

Optimized Fuzzy Logic Based Algorithm for a Mobile Robot Collision Avoidance in an Unknown Environment

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ABSTRACT: Fuzzy logic has been introduced to deal with vague, imprecise and uncertain problems. A fuzzy logic controller can be regarded as an expert system that is able to process qualitative variables and to infer crisp values out of uncertainty. Hence, fuzzy logic can find applications in many aspects of real life that exhibit incomplete information, as where there is lack of information, there is uncertainty. A good example of such an application is in autonomous mobile robot navigation in unknown environments. A mobile robot, having to navigate purposefully from a start location to a target location, needs two basic requirements: sensing and reasoning. However, the pervasive presence of uncertainty in sensing makes the choice of a suitable tool of reasoning and decision making, that can deal with incomplete information, vital to ensure a robust control system

This paper first explains what is imprecision and uncertainty in mobile robot navigation in unknown environments. It proposes a fuzzy logic approach to secure a collision free path avoiding multiple static obstacles; where the robot is the only moving object. The most peculiar aspects of the proposed method are in decreasing the number of fuzzy rules and in optimizing the choice of fuzzy sets parameters, rules, and memberships.

KEYWORD: autonomous mobile robot, collision avoidance algorithms, fuzzy logic controllers, optimisation methods.

1. INTRODUCTION:

Navigation of a machine is the control of motion of that machine from a start point to an end point in a workspace following a path that is either a curve or a series of joined segments. Autonomous navigation systems are usually classified in the following categories according to the characteristics of the environment in which they have to move: structured or known environment, semi-structured or partially known environments, and unstructured or unknown environments.

The problem of collision free navigation body in a known terrain has been extensively studied. Tzafetas¹ grouped the off-line techniques for dealing with obstacle avoidance in the following groups: "Projection, retraction and optimal motion planning techniques, configuration space techniques, gradient and potential filed techniques, variational dynamic programming techniques, finally mutli-agent techniques."

However, when the robot moves in a partially or completely unknown workspace, the off-line techniques cannot be applied¹. Thus, the sensor-based local path planning, called obstacle avoidance is required in the navigation of mobile robots. The repulsive force² and the virtual force filed concepts³ could be applied. However, these methods have shortcomings as it is difficult to find the force coefficients of effect on the velocity and direction of mobile robots in complex workspaces that can not be described as a mathematical model⁴. Another classical way is to send the robot to discover its world and define some landmarks that can used for navigation⁵. In similar conditions, the robot relies heavily on its sensors, map making and updating. However, natural workspaces present a large amount of uncertainty, and mapping techniques are time and memory consuming techniques. Hence, the need for an approach such as the fuzzy logic⁶⁷⁸ that can cope with all uncertainties and can deal with various situations without being provided or having to provide models and workspace maps.

This paper presents an algorithm to find a collision free path for a mobile robot. The robot moves from a start point S to a target point T in a completely unknown environment populated with static obstacles. The robot is equipped with an on board laser scanner.

The algorithm described adopts fuzzy logic subsets and memberships to endow the robot with an ability to take decisions despite of environmental uncertainties. Section 2 gives a background on fuzzy logic subsets and memberships. Section 3 explains about workspace uncertainties and how fuzzy logic can overcome them. The last two sections illustrate the algorithm and show some results of computer simulations used to verify the algorithm.

2. FUZZY LOGIC:

Fuzzy logic was introduced by Zadeh in 1965 as a mathematical way to represent uncertainty in everyday life. It can provide the means to represent vague and fuzzy information, manipulate it, and to draw inferences from it⁹.

In ordinary mathematics, information is of a crisp kind. It belongs to a set or it does not. The choice of a yes-or-no answer is possible and usually applied, but information could be lost in such a choice, as the degree of belonging is not taken into consideration. A fuzzy model is the idea of a fuzzy set. A fuzzy set differs from conventional (crisp) sets in its semi-permeable boundary membrane. Instead of a characteristic function that has 2 states, inclusion (1) or exclusion (0), the fuzzy set has a function that admits a degree of membership in the set from complete exclusion (0) to absolute inclusion (1). The value zero is used to symbolize complete non-membership, the value 1 is used to symbolize complete membership, and values in between are used to symbolize intermediate degrees of membership. Membership in a fuzzy subset should not be on a 0 or 1 basis, but rather on a 0 to 1 scale; that is the membership should be an element of the interval [0,1].

A fuzzy concept is a linguistic variable used to define a fuzzy subset, as CLOSE or FAR for a range of obstacle^{10 11}. A Fuzzy set comes as a generalization of conventional set theory. It is a superset of conventional (crisp) logic that has been extended to handle the concept of partial truth – truth values between “completely true” and “completely false”; allowing intermediate values between crisp values⁹.

3. UNCERTAINTY AND FUZZY LOGIC IN UNKNOWN ENVIRONMENTS:

The development of techniques for autonomous navigation in real-world environments constitutes one of the major trends in the current research on robotics, noting that a robot is autonomous when it is able to move purposefully with no help or intervention from a human user in un-engineered real-world environments.

One of the important aspects that is still deemed important to consider in mobile robots is collision avoidance. Saffiotti¹² ¹³believes that this could be due to the nature of real world environments; in the sense that maps known a priori often have insufficient information, and can be subject to dynamic changes during navigation. Prior knowledge about the environment is, in general, incomplete, uncertain, and approximate and the lack of data is the reason for uncertainty in many daily problems¹⁴. A pertinent problem in autonomous navigation is the need to cope with the large amount of uncertainty that is inherent of natural environments, plus to be cope with and respond reactively to unforeseen events as soon as they are perceived. Moreover, uncertainty can occur in sensory data caused by environmental features, and errors in the measurement interpretation process. Traditional ways of overcoming the uncertainty problem involved carefully designing the robot, or engineering the space, or both. Automated guided vehicles (AGVs) have adopted methods such as following white or magnetic lines using adequate sensors, and others. However, if the purpose is to build robots with robust control that can be used in any area of application without having to engineer the area itself, the robot should be armed with more intelligence, and should have its autonomy increased¹².

Fuzzy logic has features that make it an adequate tool to address this problem; as it takes uncertain data, processes it, and obtains certain and finite data. Applications in mobile robot navigation have been adopting fuzzy logic approaches over the last two decades^{6 7 8 15}. The approach this paper is proposing divides the space into three categories range wise and into six categories direction wise. However, this approach tries to prove that it is enough just for the areas of highest danger coefficients to cause the robot to change direction, which consequently reduces the number of fuzzy rules that control the robot motion. In the end, an optimisation algorithm is applied in the purpose of improving the system performance, where efficiency is improved by reducing the distance traveled by the robot to reach its target.

4. FUZZY LOGIC CONTROLLER:

The four principal components of the fuzzy decision-making systems are¹⁶ (see Fig. 1):

1. The fuzzification interface: determines input and output variables and maps them into linguistic variables that are to be displayed on a universe of discourse.
2. The knowledge base: is a part of expert systems that contains the domain knowledge¹⁴. Membership functions and control rules are decided by the experts at this point, based on their knowledge of the system.
3. The decision-making logic: treats a fuzzy set as a fuzzy proposition. One fuzzy proposition can imply another, and two or more fuzzy propositions can be associated by a Boolean connectivity relation to infer a final fuzzy proposition.
4. The defuzzification interface converts the fuzzy output into a crisp (nonfuzzy) value.

There are seven major tasks performed each time a fuzzy logic controller system is developed¹⁴.

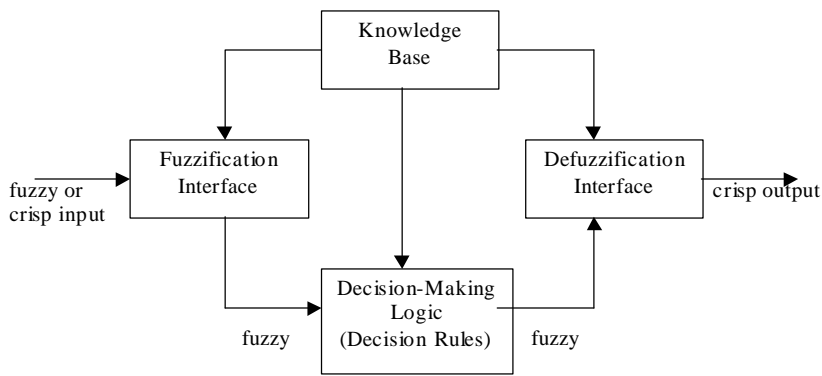


Fig.1 Basic configuration of fuzzy decision making system (FDMS)

1.1. TASK 1: DEFINE THE PROBLEM:

Our study takes place in the context of an environment totally unknown to the robot. An acquisition process is needed to obtain information about the robot environment: a laser range finder has been mounted on the front of the robot for this purpose. The laser scans in a semi-circle, returning range and direction types of data from detected obstacles.

In the workspace, the robot moves progressing toward its target, scanning in a semi-circle orthogonal to the direction of its motion. Each time the laser scans, a resolution module is applied to determine the number of detected obstacles.

Robot safety is obtained by avoiding stationary objects along the way. The Fuzzy-based collision avoidance algorithm admits two inputs: range of the obstacle from the robot, and the direction of the obstacle with respect to the robot (see Fig.2). And, two outputs are inferred: a deviation angle of the robot to avoid the obstacle and a distance the robot is advised to travel away from a feasibly obstructing obstacle to ensure its safety, before it heads back in the direction leading to the Target location.

1.2. TASK 2: DEFINE THE LINGUISTIC VARIABLES FOR INPUTS AND OUTPUTS

The linguistic variables are the same for the input and output range and direction sets. A range has the subsets: Far (F), Medium (M), Near (N). A direction has the subsets: Large Negative (LN), Medium Negative (MN), Zero Negative (ZN), Zero Positive (ZP), Medium Positive (MP), Large Positive (LP) (see Fig. 3).

1.3. TASK 3: DEFINE THE FUZZY SETS

The laser scans in a range of tens of meters. Each obstacle detected has a depth variable from the robot (see Fig.2). This depth or range data has a different membership in each of the three range subsets. The range universe of discourse is

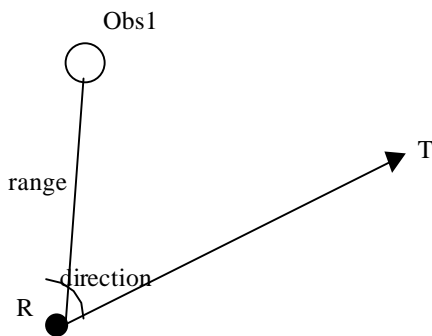


Fig.2 Robot-Obstacle relationship

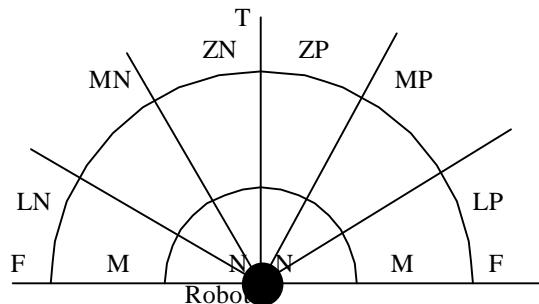


Fig.3 Division of the space in fuzzy subsets

discretized into 8 parameters or levels with 3 fuzzy sets, where parameters and membership functions are chosen heuristically (see Fig. 4).

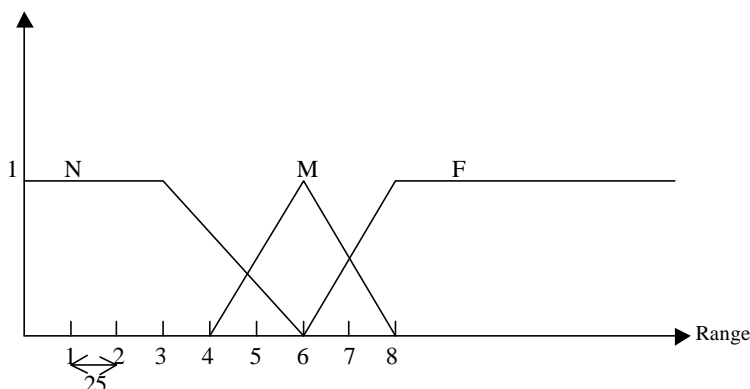


Fig.4 The Membership function for the set "range"

The laser scans from -90° to $+90^\circ$. This scope is divided in six subsets: Left Negative, Medium Negative, Zero Negative, Zero Positive, Medium Positive, Large Positive; where each subset has a membership function. Fig.5 shows the distribution of the directions with respect to the six fuzzy concepts or subsets, where the range universe of discourse is discretized into 13 parameters or levels with 6 fuzzy sets, where parameters and membership functions are chosen heuristically.

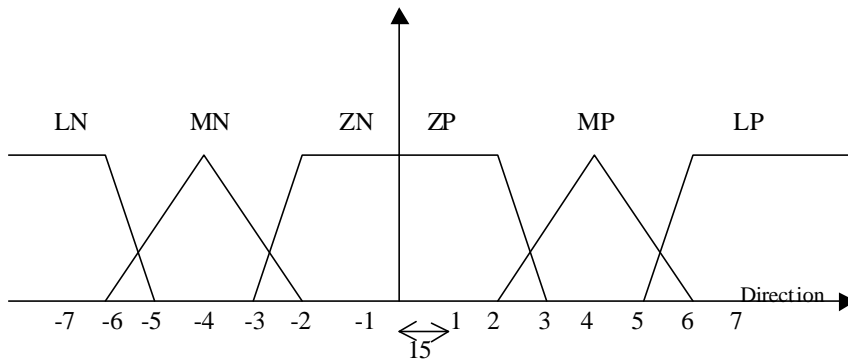


Fig.5 Membership function for the set “direction”

1.4. TASK 4: DEFINE THE FUZZY RULES

Each rule in the fuzzy knowledge base corresponds to a fuzzy relation. There are rules that contain single premises of the form “IF X THEN Y). However, rules with multiple premises are more widely used, such as “IF X AND Y THEN Z”.

For an autonomous robot navigating among stationary obstacle in an unknown environment, it would be computationally expensive to produce $3*6=18$ rules as well as inefficient to divert the robot from its trajectory for each fired rule. Hence, this paper considers the zones of highest risk which happen to be combinations of (Near And Zero Negative), or (Near And Zero Positive).

Each rule admits two inputs and implies two outputs, as follows:

- If (range is Near And angle is Zero Positive) Then distance is Medium and angle of deviation is Zero Negative.
- If (range is Near And angle is Zero Negative) Then distance is Medium and angle of deviation is Zero Positive.
- If (range is Medium And angle is Zero Positive) Then distance is Near and angle of deviation is Zero Negative.
- If (range is Medium And angle is Zero Negative) Then distance is Near and angle of deviation is Zero Positive.

(The system is tested in 1.6)

1.5. TASK 5: DEFUZZIFICATION

The laser range finder upon detecting an obstacle, returns range and orientation information to the fuzzy logic. A “GetMembership” routine is applied iteratively to get different range and direction memberships. The specified fuzzy rules are applied afterwards (see Fig. 6).

In a crisp system the intersection of two sets contains the element that are common to both sets. This is equivalent to the common logical AND operation. In conventional fuzzy logic, the AND operator is supported by taking the minimum of the truth membership grades. Range Outputs and Deviation Outputs from all the fired rules are respectively multiplied in a Maximum relation so that final outputs are defuzzified using the Centroid method¹⁴ (see Fig. 6). One of the most commonly used method for defuzzification is the Centroid method also known as Centre of Area (COA) method.

Where d_i is the i 'th domain value, and $\mu(d)$ is the truth membership value for that domain point.

$$R = \frac{\sum d_i \cdot \mu_A(d_i)}{\sum \mu_A(d_i)} \quad (i=0,n),$$

1.6. TASK 6: TEST THE SYSTEM

To verify the algorithm a simulation was run. The navigation algorithm described was implemented as a C program running in a Windows 95 environment. For the simulation test we have just specified the start point, the target point and velocity of the point robot. It has been done different simulated navigation tests in real time. Fig 7.1 and Fig 7.2 show examples of robot navigation in cluttered environments. In these examples, the environment is totally unknown by the robot and no memorisation or mapping has been done (see Fig7.1 and Fig 7.2).

1.7. TASK 7: TUNE THE SYSTEM

Efficiency is increased by minimising both the distance travelled and travel time, but to obtain the optimal set of fuzzy memberships and rules is not an easy task. And despite the fact that a heuristic and iterative procedure for altering the fuzzy memberships and rules to improve performance has been proposed, it is still not optimal. Recently, more interest is being shown in “tuning” fuzzy sets, memberships and rules such as using “genetic algorithms”, “neural network”, and “simulated annealing”¹⁷. Simulated annealing is the scheme currently applied for tuning the proposed system.

5. CONCLUSION:

This paper deals with the real-time navigation of a mobile robot in a totally unknown environment. It applies fuzzy reasoning to endow a mobile robot with the human being ability to reason and perceive danger.

Based on fuzzy logic, a collision free algorithm has been proposed that partitions a robot space into twelve zones of danger, where just four of them triggers the fuzzy rules. The obstacle with the highest danger coefficient is specified and a retreat vector is calculated by the defuzzification process. The fuzzy logic controller system is tuned using an optimisation method “simulated annealing”. This algorithm has been validated in different unknown environments cluttered with static obstacles and has proven to give the robot the means of safely reaching the Target.

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