very small positive numbers.

To show the map building method is correct, the contrast experiments are carried on the Matlab. The environment is 9m×7m and the grid size is 0.05m×0.05m. There are a rectangle and a circle obstacle in the environment. The robot is equipped with five ultrasonic sensor in the left (L), left front (LF), front (F), right front (RF), right(R) with the interval angle of 45 degrees, as is shown in Fig. 3. In order to avoid the disturbance of the sensors, the five sensors is divided into two groups to realize the time division multiple access. First the L, F and R sensors work, then LF and RF sensors work after 0.1s. Assuming the detected range of sensor is between 0.2m and 2m, and the field angle is 15 degree. The mobile robot max speed is 0.05m/s, and the path is shown in Fig. 4. The grid maps built by the method in reference [10] and provided method are separately shown in Fig. 5 a) and b). Compared with Fig. 5 a) and b), the improved method in this passage can acquire more accurate environment information by 20 percent which can make robot location and navigation easier.

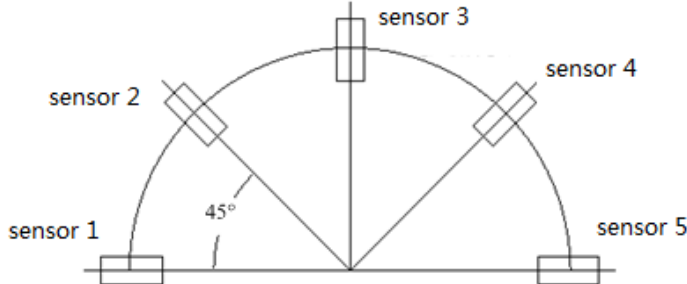


Fig.3 Distribution of ultrasonic sensors

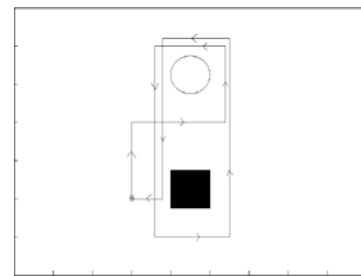
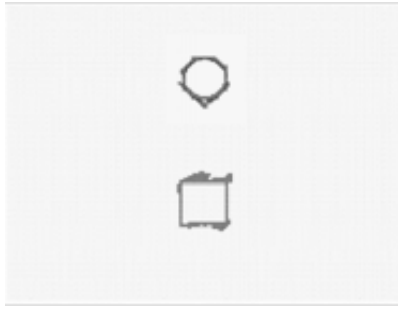


Fig. 4 The environment and robot path



a) Simulation result using method in reference [10]



b) Simulation result using provided method

Fig.5 Comparison of simulation results

Conclusions

Based on the three region ultrasonic sensor model, the environment grid map is built by the improved D-S evidence method for sensor data fusion. This method adopts adaptive numerical approximation to handle the evidence and removes the counter-intuitive behavior. The simulation results also show the provided method is efficient.

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