J. Automation & Systems Engineering 1-1 (2007): 12-22

Regular paper

JASE
Journal of Automation & Systems Engineering

MAP BUILDING FOR MOBILE ROBOT USING FUZZY LOGIC

F. Lachekhab, H. Rezine and L. Kahoul

We present in this paper, a method of map building using the information of the ultrasonic sensors of a mobile robot. This method is based on the decomposition of the environment to square cells and the concepts of fuzzy logic where at each cell a membership function occupied or empty is affected. This ¶local information will be aggregate by filtering out insufficient or conflicting information in a global representation of empty and occupied spaces to obtain a representative map of the environment.

Keywords:.

1. INTRODUCTION

One of the most important problems in mobile robotics is to equip the robot with the possibility of moving in an unknown environment. This faculty is essential when the robot exerts its tasks in hostile environments (contaminated zone, space, sea …), or for the robots of service (cleaning, service....). In order to facilitate the installation of a mobile robot in a new environment, it is important that the robot can also explore its workspace in an autonomous way but most effectively possible.

Indeed, if the robot must achieve several tasks in a working area of a static environment, it can be convenient to make an exploration in order to rebuild the environment exactly. The high cost of such operation (computing time and the memory capacity), will be compensated by the facility to plan on an overall known map. In addition, a total knowledge of the environment allows an optimization of trajectory by minimizing a given criterion. In this paper, we present a method of map building of the environment using the perceptual information of the ultrasonic sensors. This map must be available at each moment.

The paper is organized as follows. In section II, we present our experimental platform witch is the mobile robot Pioneer II. In section III we detail, the various concepts of this approach which is based on the decomposition of the environment in cells and the concepts of fuzzy logic where we affect at each cell a membership function of empty or occupied. The experimental results are presented in section IV with their discussions. In section V we give the influence of different parameters used in our approach.

2. EXPERIMENTAL PLATFORM

Consider a mobile robot Pioneer II (Figure 1) with ultrasonic range finders (8 ultrasonic sonar) that must travel from its initial position to a final desired position across unknown two-dimensional (2-D) environment.

Laboratory of control and command, EMP BP 17, BEB 16111, Algiers ALGERIA. Fadila_la@yahoo.fr, rezine_hacene_emp@yahoo.fr.
Laboratory of Structure Mechanics, EMP BP 17, BEB 16111, Algiers ALGERIA. kahoul_l@yahoo.fr

Figure 1. The robot Pioneer II.

Pioneer P2-dx with its modest size lends it to navigation in the tight corners and spaces encumbered such as classrooms, the laboratories and small offices. For the detection of obstacles, it has a line of eight ultrasonic sensors through eight transducers placed in its front. The fields of measurements of these sensors lie between 10 cm of minimal range and 5 m maximum range.

The robot Pioneer II is controlled by the Saphira software developed by Kurt Konolige of the International Laboratory of Artificial Intelligence (SRI). From the version 8.x, several functions of core of Saphira were moved completely with the software ARIA "Activmedia Robot Interfaces for Application". Saphira and Aria are written in C++ language, and their API is used for of the properties of the objects C++ to provide an effective interface to the programming of the robots.

For facilities of programming, we used a diagram block, integrated in Simulink and using the API (S-Function), which gathers the principal functions of Saphira of perception, localization and orders.

Throughout the paper, we assume that a localization system provides the robot with its absolute position with respect to a fixed inertial frame.

3. THE PROPOSED APPROACH

The solution suggested allows the incremental construction of a representation of the environment of the mobile robot. Its originality arises mainly in the use of a particular model of the environment which is easily incorporated and modified during the movement of the robot by an algorithm without memory which does not require any post-processing.

By choosing a suitable model of the environment, we must take account of the insufficiencies of the ultrasonic sensors, which can give erroneous information in some conditions. Fuzzy logic provides a robust and effective tool to control the uncertainty presented by the ultrasonic sensors. In fact, the fundamental theory is developed starting from less axioms of constraint than the theory of probability, so that a broader choice of the operators is available to model uncertainty and to incorporate information coming from the multiple sources.

Consequently, instead of trying to rebuild a deterministic model of the environment, we adopt an intrinsically dubious map, defined by a graph in which at each node (or cell) is associated to fuzzy sets "occupied" or "empty" [1]: the degree of membership associated to these fuzzy sets reflects the possibility of membership or not of an obstacle. The resulting representation is similar to a grid of occupation, generally obtained by using the stochastic techniques.

The map building process is in charge of gathering through the sensors information about the environment at a given robot position and of processing it in order to update the available map in accordance. The basic steps are as follows (figure 2).

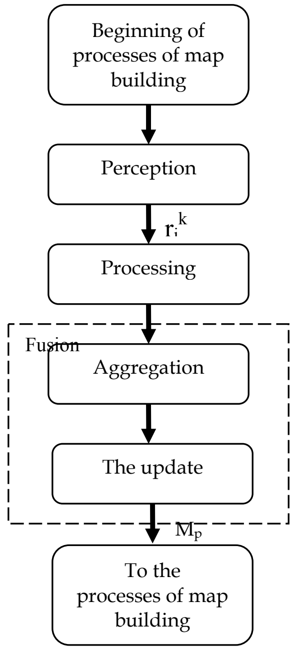


Figure 2. The proposed approach

As mentioned in the previous section the k^{th} map building process consist of three phases, i.e perception, and fusion see (figure 2). In the perception phase, a packet of ultrasonic measures r_i^k for $i = 1,.., n$ are collected from the same robot position and fed to the processing phase, which is in charge of generating two local representations of the empty and the occupied space, i.e. two local fuzzy sets ζ^k and ∂^k.

During the fusion phase, the local information is aggregated to the global representation of the empty and occupied space, which is contained in two global fuzzy sets ζ and ∂ so as to update the further fuzzy set M_p (planning map).

Below, each phase of the map building process is described in detail.

4. THE MAP BUILDING PROCESS

It takes care of the collection of the information given by the various ultrasonic sensors on the environment for a given position of robot and their treatment in order to update the map of the environment. The basic steps of this process are as follows: perception, treatment, fusion. The local representation is integrated in the total representation by eliminating contradictory and insufficient information.

3.1 Perception

The multi-lobe model of the beam of the transmitter of each sonar can be represented by the function of directivity of radiation:

$$D(\vartheta) = 2\frac{J_1(\omega p \sin\vartheta)}{\omega p \sin\vartheta} \quad (1)$$

where J_1 is the first order Bessel function, $\omega = 2\pi l$ depends on the wave length. $l = c/v$ with c is sound speed in air and v is a constant 49.410 KHz, ϑ is the azimuthally angle measured with respect to the beam central axis [2]. For practical considerations, it is sufficient to take into account only the principal lobe.

3.2 Processing

The objective of this phase is to build the fuzzy sets ζ^k and ∂^k respectively representing the empty cells and the occupied. To model each reading sonar, we introduce the following membership function:

$$f_\zeta(\rho, r) = \begin{cases} k_\zeta & 0 \le \rho < r - \Delta r \\ k_\zeta (\frac{r-\rho}{\Delta r})^2 & r - \Delta r < \rho < r \\ 0 & \rho \ge r \end{cases} \quad (2)$$

$$f_\partial(\rho, r) = \begin{cases} 0 & 0 \le \rho < r - \Delta r \\ k_\partial \left[1 - (\frac{r-\rho}{\Delta r})^2\right] & r - \Delta r < \rho < r + \Delta r \\ 0 & \rho \ge r + \Delta r \end{cases} \quad (3)$$

These expressions (figure 3) combine the possibilities and the certainty on the occupation of the cells [3]. They characterize the degree of certainty of the assertions "space is empty" and "space is occupied" according to the variable ρ which represents the distance from sonar given to a point of the environment.

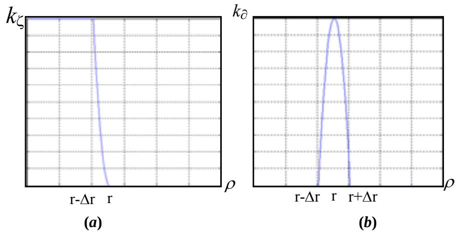


Figure 3. The two certainty functions (*a*) f_ζ. (*b*) f_∂.

The intensity of the principal lobe decreases from the principal axis of the cone and tends towards zero on the sides of the cone.

This characteristic can be modeled by the function of modulation m (ϑ) figure (5)

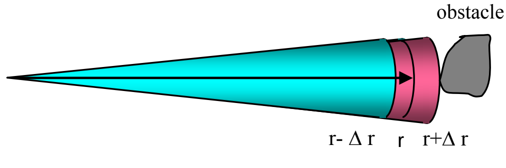


Figure 4. Ultrasonic sensing.

This characteristic can be modeled by the function of modulation m (ϑ) figure (5)

$$m(\vartheta)=\begin{cases}D(\vartheta) & |\vartheta|\le 12.5^\circ \\ 0 & |\vartheta|\ge 12.5^\circ\end{cases}$$

$D(\vartheta)$ is the function defined by the equation (1).

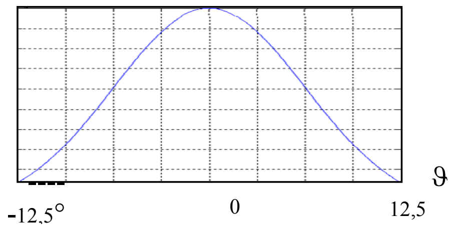


Figure 5. Modulation function $m(\vartheta)$.

We define also another function known as function of visibility as follows:

$$v(\rho)=\begin{cases}1 & \rho\le\rho_v \\ 0 & \rho>\rho_v\end{cases} \quad (5)$$

Where ρ_v is a constant which depends on the characteristics of the environment to model. This function limits the influence of the reading to an area close to the position of the sensor and to limit the effect of the false reflections of the ultrasonic waves.

Thus for a set r_i^k of measurements, two fuzzy sets ζ_i^k and ∂_i^k are defined by their membership functions:

$$\mu\zeta_i^k(\rho,\vartheta)=f_\varepsilon(\rho,r_i^k)m(\vartheta)v(\rho)$$
$$\mu\partial_i^k(\rho,\vartheta)=f_\partial(\rho,r_i^k)m(\vartheta)v(\rho) \quad (6)$$

The final step of this phase consists in determining the fuzzy subsets ζ^k and ∂^k in which are collected the local information obtained by the sonar's by using the fuzzy operator of union to measures of the sensors.

$$\zeta^k=\cup_i\zeta_i^k$$
$$\partial^k=\cup_i\partial_i^k \quad (7)$$

3.3 Fusion

The task of this phase is double:

- To integrate local information ζ^k and ∂^K in two global sets ζ and ∂ (spaces free and occupied respectively).
- To combine these sets suitably in order to calculate the fuzzy map M_p, this is used in the process of navigation, i.e. the map update.

1) Aggregation

The fusion of the data is carried out by the use of an operator of aggregation. The choice of this last depends on the nature of the data [3] [8]. In our study we carried out several tests with the various types of the operators and we noted that the operator max gives satisfactory results. The global fuzzy sets are then given by the equation (8).

$$\begin{aligned} \zeta &:= \zeta \otimes \zeta^k \\ \partial &:= \partial \otimes \partial^k \end{aligned} \tag{8}$$

The new functions of membership for a cell C are thus given by the equations (9) and (10)

$$\mu_{\varepsilon \cup \varepsilon^k}(C) = \frac{(N_k(C) - 1)\mu_\varepsilon(C) + \mu_{\varepsilon^k}(C)}{N_k(C)} \tag{9}$$

$$\mu_{\partial \cup \partial^k}(C) = \frac{(N_k(C) - 1)\mu_\partial(C) + \mu_{\partial^k}(C)}{N_k(C)} \tag{10}$$

Where $N_k(C)$ is the number of perception.

2) Update of the map

The final step of the process of the map building of the environment consists in updating the fuzzy map M_p (planning map) by using the results of aggregation: global fuzzy sets ζ and ∂. Since the fuzzy sets □and of the occupied and empty cells are not complementary, their intersection gives the fuzzy set of the ambiguous cells with a membership functions representing the degrees of contradiction:

$$A = \zeta \cap \partial \quad A=\zeta\cap\partial \tag{11}$$

In the same manner, the fuzzy set of the unspecified cells is defined like the complement of the fuzzy set of the ambiguous cells:

$$I = \overline{\zeta} \cap \overline{\partial} \tag{12}$$

For planning, we determine a fuzzy map in which these cells are acceptable for planning. We define then the map Sp (safe for planning):

$$S_p = \zeta^2 \cap \overline{\partial} \cap \overline{A} \cup I \tag{13}$$

Finally, the map M_p of planning is given by (14):

$$M_p = \overline{S}_p \tag{14}$$

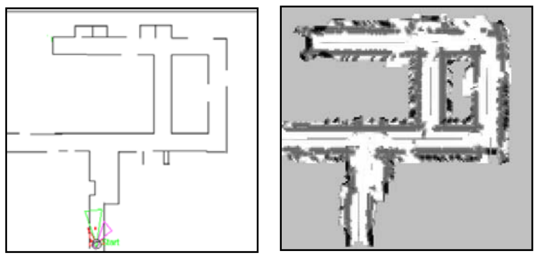
4. RESULTS OF EXPERIMENTATION

We present some results of map building obtained by the method detailed previously. Our first test is carried out on one surround made up of several rooms and corridors having of the openings towards the others as it are represented on the figure (6).

The environment of widths (6m×7m) is decomposed into (60×70) square cells of dimension 100mm. The robot moves in the corridors without entering the rooms. The explored areas which not contain any obstacle are represented in white, figure (6) right and the areas where the occupied cells (presence of obstacles) are represented on the same figure in black, grey space represents the areas which were not still explored by the robot.

We observe on the elaborate map that the shapes of the corridors and the rooms are reproduced by the process of map building suggested.

Dimensions of the environment are overall respected. On the fuzzy map, some details are correctly reproduced (as the reinforcement in top on the right) but on the other hand certain too fine details (too small openings) of the environment are not easily identifiable in a clear way.



Map of the real environment

Fuzzy map of environment

- Empty space (free)
- Space not yet explored
- Occupied space (obstacles)

Figure 6. Map of the real environment 1 and its fuzzy map Mp

We chose of the values from the K_ζ constants, K_∂ and ρ_v must be done according to the nature of the obstruction of the environment [7]. In this simulation we used the same opening of 25° for the cones of all the sensors ultrasounds and the following values of the parameters indicated in Table I.

TABLE I Values of THE PARAMETERS Used

K_ζ	K_∂	Angle of the cone	ρ_v	Δr
0.1	0.1	25°	1.2 m	200 mm

In the second test we increase the obstruction of the environment like its dimensions (15m×15m). It contains five rooms and of the corridors of different widths. To build the map corresponding to this environment, initially we decompose to square cells of dimension 100mm. The elaborate M_p map is represented on the figure 7. The occupied cells which correspond to obstacles or walls are represented in black. It is noted that some obstacles do not appear very clearly and this is due mainly to the false reflections of the wave sonar's. Open spaces which were explored by the robot are represented in white. They correspond to the corridors connecting the rooms. The unexplored cells are represented in clear gray. They correspond to the spaces not seen by sonar.

In the following we present a construction of map of part of the corridor of the laboratory of control and command (fig 8 left) which comprises an opening (a half open door) with the real robot. The robot moves in the corridor and during its displacements, it builds the walls and the exits on the map of fig (8). The process of construction adopted reproduced the environment satisfactorily.

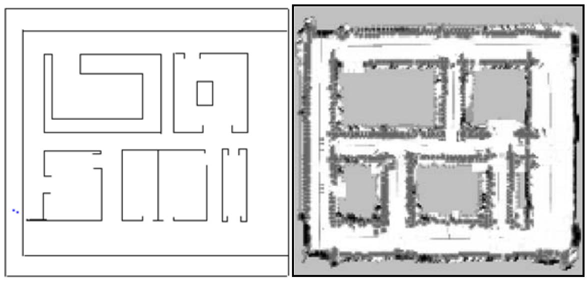


Figure 7. Map of the real environment 2 and its fuzzy map Mp

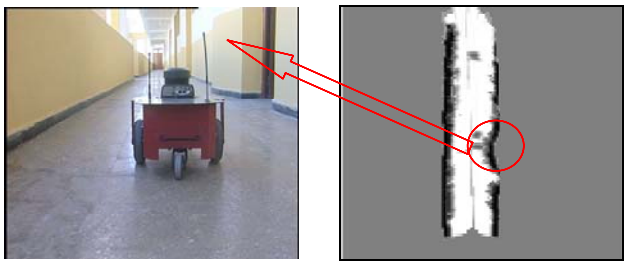


Figure 8. Map building of the real environment with the robot Pioneer II

5. INFLUENCE OF THE PARAMETERS

To study the influence of the parameters we chose a representative simple environment in which several possible situations are considered figure 9. The robot must move from the initial point **A** towards the final point **B**, the obstacles are located on both sides course. Between the various obstacles there are openings of different size.

The universes of the membership functions (occupied and empty) are determined by the values of the distance r and Δr, the value of this last distance must be carefully selected to reproduce a more or less faithful representation of the real environment

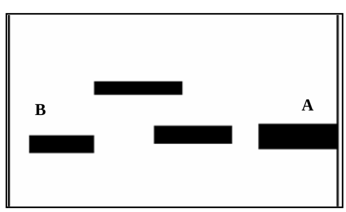


Fig .9. Test environment

In the first, we study the influence of the variation of the parameter Δr on the map built while keeping the values of the other constants fixed in all simulations. The openings of the cones of all the sonar are identical.

The values of the parameters used are given in the following table:

TABLE II: Values of the used parameters.

K_ζ	K_∂	Angle of the cone	ρ_v	Δr
0.1	0.1	25°	1.2 m	200 mm

A. Influence of the value of Δr

The general form of the environment is recognized for all the values of Δr tested and the obstacle of the top and the three others of bottom are detected. The obstacles are represented in black, open space or vacuum is represented in white and surfaces in gray represent the environment not explored by the robot.

From fig (10) we can make the following observations:

- If the value of Δr is more significant, the obstacles are better represented (fig 10 (a) and (d)).The increase in the value of Δr underlines the obstacles and the fact of appearing, in the map, by broad surfaces.
- If the value of Δr is more significant, so the small openings are detected. By comparing figures (10) (a) and (d) we observe that the small opening of the bottom on the right of the environment in (d) is not detected.

In conclusion, the parameter Δr must be correctly

adjusted so as to find a good balance between the clearness of the detected obstacles and the precision with which details of the environment are reproduced.

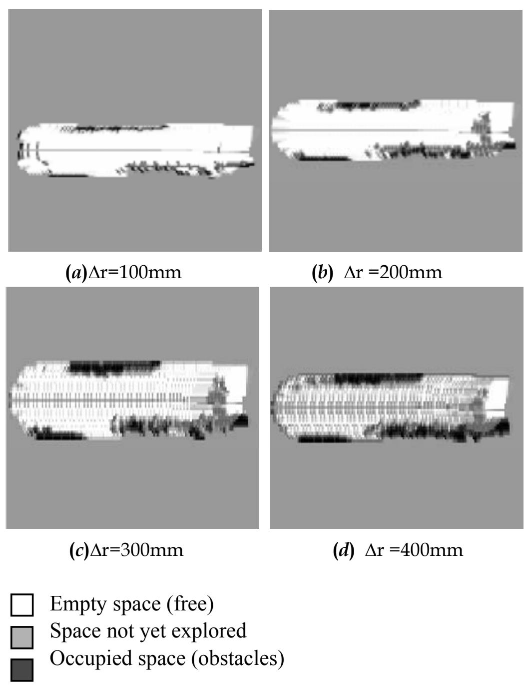


Figure 10: Influence of the parameter Δr.

B. Influences of the parameters K_ζ *and* K_∂

In a second test, we study separately the influence of the parameters K_ζ and K_∂. The values of the other parameters are indicated in Table III.

K_ζ and K_∂ are the maximum values which the membership functions of empty "and " occupied " can have respectively". For values of K_ζ higher than 0.2, the obstacles practically also do not appear in our tests we took values lower than this value.

TABLE III: Values of the used parameters

Δr	P	Angle of the cone	ρ_v
200mm	0.0201	30°	1.2 m

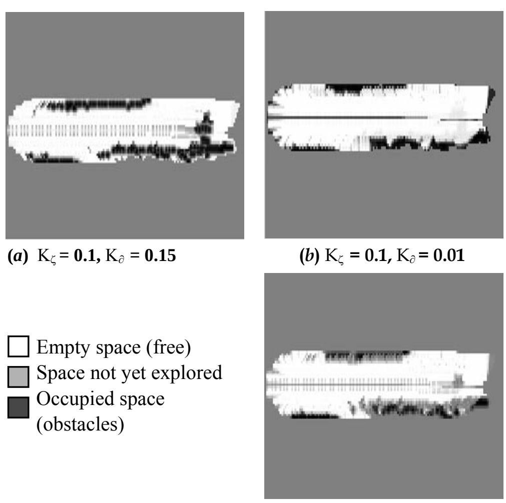
By fixing the value of the parameter K_ζ at 0.1, we study the effect of the parameter K_∂.

When this parameter is equal to the value of 0.15, the obstacles as well as the openings are well represented except for the small opening of the bottom on the right of the real environment. On the built map, the obstacles appear clearly at the borders of the explored zone. In the case of a low value of K_∂, the obstacles are more largely announced and more inside the explored zone and the small opening of the bottom on the right of the environment is practically not detected.

Thus for the parameter K_∂, it is necessary to avoid choosing too low values. Values close to 0.15 should provide results of an acceptable quality.

The influence of K_ζ is studied by comparing figures (11) (b) and (c). Low values of K_ζ make it possible to obtain a better representation of the environment, thus on the figure (c) the obstacles appear wide and rather clear at the borders of the explored zone. Moreover small details of the real environment are reproduced better than for larger values of K_ζ (0.1).

In conclusion, it is preferable to choose values of the parameter K_ζ lower than 0.1 and values of K_∂ higher than 0.1.



(*a*) K_ζ **= 0.1,** K_∂ **= 0.15** (*b*) K_ζ **= 0.1,** K_∂ **= 0.01**

(*c*) K_ζ **= 0.010,** K_∂ **= 0.01**

Figure 11. Influences parameters K_ζ and K_∂

6. CONCLUSION

In this paper, we presented a method which allows the incremental construction of a representation of the environment starting from the readings sonar. The principal interest of this method lies in its simplicity of implementation and its operation in real time.

By choosing a suitable model of the environment, we must take account of the insufficiencies of the ultrasonic sensors, which can give erroneous information under certain conditions. Fuzzy logic provides a robust and effective tool to control uncertainty related to the measurements provided by the sensors ultrasounds. Then, we examined the influence of the principal parameters of the method on quality of the built map. The results obtained are considered to be satisfactory.

REFERENCES

[1] G. Oriolo, G.Ulivi, and M. Vendittelli : "Fuzzy Maps: A New Tool For Mobile Robot Perception and Planning", Department of Informatic Systematic, University of Roma, Italy, Department of Mechanics and Automatic, University Terza Roma, Italy, 2000.

[2] G. Oriolo, G.Ulivi, and M. Vendittelli: "Real-Time Map Building and Navigation for Autonomous Robots in Unknown Environments", Member, IEEE, IEEE Trans. On SMC- Part Cybernetics, Vol. 28, N°3, June 1998.

[3] G. Oriolo, G. Ulivi, and M Vendittelli: "Real-Time Map Building and Navigation for Autonomous Robots in Unknown Environments", IEEE Trans. on SMC, 1999.

[4] K. Singh and K. Fujimura: "Map Making by Cooperating Mobile Robots". Proceedings of the IEEE International Conference on Robotic and Automation. Vol .2 Atlanta, Georgie, 1993, pp. 254-259.

[5] S. Thrun: "Learning Maps for Indoor Mobile Robot Navigation", Computer Science, Department and Robotics Institute, Carnegie Mellon University, Pittsburgh, September 1997, pp. 1-60.

[6] S. Thrun: "Learning Metric-Topological Maps for Indoor Mobile Robot navigation". Artificiel Intelligence, 1999, pp 21-71.

[7] H. Moravec and A. Elfes: "High Resolution Maps from Wide Angular Sensors". In Proceedings of the IEEE International Conference, On Robotics and Automation. IEEE Computer Society Press, 1985.

[8] O. Sullivan: "An Empirical Evaluation of Map Building Methodologies in Robotics Using the Feature Prediction Sonar Noise Filter and Metric Grid Map Benchmarking suite". University of de Limerick, Master Thesis, November 2003.

[9] F. Lachekhab: "Planification et navigation à base de la logique floue d'un robot mobile dans un environnement partiellement connu". Polytechnic Military School, Magister Thesis, Alegria, Decembre 2005.