Fuzzy Path Generation for Autonomous Mobile Robot Navigation

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***Abstract*—**In this paper we present an algorithm for fuzzy path planning to a target for mobile robot in unknown environment. The aim of this work is to develop an algorithm which allows a mobile robot to navigate through static obstacles, and finding the path in order to reach a specified target. We propose an algorithm that provides the robot a trajectory to be followed to move from the initial position to the specified target. The robot trajectory is designed in a grid-map form of a known environment with static unknown obstacles. The proposed approach can deal a wide number of environments. This system constitutes the knowledge bases of FL *approach* allowing recognizing the fuzzy situation of the target localization and obstacle avoidance, respectively. This approach can be realized in efficient manner and has proved to be superior to combinatorial optimization techniques, due to the problem complexity. This approach based on intelligent computing offers to the autonomous mobile system the ability to realize these factors: recognition, learning, decision-making, and action (the principle obstacle avoidance problems). The algorithm permits the robot to move from the initial position to the desired position following an estimated fuzzy trajectory.

***Keywords*—**path planning, fuzzy logic, Autonomous Mobile Robot (AMR), navigation.

I. Introduction

The control complexity is overcome by decomposing the navigation control problem into more simple and well-defined sub-problems that can be controlled independently and in parallel. These sub-problems and their controllers are known as reactive behaviours, and this approach is known as behaviour robotics. It has attracted the interests of many roboticists and has even been used in industrial process control applications .Since its introduction in some research reports the behaviour robotics has grown quickly resulting in the development of reactive fuzzy behaviour.

The concept of behaviour control was initially seen as a special form of decentralized switching control in which each behaviour is fully autonomous, and when allowed, can control the robot on its own without regard to other behaviours.

Under what we will call the standard behaviour paradigm, each behaviour triggers a single control command that best meets the control responsibilities specific to that behaviour. Hence, the behaviours are essentially competing. This 'switched parallel' structure works fairly well when the switching is relatively rare, but the performance of the robot to be indecisive. If used in cluttered environments, where behaviour switching is likely to be high, such approach behaviours as fully autonomous, which tends to cause the robot to be indecisive when the behaviours have mutually exclusive interests with nearly equal importance. This observation led becomes very poor if the behaviour switching frequency becomes high, which can lead the robot to be indecisive. If used in cluttered environments, where behaviour switching is likely to be high, such an approach is also likely to fail.

A robot is a mechanical intelligent agent that can perform tasks automatically or with guidance, typically by remote control. In practice a robot is usually an electro-mechanical machine that is guided by computer and electronic programming. One of the major challenges in the field of robotics is transportation, scientist are always looking for new ways to make robots moving faster and carrying heavier loads and turning around tightly.

The transportation models that were used where either robots that move on 4 wheels, or robots that move on.
two legs, however both these robots have drawbacks , the robots that move on four wheels move fast and carry heavy loads , however they cannot turn tightly, they need a relatively large area to turn from one direction to another, in the other hand the robots that moves on two legs '' humanoid robots'' can turn from one direction to the other easily and in a small space, however the humanoid robots cannot carry heavy loads, and cannot move fast, so the challenge was how to invent a robot that is able to move fast and carry heavy loads and at the same time it can turn quickly and in a relatively small area.

Over time, there have been concerted efforts to make behaviours run cooperatively so that the overall robot reaction is generally an amalgamation of the commands from the individual behaviours through some form of command fusion. However, most of these efforts have been based on developing fuzzy versions of the standard behaviour structure in which each behaviour chooses one action out of the possible actions, in this case a fuzzy action.

These structures were found to have performance problems especially since they treat to the introduction of what we will collectively refer to as
preference-based behaviour systems[1,3,4,5,6,7].

The autonomous robot navigation problem has been studied thoroughly by the robotics research community over the last years. Contemporary methods for robot navigation do not considerably take into account the robot motion uncertainty, which may lead to the execution of false actions by the robot. Probabilistic methods that integrate uncertainty in motion planning have not been well studied until now, in contrast to probabilistic methods for mapping and localization. The basic feature of an autonomous mobile robot is its capability to operate independently in unknown or partially known environments. The autonomy implies that the robot is capable of reacting to static obstacles and unpredictable dynamic events that may impede the successful execution of a task. To achieve this level of robustness, methods need to be developed to provide solutions to localization, map building, planning and control.

The development of such techniques for autonomous robot navigation is one of the major trends in current robotics research.

The robot has to find a collision-free trajectory between the starting configuration and the goal configuration in a static or dynamic environment containing some obstacles. To this end, the robot needs the capability to build a map of the environment, which is essentially a repetitive process of moving to a new position, sensing the environment, updating the map, and planning subsequent motion
Autonomous robots which work without human operators are required in robotic fields. In order to achieve tasks, autonomous robots have to be intelligent and should decide their own action. When the autonomous robot decides its action, it is necessary to plan optimally depending on their tasks. More, it is necessary to plan a collision free path minimizing a cost such as time, energy and distance. When an autonomous robot moves from a point to a target point in its given environment, it is necessary to plan an optimal or feasible path avoiding obstacles in its way and answer to some criterion of autonomy requirements such as : thermal, energy, time, and safety for example. Therefore, the major main work for path planning for autonomous mobile robot is to search a collision free path. Many works on this topic have been carried out for the path planning of autonomous mobile robot[10,11,12,13,14].

Motion planning is one of the important tasks in intelligent control of an autonomous mobile robot . It is often decomposed into path planning and trajectory planning. Path planning is to generate a collision free path in an environment with obstacles and optimize it with respect to some criterion. Trajectory planning is to schedule the movement of a mobile robot along the planned path . Several approaches have been proposed to address the problem of motion planning of a mobile robot. If the environment is a known static terrain and it generates a path in advance it said to be off-line algorithm. It is said to be on-line if it is capable of producing a new path in response to environmental changes.

Previous research on the path planning can be classified as following one of two approaches: model-based and sensor – based. In general, the model-base approach considers obstacle avoidance globally it uses prior models to describe known obstacles completely in order to generate a collision free path. In contrast, the sensor-based approach aims to detect and avoid unknown obstacles.

This paper deals with the fuzzy intelligent path planning of intelligent autonomous mobile robots AMR in an unknown environment. The aim of this paper is to develop an AMR algorithm for the AMR stationary obstacle avoidance to provide them more autonomy and intelligence[2].

Artificial intelligence, including Fuzzy logic has been actively studied and applied to domains such as automatically control of complex systems like robot. In fact, recognition, learning, decision-making, and action constitute the principal obstacle avoidance problems, so it is interesting to replace the classical approaches by technical approaches based on intelligent computing technologies. This technologies FL is becoming useful as alternate approaches to the classical techniques one. The proposed approach can deal a wide number of environments. This system constitutes the knowledge bases of FL *approach* allowing recognizing the fuzzy situation of the target localization and obstacle avoidance, respectively. This approach can be realized in efficient manner and has proved to be superior to combinatorial optimization techniques, due to the problem complexity. This approach based on intelligent computing offers to the autonomous mobile system the ability to realize these factors: recognition, learning, decision-making, and action (the principle obstacle avoidance problems). The results are promising for next development.

II. Movement sensors

Sensors measure the movement of the robot and pass that information to the PIC microcontroller. Several movement sensing techniques are used today; the most common of these are: Light sensors, accelerometers, ultrasonic sensors. The main characteristics of sensors are:

Accuracy

Accuracy is the capacity of a sensor to give results to give results close to the true value of the measured quantity.

Resolution

Resolution is the minimal change of the input necessary to produce a detectable change at the output.

Precision

Precision is the capacity of a sensor to give the same reading when respectively measuring the same quantity under the same prescribed conditions.

D. Range

Range is the maximum and the minimum value range over which a sensor work we

E. Linearity

Linearity is the closeness of the calibration curve to a specified line.

Types of sensors are

A. Ultrasonic sensors

The Ultrasonic sensor is a device you can use with the microcontroller to measure how far away an object is. We can use the ultrasonic sensor to measure the position of the robot with respect to the floor, by offsetting this sensor a two centimeters from the axle of rotation of the robot and pointing it toward the floor, the microcontroller calculates the time taken by the sound to travel to the floor and back

to the microphone, this time will increase or decrease as a function of the angel formed by the robot and the floor.

B. Accelerometers

An accelerometer is a device that measures the vibration, or acceleration of motion of a structure. The force caused by vibration or a change in motion (acceleration) causes the mass to "squeeze" the piezoelectric material which produces an electrical charge that is proportional to the force exerted upon it. Since the charge is proportional to the force, and the mass is a constant, then the charge is also proportional to the acceleration.

C. Light sensors

Light sensors can be used to measure the distance of an object with respect to the floor , and thus light sensors can be used as movement sensors. we have many kinds of light sensors, the most commonly used sensors are : the photovoltaic cells.

III. Mapping and Cognition of the Environement

The use of map to structure our environment has often been more efficient than previous technique. The difficulty in building a map of the environment lies in the cognition representation. For same types of navigation, it is more advantageous to use an implicit one. In the intelligent robot behaviour, this environment model map has an important role to play.

Hence, attracting the sensory input space is more interesting to understand and to extract information from the space of navigation. This is can be interpreted by map building. Map building is based on three descriptions which are: geometrical level, topological level and semantic level. For the first one the aim work is focused on the cartographer work" where the flat earth model viewable area is an ideal planner surface S defined by the points of contact of the objects projected into the ground.

The second illustrates the features map; it consists of the decomposition on free and occupied space, and gives a relationship between the free spaces. In this case, a grid-map is more suitable for the unknown environment.

To search a valid, safe path in the model of grid-map presentation, an intersection of parallel horizontal and vertical lines is the key of digital field analysis that is the way to interpret safety and danger areas. In the previous step , the topological level provides the entering of organization map and offers all features associated with the appropriate environment. In this context, the homogenous grid-map obtained must be associated with appropriate level useful in real-time, learning , generalizing, and approaching human-like reasoning for each particular situation, this association is achieved by :

P is 1 : if grid is occupied (danger *obstacle* area) .
P is 0 if not.

Robot control navigation

Traditionally, motion planning and control have been separate fields within robotics. However, this historical distinction is at best arbitrary and at worst harmful to the development of practically successful algorithms for generating robotic motion. It is more useful to see planning and control as existing on the same continuum.

The control task becomes more complex when the configuration of obstacles is not known a priori. The most popular control methods for such systems are based on reactive local navigation schemes that tightly couple the robot actions to the sensor information. Because of the environmental uncertainties, fuzzy behaviour systems have been proposed by researchers. The most difficult problem in applying fuzzy-reactive-behaviour-based navigation control systems is that of arbitrating or fusing the reactions of the individual behaviours, which is addressed in this work by the use of preference logic.

It was shown in simulation and experimental results that the proposed method allows the robot to smoothly and effectively navigate through cluttered environments such as dense forests.

The goal of the navigation process of mobile robots is to move the robot to a named place in a known, unknown or partially known environment. In most practical situations, the mobile robot can not take the most direct path from the start to the goal point.

Hence, navigation techniques must be used in this situation, and the simplified kinds of planning mission involve going from the start point to the goal point while minimizing some cost such as time spent, chance of detection, or fuel consumption.

One of the key issues in the design of an autonomous robot is navigation, for which, the navigation planning is one of the most vital aspect of an autonomous robot. Therefore, the space and how it is represented play a primary role in any problem solution in the domain of mobile robots because it is essential that the mobile robot has the ability to build and use models of its environment that enable it to understand the scene navigation's structure. This is necessary to understand orders, plan and execute paths.

Moreover, when a robot moves in a specific space, it is necessary to select a most reasonable path so as to avoid collisions with obstacles. Several approaches for path planning exist for mobile robots, whose suitability depends on a particular problem in an application. For example, behaviour-based reactive methods are good choice for robust collision avoidance. Path planning in spatial representation often requires the integration of several approaches. This can provide efficient, accurate , and consistent navigation of a mobile robot.

The major task for navigation for single mobile robot is to search a collision –free path. The work in path planning has led into issues of map representation for a real world. Therefore, this problem considered as one of challenges in the field of mobile robots because of its direct effect for having a simple and computationally efficient path planning strategy.

The multi-level structure of path planning and execution propounded in provides a basic framework for dealing with problems in the control of autonomous vehicles.

IV. Navigation

Navigation is the ability to move and on being self-sufficient. The AMR must be able to achieve these tasks: to avoid obstacles, and to make one way towards their target. In fact, recognition, learning, decision-making, and action constitute principal problem of the navigation.

One of the specific characteristic of mobile robot is the complexity of their environment. Therefore, one of the critical problems for the mobile robots is path planning, which is still an open one to be studying extensively. Accordingly, one of the key issues in the design of an autonomous robot is navigation, for which, the navigation planning is one of the most vital aspect of an autonomous robot. Therefore, the space and how it is represented play a pivotal role in any problem solution in the domain of the mobile robot, because:

*it provides the necessary information to do path planning.

*It gives information for monitoring the position of the robot during the execution of the planned path.

Several models have been applied for environment where the principle of navigation is applied to do path planning. For example, a grid model has been adopted by many researchers, where the robot environment is dividing into many line squares and indicated to the presence of an object or not in each square. On line encountered unknown obstacle are modelled by piece of "wall", where each piece of "wall" is a straight-line and represented by the list of its two end points. This representation is consistent with the representation of known objects, while it also accommodates the fact the only partial information about an unknown obstacle can be obtained from sensing at a particular location.

In the figure 1 we present one example of navigation approach using a square cellule grid for the movement.

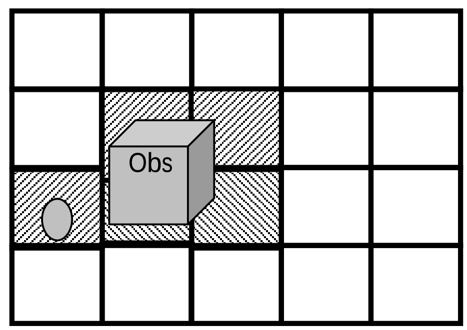

Fig. 1 an example of a square cellule grid navigation

V. Fuzzy Logic

The implied natural language is represented through fuzzy sets involving classes with gradually varying transition boundaries. As human reasoning is not based on the classical two-valued logic, this process involves fuzzy truths, fuzzy deduction rules, etc. This is the reason why FL is closer to human thinking and natural language than classical logic[8,914,15].

Furthermore, to build machines that are able to perform complex task requiring massively parallel computation, knowledge of the environment structure and interacting with it involves abstract appreciation of natural concepts related to, the proximity, degree of dangers, etc. Also, FL can be viewed as an attempt to bring together conventional precise mathematics and human-like decision-making concepts, see the Figure2.

Where:
A_i: the direction of the robot. Di: intermediate distance (see the figure3).

The membership labels for distance Di in the figure 4 are defined as:
-SP: Start position.
-MP: Middle position,.
-VP: Visual position.

The membership functions of direction A_i are presented in figure 5, where fuzzy labels are defined as:
-IO: Initial orientation.
-MO: Middle orientation.
-VO: Visual orientation.

The membership labels of distance D_f are defined as (see the figure 6):
-IAP : Initial arranged position.
-MAP :Middle arranged position.
-VAP: Visual arranged Position .

The membership functions of direction A_f are presented in figure 7, where fuzzy labels are defined as:
-IAO: Initial arranged orientation.
-MAO: Middle arranged orientation.
-VAO: Visual arranged orientation.

The direction Ai and DI are arranged at the end to get the best direction and position of avoiding the obstacle and attending target. The vehicle must learn to decided A_I and D_I using FL from a fuzzy linguistic formulation of human expert knowledge. This FL is trained to capture the fuzzy linguistic formulation of this expert knowledge is used and a set of rules are then established in the fuzzy rule as shown in Table 1.

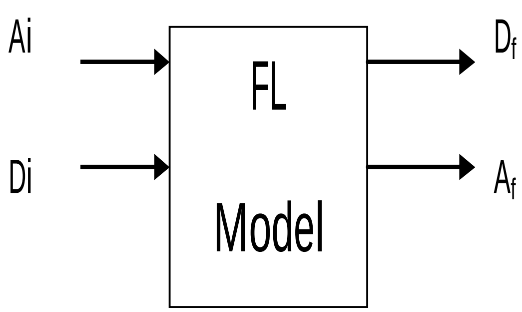

Fig. 2 Fuzzy model

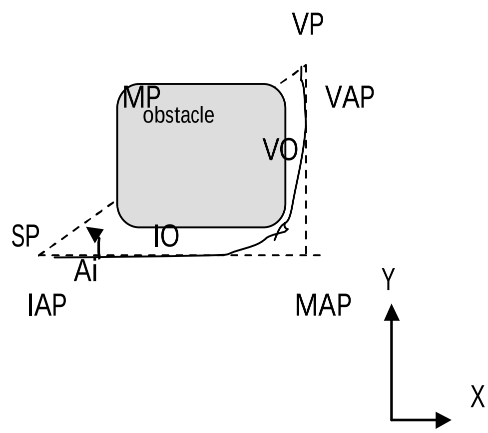

Fig. 3 Robot obstacle mode avoidance

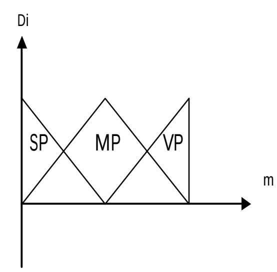

Fig. 4 Memberships function of distance Di

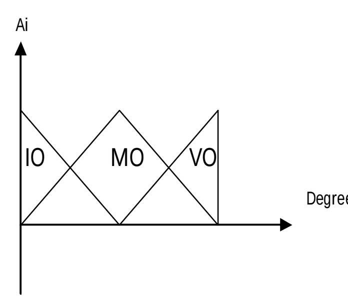

Fig. 5 Memberships function of direction Ai

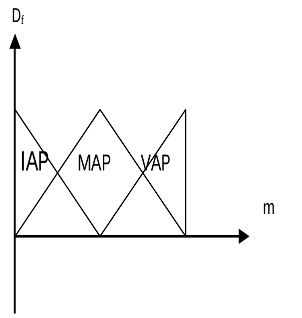

Fig. 6 Fuzzy model

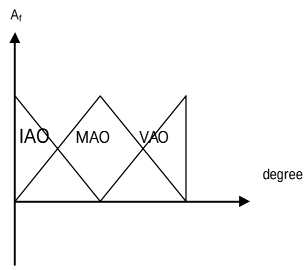

Fig.7 Memberships function of distance D_f

If ((Ai is IAP and (Di is SP)) then ((Df is IAP and (Af is IAO))   ***If ((Ai is MAP) and(Di is MP)) then ((Df is MAP) and (Af is MAO))***   ***If ((Ai is VAP) and(Di is VP)) then ((Df is VAP) and (Af is VAO))***

Table 1: Rule inference

The rules governing a fuzzy system are often written using linguistic expressions, which formalize the empirical rules by means of which a human operator is able to describe the process in question using his own experience. More, it is a way of linking input linguistic variables to output ones.

VI. Simulation results

The Fuzzy Logic Controller FLC can be considered as a system given an input vector computes, and an output vector by a linguistic rule. To define the complexity of a fuzzy controller we consider some typical parameters such as the number Input and the number output, the dimension of the rule base, the number of membership functions per input, the precision and the methods chosen to performed the three well known steps: fuzzification, inference and defuzzification steps. Fuzzy logic is based on the concepts of linguistic variables and fuzzy sets.

The fuzzy logic proves to be a robust tool to solve all one imprecise problem. The three well-known stages used generally are: the fuzzification, the Inference rules and the defuzzification, which are the stages keys to realize the fuzzy principle.

To build intelligent systems that are able to perform complex requiring massively parallel computation, a knowledge of the environment structure and interacting with it involves abstract appreciation of natural concepts related to, the proximity, degree of danger, etc.

The implied natural language is represented through fuzzy sets involving classes with gradually varying transition boundaries. As human reasoning is not based on the classical two-valued logic, this process involves fuzzy truths, fuzzy deduction rules, etc.

We denote that the configuration grid is a representation of the configuration space. In the configuration grid starting from any location to attend another one, cells are thus belonging to reachable or unreachable path.

Note that the set of reachable cells is a subset of the set of free configuration cells, the set of unreachable cell is a subset of the set of occupied configuration cells. By selecting a goal that lies within reachable space, we ensure that it will not be in collision and it exists some “feasible fuzzy path” such that the goal is reached in the environment. Having determined the reachability space, the algorithm works and operates on the reachability grid .This one specifies at the end the target area.

To maintain the idea; we have created several environments which contain many obstacles. The search area (environment) is divided into square grids. Each item in the array represents one of the squares on the grid, and its status is recorded as walkable or unwalkable area (obstacle). The robot starts from any position then using fuzzy logic learning must move and attends its target. The trajectory is designed in form of a grid-map, when it moves it must verify the adjacent case by avoiding the obstacle that can meet to reach the target at the same line. The path is found by figuring all the fuzzy squares.

Four colours are assigned in the simulation:

- The red colour designs the robot body.
- The green colour is the target position .
- The dark colour is the obstacles area
- The white colour designs the free area

The squares are small enough to permit the robot land in the next square horizontal at just one step of robot. The path is

found by figuring all the squares. Once the path is found, the robot moves from one square to the next until the target is reached. We have fixed the starting position, it moves forward horizontally as shown above in figure 8.
The robot meets an obstacle, it moves a step until it meets another obstacle.

The robot keeps navigation in this manner until the target is found.. Once the path is found, the robot moves from one square to the next until the target is reached, once we have simplified our search area into a convenient number of sub positions , as we have done with the grid design, the next step is to conduct a search to find the path.

We do this by starting point, checking the adjacent squares, and training fuzzy model outward until we find our target. We start the search by the following steps: we have selected the starting position, it moves fuzzily forward as shown above in figure 8.The robot meets an obstacle, it moves a step down then back until it meets another obstacle. The robot keeps navigation in this manner until the target is found, as shown in figure 9.

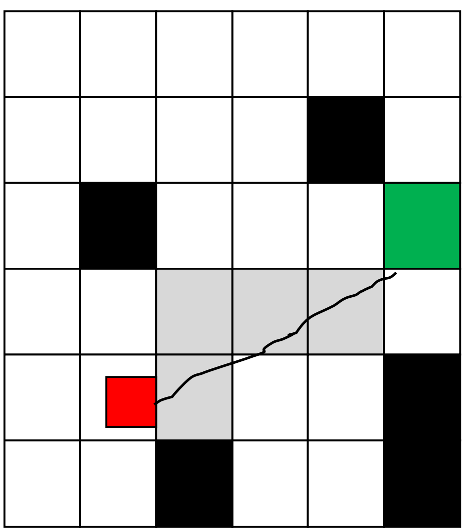

Fig. 8 Fuzzy path environment setup1

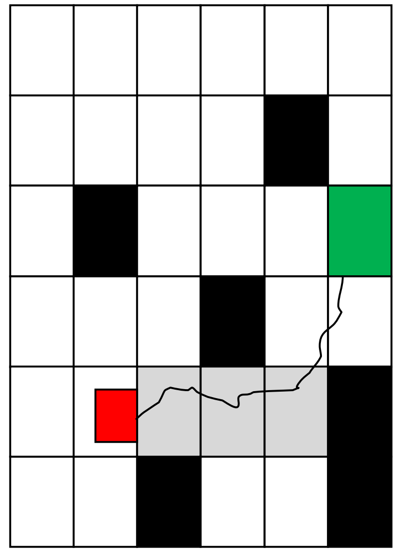

Fig. 9 Fuzzy path environment setup2

VII. CONCLUSION

In this present paper, we have presented our algorithm of work of fuzzy path navigation of an autonomous mobile robot in unknown environments. We have run our simulation using several environments set up. In each situation: the robot reaches the target by avoiding obstacle regardless of the number of square it takes. The path is found by fuzzy rule squares. This navigation approach has an advantage of adaptivity such that the mobile robot algorithm works perfectly even if an environment is unknown.
This proposed approach has made the robot able to achieve these tasks: avoid obstacles, deciding, perception, and recognition and to attend the target which are the main factors to be realized of autonomy requirements

In this paper, we have presented a fuzzy logic implementation of navigation approach of an autonomous mobile robot in an unknown environment using hybrid intelligent. Indeed, the main feature of FL combined with ES is the task fuzzy reasoning and inference capturing human expert knowledge to decide about the best avoidance direction getting a big safety of obstacle danger**.**

Besides, the proposed approach can deal a wide number of environments. This system constitutes the knowledge bases of our *approach* allowing recognizing situation of the target localization and obstacle avoidance, respectively. Also, the aim work has demonstrated the basic features of navigation of an autonomous mobile robot simulation .We have run

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