Cooperative Map Building of Multi-robot Based on Grey Fusion

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Abstract:

This paper focuses on an uncertainty variational environment to build a cooperative map of distributed multi-robot system. A sensor information express method with grey number is introduced, and a sub grid map building of single robot is introduced too. There is a precondition that the autonomous mobile robot have localized by its cyber-vision. Based on grey system theory, a grey fusion method of multi sub-map is designed to gain whole grid map which describes whole environment via communication cooperation among multi-robot. Furthermore, a method is proposed which avoids the sonar interfere among robots. Map building experiments are performed finally on simulation platforms of autonomous robot soccer system. It's shown that the whole cooperative map building method is effective, efficient robust.

Keywords:

Multi-robot, map building, grey fusion, cooperation, uncertainty information

1. Introduction

Environment of autonomous mobile robot includes all kinds of objects connected with it in it's operation space[1]. Firstly, the basic functions of autonomous mobile robot included: identification of object and signpost, self-localization, acquisition of environmental map（building a reasonable environment model）, etc. The mobile robot have to establish maps with it's sensors (such as electronic compass , sonar , laser range finder , vision, etc), when it is in an unknown environment with less priori knowledge. In fact, the processing of a robot establishing maps, is the environment model building of it's operating space with sensing of sensors. The environment model is usually three-dimensional, but can be predigested to two-dimensional model for mobile robot. There are grid maps, geometric maps and topological maps. Among them, grid maps is easy to create and maintain, each grid corresponds to a zone in real environment, and it is convenient for self-localization and path planning, all those make grid maps to be used widely. And gird maps are not suitable for giant environment maps, or instances detailed information are needed.

In distributed multi-robot system, the behavior of each robot is determined by one's own rule, which means they are more flexible and more robustness. So it is more efficient to use multi-robot than single robot in unknown environment exploring, and through the integration of information of different robots, we can improve the accuracy of environmental modeling[2]. Research on map building of multi-robot is at beginning, though it is popular to create maps with single robot in stable unknown environment. More and more attention are put on multi-robot map creating, and people realize it is harder because it's strictly called for the real-time character.

When multi-robot creates maps, we must solve followed problems:

·How to describe uncertainty of sensed information, and create maps of single robot with those information.

·How to cooperate, mutual orientation, merge whole maps with sub maps, and update maps dynamically.

Randomness, fuzzy and grey are three different uncertainty[3]. Randomness is the prediction uncertainty of the test caused because the condition is insufficient. There are uncertainty about thing's character and behavior definition when we are going to understand thing's intermediary between it's respect vertically and horizontally, this is fuzzy. Grey is caused by information incompletion, and can be reduced by information enhanced. They are of three levels of uncertainty, fuzzy is deeper than randomness, and grey is deeper than fuzzy. So grey is more essential and extensive than the other two.

In study of map creating based on sonar

sensed information, fuzzy logic and probability theory are two representative methods [4]. Recently, grey systematic theory has been used for describing and dealing with the uncertainty of sonar information, and creating of environmental grid maps by information merging[5]. As to those methods, least calculation is needed in grey merging, which means grey merging is much suitable for real-time dynamic maps building.

2. The sub grid map building of single robot

In distributed multi-robot system, each robot is an independent autonomous intelligent unit, has it's own subsystems such as decision, communication, vision and perceiving, and electromechanics control. Among them, vision and perceive subsystem can be called information gathering subsystem, including vision and multi-sensor information merging two parts, composed by colored CCD lens, infrared, ultrasonic wave, photoelectricity sensor, electronic compass and their processing systems. Each robot set up sub grid map with it's own perceive (sonar and electronic compass, etc.) at first.

There are two basic problems must be solved in single robot's sub grid map building: uncertainty describing and map expressing. The key step is describing and processing of uncertainty information, since both the esthesia information and uncertainty of those information are shown in the map.

2.1. The description of uncertainty sensor information

Sonar sensor are widely used in mobile robot navigating, as it is low-priced , simple to use , convenient for data processing. At the same time, there are great uncertainty in the sonar sensing information, as it's emissive wave is cone-shaped with low angle, and multi-reflection exists in it's echo.

Mobile robot measure the distance between itself and obstacle with sonar sensor, gather obstacle information in relative short range (3 meters commonly). This method is called time-of-flight. Reference [6] provides the sonar characteristic of time-of-flight through a large number of experiment research, which consist of distance characteristic and angle characteristic. If we use $\Delta(\rho)$ represent distance confidence function and $\Gamma(\theta)$ represent angle confidence function, we'll get:

$$\Gamma(\theta)=\begin{cases}1-21(\frac{\theta\pi}{180})^2, & |\theta|\le\alpha/2\\ 0, & |\theta|>\alpha/2\end{cases} \qquad (1)$$

$$\Delta(\rho)=1-\frac{1+\tanh(2(\rho-\rho_v))}{2} \qquad (2)$$

Among them, ρ means the distance between a random point (x, y) and the sonar, θ means the azimuth of this point to the axis of sonar's sound wave, α is the biggest scattering angle that the sonar sensor can be perceived, ρ_v is sonar sensor's smooth transition from relative fixed range to uncertain range. And we can figure out Fig. 1(a) and 1(b) below:

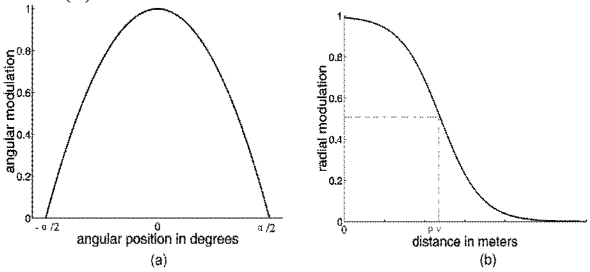

Fig.1 the confidence function of sonar sensor

In addition, Reference [5] describes the uncertainty of sonar's axial measurement value with confidence function f_1:

$$\underline{f}_1(\rho,r)=\begin{cases}0, & |\rho-r|\ge\Delta r\\ 1-(\frac{\rho-r}{\Delta r})^2, & |\rho-r|<\Delta r\end{cases} \qquad (3)$$

$$\overline{f}_1(\rho,r)=\begin{cases}1, & \rho\le r-\Delta r\\ 0, & \rho>r-\Delta r\end{cases} \qquad (4)$$

Among them, r is distance to the obstacle, Δr is estimated coverage width of the obstacle.

2.2. The grey number express of map

In grey systematic theory, grey number is a number which we know it's range but do not know it's precise value, it may be an uncertain number in a district or a data aggregation, we can name grey number with 'Θ'. District grey number can be expressed as $\Theta\in[a, b]=\{(x, v(x)| x [a,b], a,b\in R\}$. $[a, b]$ is Θ's grey field, b is upper certain limit, while a is bottom certain limit. If a grey number can be defined as a certain value, then this certain value is the grey's white value. We can turn grey number to white value with more and more additional information added.

We define the background of grey number Θ with Ω , $\Theta\subset\Omega$, and we can call $\overline{\Theta}=\Omega-\Theta$ is Θ 's complementary aggregation. Then we define measure degree of grey number Θ value filed with $\mu(\Theta)$, we can define information quantity of grey with this equation:

$$I(\Theta)=\mu(\overline{\Theta})/\mu(\Omega) \qquad (5)$$

And, $0\le I(\Theta)\le 1$, $I(\Omega)=0$。

If we grid robot's active area U to grid $m\times n$, each grid C_{ij} has acreage $\delta\times\delta$. Then, every point in this area correspond to a certain grid $C_{ij}(x, y)$, we describe U as :

$$U=\{C_{ij}(x, y) \mid i \in [1 \ldots m], j \in [1 \ldots n]\} \quad (6)$$

Each grid $C_{ij}(x, y)$ represent a continuous grey number district $\Theta_{ij} \in [a_{ij}, b_{ij}]$, which indicate the possibility of this grid been occupied by obstacle. When the background is $\Omega = [0, 1]$, which means $a_{ij}, b_{ij} \in [0, 1]$, we get:

$$a_{ij} = v\underline{f}_1(\rho, r)\Gamma(\theta)\Delta(\rho) \quad (7)$$

$$b_{ij} = 1 - v\overline{f}_1(\rho, r)\Gamma(\theta)\Delta(\rho) \quad (8)$$

Among them, a_{ij} means the most optimized estimation (no obstacle), however, b_{ij} means the most pessimistic estimation[5].

We define arithmetic average value of grey number with $\Theta_M = (a + b) / 2$, which shows comprehensive evaluation of uncertainty. Then, we can use this number as white number of the grid:

$$\Theta_{Mij} = (a_{ij} + b_{ij})/2$$

$$= \begin{cases} [1 - v\Gamma(\theta)\Delta(\rho)]/2, & r - \Delta r \geq \rho \\ [1 + v\underline{f}_1(\rho, r)\Gamma(\theta)\Delta(\rho)]/2, & r - \Delta r < \rho < r + \Delta r \\ 1/2, & r + \Delta r \leq \rho \end{cases} \quad (9)$$

At the beginning of map building, environment information are all zero, and all grid can be initialized to : $\Theta_{ij} \in [0, 1]$, $\Theta_{Mij} = 0.5$.

2.3. The sub grid map building

If the robot number in a multi-robot is N, we represent the k-th (k=1, 2…N) robot with R_k. Based on the vision system has been self-localized, position of a robot and it's sensor is $R_k(x_k, y_k)$, and it is in grid $C_{pq}(i=p, j=q)$. In ideal environment, a robot occupies one grid, and this grid's white value is 1, $\Theta_{pq}=1$, $a_{pqk} = b_{pqk} = 1$.

There are 16 evenly distributed sonar sensor around each mobile robot. Each sonar sensor deals with a fan-shaped area, circled on the robot and contained angle 22.5°. In order to avoid inter infection of these sonar, each sonar detect it's own area alternate with time slot τ. To those sonar with confident range of 3 meters, $\tau = 20ms$. We know scattering angle of each sensor ($\alpha \geq 22.5°$), and the measured distance r to obstacle. As to any point (x, y) in U, we can get the distance ρ between this point and the sonar which can sense it, and we can get azimuth θ of this point to the axis of sonar's sound wave.

We bring this parameters into (9) and get the arithmetic average grey value Θ_M of the grid correspond to this point (x, y). We represent mobile robot's sub grid map with a $m \times n$ matrix consisted of Θ_M.

$$\overrightarrow{M_k} = [\Theta_{M\,ij}]_{m \times n} \quad (10)$$

After that, we bring those parameters into (7) and (8), we will get upper and bottom certain limit (a_{ij}, b_{ij}) of gird correspond to this point. Then we make a $2m \times n$ matrix consisted of (a_{ij}, b_{ij}), this matrix will describe the sub grid map of mobile robot:

$$\overrightarrow{R_k} = [a_{ij}, b_{ij}]_{2m \times n}$$

$$= \begin{bmatrix} a_{11} & b_{11} & a_{12} & b_{12} & \cdots & a_{1n} & b_{1n} \\ a_{21} & b_{21} & a_{22} & b_{22} & \cdots & a_{2n} & b_{2n} \\ \cdots & \cdots & & & & & \\ a_{m1} & b_{m1} & a_{m2} & b_{m2} & \cdots & a_{mn} & b_{mn} \end{bmatrix}_{2m \times n} \quad (11)$$

The sub grid map $\overrightarrow{R_k}$ provides grey number district $[a_{ij}, b_{ij}]$ for grey fusion. And another sub grid map $\overrightarrow{M_k}$ with $m \times n$ matrix will provide robot uncertainty comprehensive evaluation of it's active area.

In a stable unknown environment, every new sub grid map will be information complementarity to maps those have built before. A new map can be built from old maps and new information. But in a variational environment, especially environment with great changing (such as autonomous robot soccer system), new map are built from new gathering information. Certainly, the boundaries of map may be stable.

3. The whole grid map building of multi-robot

The communication system of distributed multi-robots is Wireless LAN (WLAN) based on IEEE 802.11b standard, with which robots can communicate with each other in point to point type or broadcasting type. IEEE 802.11b standard supports each information transmission quantity to 2312 bytes (18496 bits) at the most. If we represent transmit relevant controlling information with 12 bytes (such as information type, object and source code, grid code p and q of source robot etc.), then the largest map information that can be transmitted once will reach 2m×n=2300 bytes, and corresponded map will be m×n=1150 bit.

A robot is appointed as RC in advance in multi-robot system. Robot RC will require sub grid map from every robot regularly, and each robot will send it's sub grid map to robot RC.. Then RC will merge all R_k with grey number, and a whole grid map will be built and broadcasted to every robot.

3.1. The grey fusion of two sub grid map

As for gird unit C_{ij}, grey number from different sub map of robot R_k and robot R_l will be represent separately as $\Theta_{ij}^k \in [a_{ij}^k, b_{ij}^k]$ and $\Theta_{ij}^l \in [a_{ij}^l, b_{ij}^l]$, $l \neq k$, $k, l = 1, 2 \ldots N$.

While environmental information is zero and grey number is completely uncertain, arithmetical average grey value Θ_M will be 0.5. Make this as the boundary, if Θ_{Mij}^k and Θ_{Mij}^l both greater or less than 0.5, we call it information consistent; if one of Θ_{Mij}^k and Θ_{Mij}^l is greater than 0.5 and the other one less than 0.5, we call it information inconsistent.

The grey fusion of map information will be separated into three conditions: information is zero, information consistent and information inconsistent, and corresponded grey fusion arithmetic will be:

1) information is zero

$[a_{ij}^k, b_{ij}^k]\equiv[\max(a_{ij}^k, a_{ij}^l), \min(b_{ij}^k, b_{ij}^l)$;

2) information consistent

$\Theta_{ij}^k \equiv \Theta_{ij}^k \cap \Theta_{ij}^l$

If Θ_{Mij}^k and Θ_{Mij}^l both greater than 0.5:

$[a_{ij}^k, b_{ij}^k]\equiv[\max(a_{ij}^k, a_{ij}^l), \max(b_{ij}^k, b_{ij}^l)$

If Θ_{Mij}^k and Θ_{Mij}^l both less than 0.5:

$[a_{ij}^k, b_{ij}^k]\equiv[\min(a_{ij}^k, a_{ij}^l), \min(b_{ij}^k, b_{ij}^l)$

3) information inconsistent

$\Theta_{ij}^k \equiv \Theta_{ij}^k \cap \Theta_{ij}^l$,

$[a_{ij}^k, b_{ij}^k]\equiv[\min(a_{ij}^k, a_{ij}^l), \max(b_{ij}^k, b_{ij}^l)$

Here, in order to make it convenient for grey fusion of every two robots, grey number after fusion will be : $\Theta_{ij}^k \in [a_{ij}^k, b_{ij}^k]$.

3.2. The whole grid map building

According to grey fusion arithmetic before, robot R_C merge every two maps of all N pieces of maps $\overrightarrow{R_k}$, after (N-1) times of calculation, whole grid map $\vec{R}$ will be created. And $\vec{R}$ will be a $2m\times n$ matrix too. The merging process is as Fig.2 shows:

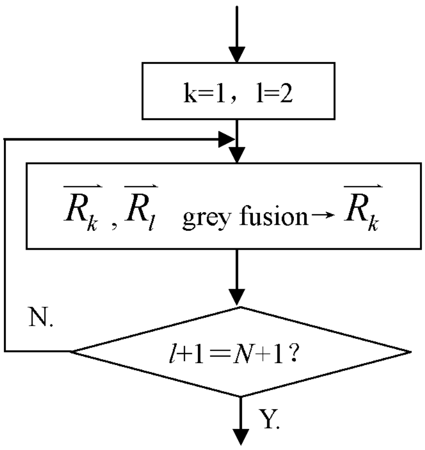

Fig.2 a grey fusion flow of multi map

We get white value Θ_{Mij} of each grid with equation (9), then consist those values into whole gird map represent as $m\times n$ matrix:

$$\overrightarrow{M} = [\Theta_{M\ ij}]_{m\times n} \tag{12}$$

Sub gird map $\vec{R}$ represents as $2m\times n$ matrix are used in multi map grey fusion, and whole gird map $\overrightarrow{M}$ represent as $m\times n$ matrix offers global localizing, path planning and behavior decision to robot.

In a stable unknown environment, multi-robot cooperating is aimed to get whole grid map more accurately and comprehensive. At this condition, robot R_C broadcasts $\vec{R}$ to every robot, then every robot merges new sub grid map it measures with $\vec{R}$ and builds a new map. More and more information will be complemented into maps in this kind of circular repeating, until the system get stable whole grid map finally.

In a variational environment, multi-robot cooperating is aimed to get whole grid map more comprehensive. Since each robot does not need remerging of new measurement, it just need real-time dynamic environment information. At this condition, robot R_C broadcasts $\overrightarrow{M}$ to every robot.

4. The sonar interfere and its resolvent

There are mainly two kinds of sonar interfere in distributed multi-robot system. One kind of interfere is among different sonar of one same robot, since each robot has a lot of sonar senor. Another kind of interfere is between sonar of robot R_k and robot R_l, $k,l=1, 2...N, l\neq k$. As to the first, every robot's each sonar emits and receives ultrasonic in turn with time slot τ *(see chapter 2.3).*

While robot R_k and robot R_l are both in effective range of sonar detecting, they maybe receive ultrasonic from each other, and cause mistakes of judgment and distance measurement. This paper solves this problem with the principle of CDMA (Code Division Mulitiple Access) [7] .

Ultrasonic wave is a kind of square wave with frequency 40KHz and cycle 25μs. We suppose a sonar emit 8 pulses each time, correspond to 8 bit binary code. We define it as ID code of each robot, which can be regard as each station's chip code sequence in CDMA system. According to principle of CDMA, 0 in chip code sequence will be written as -1, and 1 in code serial will be written as 1, then this binary chip code sequence will be turned to code vector.

Chip code sequence of each station in CDMA system must be different and vertically from each other. Vertically from each other means vectorial accumulation of two different vector is 0. Only code vector's own vectorial accumulation is 0. Vertically code serial adopts false random serial.

When a robot emits ultrasonic, hardware circuit will handle sonar source with it's ID code to process ASK of serial code. If there are other robots' sonar interfere exist, information the robot received will be superposing of all ultrasonic. Therefore, firstly hardware circuit will regulate figure of ultrasonic, identify code serial of received signal and turn it into chip code vectors, then get the vectorial accumulate result of the receiving chip code vector and the hardware circuit's chip code vector, only vector with result not zero will be pick out as it's echo.

So, in order to avoid sonar interfere of different robot, every robot emit 8 pulses of ultrasonic, and these ultrasonic will be coded with 8 bit binary code vertically with each other.

5. The imitate result

Fig. 3 is a field of autonomous robot soccer system of RoboCUP Middle-Size League. Suppose the gate line of own half field is X axle of world coordinate system, and left boundary line of own half field is Y axle of world coordinate system, and left corner as origin point *O*, the line passing center point of the robot and parallel to the line passing two center points of the robot's trailing wheels is axes *QQ'* , and the angle ψ between *QQ'* and X axle of world coordinate system is azimuth of soccer robot. Then a random point P in U has a position coordinate $P(x, y)$, a robot's station can be described as $R_k(x_k, y_k, \psi_k)$. If we make $R_k(x_k, y_k)$ as origin of polar coordinates, point P's polar coordinate will be $P(\rho, \varphi)$. Then we can get:

$$\rho = \left| \sqrt{(x-x_k)^2 + (y-y_k)^2} \right| \tag{13}$$

$$tg\phi = \frac{y-y_k}{x-x_k} \tag{14}$$

Each mobile robot have 16 evenly distributed sonar around, and if we give the sonar sensor which has central axes coincident with *QQ'* a serial number $v=0$, and other sonar sensor with serial number $v=1,2...15$ in anticlockwise direction. Then, each azimuth θ_v of point P to each sonar sensor's wave central axes will be :

$$\theta_v=\psi+22.5v-\varphi \tag{15}$$

And $v=0,1...15$。

RoboCUP Middle-Size League stipulates: the projection of soccer robot in the field must be less than 50cm×50cm. When the match field U is 6m×9m, δ=25cm , acreage of each grid C_{ij} will be 25cm×25cm, and number of girds will be $m \times n$=24×36. The largest map information will be $2m \times n$=1728 bytes, less than the limit length WLAN and can be transmitted one time.

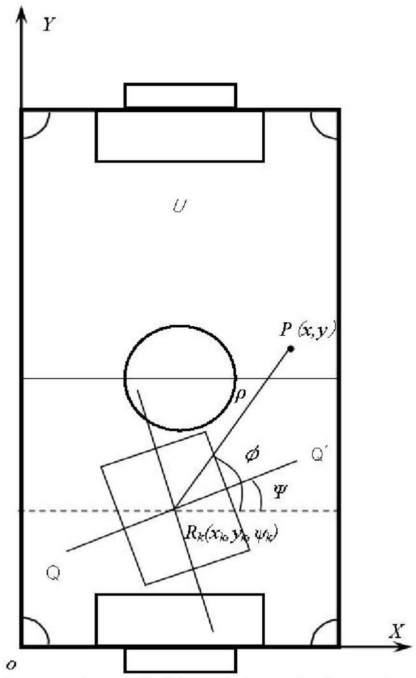

Fig.3 the *U* field and the relation of two coordinates

Fig. 4(a) is one moment status in a 3 VS 3 of RoboCUP Middle-Size League. Fig. 4 (c), Fig. 4 (d) and Fig. 4 (e) are sub gird maps of robot number 1、2 and 3. And Fig. 4(b) shows the last whole grid map based on grey fusion.

As we can see, the map built can basically reflect the situation of environment obstacles, and realize the cooperated map building of autonomous robot soccer system.

6. Conclusion

Multi-robot cooperated map building is based on grey fusion, and grey number is used to represent uncertain information of sonar, and sub grid map of single robot is set up. There is a precondition that the autonomous mobile robot have localized by its cyber-vision. And then focuses on a variational unknown environment, a grey fusion method of multi sub-map is designed to gain whole grid map which describes whole environment via communication cooperation among multi-robot, based on grey system theory.

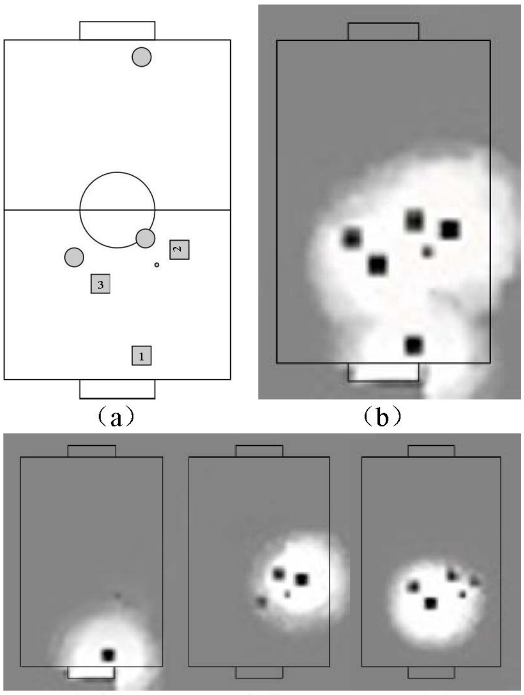

Fig.4 the imitate result

This paper analyze problems such as robot's ID identification and sonar's interfere, a method is proposed which avoids the sonar interfere among robots. Map building experiments are performed finally on simulation platforms of autonomous robot soccer system. It's shown that the whole cooperative map building method is effective, efficient robust. Any mistake of single robot will not affect operation of the whole system. It is especially suitable for dynamic map building of autonomous multi-robot system.

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