

The proposed Fuzzy Logic Navigation approach of Autonomous Mobile robots in unknown environments

O. Hachour

Abstract—In this paper we discuss the ability to deal with a fuzzy logic navigation approach for intelligent autonomous mobile robots in unknown environments. The aim of this work is to develop hybrid intelligent system combining Fuzzy Logic (FL) and Expert System (ES). This combination provides the robot the possibility to move from the initial position to the final position (target) without collisions. This combination is necessary to bring the machine behaviour near the human one in reasoning, decision-making and action. That was the current reason to replace the classical approaches related to navigation problems by the current approaches based on the fuzzy logic and expert system. The robot moves within the environment by sensing and avoiding the obstacles coming across its way towards the unknown target. The focus is on the ability to move and on being self-sufficient to evolve in an unknown environment. The proposed hybrid navigation strategy is designed in a grid-map form of an unknown environment with static unknown obstacles. This approach must make the robot able to achieve these tasks: to avoid obstacles, and to make ones way toward its target by *ES_FL* system capturing the behavior of a human expert. The integration of ES and FL has proven to be a way to develop useful real-world applications, and hybrid systems involving robust adaptive control. The proposed approach has the advantage of being generic and can be changed at the user demand. The results are satisfactory to see the great number of environments treated. The results are satisfactory and promising.

Keywords—Intelligent Autonomous Vehicles (IAV), Expert System, Fuzzy Logic(FL), navigation.

I. INTRODUCTION

THE objective of intelligent autonomous robot is to improve body autonomy. This improvement concerns robot performances, taking a correct decision and must operate at a human level with adapt action and learning capacities. In effect, thinking, reasoning, recognition, decision-making, learning and action are the principals' factors to be endowed by the intelligent autonomous mobiles robots.

The history of autonomous mobile robotics research has largely been a story of closely supervised, isolated experiments on platforms which do not at long beyond the end of the experiment. There is no universally accepted definition of the term robot. Typical definitions encompass notion of mobility, programmability, and the use sensory feedback in determining subsequent behaviour.

The theory and practice of Intelligent Autonomous Robot IAR are currently among the most intensively studied and promising areas in computer science and engineering which will certainly play a primary goal role in future. These theories and applications provide a source linking all fields in which intelligent control plays a dominant role. Cognition, perception, action, and learning are essential components of such-systems and their use is tending extensively towards challenging applications (service robots, micro-robots, bio-robots, guard robots, warehousing robots).

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.

The intelligent mobile robots have many possible applications in large variety of domains. The recent developments in autonomy requirements, intelligent systems, and massively parallel computers have made Intelligent autonomous vehicles (IAV) very used in many applications from spatial applications (planetary explorations) to underwater and hostile environments. In fact, the researchers search to create intelligent systems able to navigate and achieve intelligent behaviours like human in real dynamic environments were conditions are laborious.

Industrial robots used for manipulations of goods; typically consist of one or two arms and a controller. The term controller is used in at least two different ways in this context, we mean the computer system used to control the robot, often called a *robot work-station* controller. The controller may be programmed to operate the robot in a number of way; thus distinguishing it from hard automation. The controller is also responsible for the monitoring of auxiliary sensors that detect

the presence, distance, velocity, shape, weight, or other properties of objects. Robots may be equipped with vision systems, depending on the application for which they are used. Most often, industrial robot are stationary, and work is transported to them by conveyer or robot carts, which are often called autonomous guided vehicles (AGV). Autonomous guided vehicles are becoming increasingly used in industry for materials transport. Most frequently, these vehicles use a sensor to follow a wire in the factory floor. Some systems employ an arm mounted on an AGV.

Robot programmability provides major advantages over hard automation. If there are to be many models or options on a product, programmability allows the variations to be handled easily. If product models change frequently; as in the automotive industry, it is generally far less costly to reprogram a robot than to rework hard automation. A robot workstation may be programmed to perform several tasks in succession rather than just a single step on a line. This makes it easy to accommodate fluctuations in product volume by adding or removing workstations. Also; because robots may be reprogrammed to do different tasks; it is often possible to amortize their first cost over several products. Robots can also perform many applications that are poorly suited to human abilities. These include manipulation of small and a large object like electronic parts and turbine blades, respectively. Another of these applications is work in unusual environments like clean rooms, furnaces, high-radiation areas, and space.

Robot programming is the mean by which a robot is instructed to perform it task .The guiding for example, is the process of moving a robot trough a sequence of motion to “show it “what it must do”. One guidance method is to physically drag around the end effectors of the robot, while it records joint position at frequent intervals along the trajectory. The robot then plays back the motion just as it was recorded. An alternative is a master-slave or teleoperation configuration. Early systems of this type were first used or manipulate radioactive material remotely. Tele-operator techniques are now employed to guide the space shuttle manipulator. Guiding may also be applied using a *teach pendant*; which is a box keys that are used to command the robot. Several modes of operation are often available on the each pendant. Guiding is limited as a robot-programming technique, because it does not provide conditionality or iteration. Some systems provide called extended guiding capability that includes teaching in a coordinate system that may be moved at run-time and conditional branching between motion sequences. Robot programs must command robots to move: thus, the way in which motion is specified is important. Also, the program uses information obtained from sensors. One way of using sensory information is to monitor sensor until prescribed condition occur and then perform or terminate a specified action is to use feedback from sensors to modify the robots behaviour continuously.

A robotic systems capable of some degree of self-sufficiency is the overall objective of an Autonomous Mobile Robot AMR and are required in many fields [1,5,7,8]. The

focus is on the ability to move and on being self-sufficient to evolve in an unknown environment for example. Thus, the recent developments in autonomy requirements, intelligent components, multi-robot systems, and massively parallel computer have made the AMR very used, notably in the planetary explorations, mine industry, and highways [12,13,14,15].

The ability to acquire all faculties to treat and transmit knowledge constitutes the key of a certain kind of intelligence. Building this kind of intelligence is, up to now, a human ambition in the design and development of intelligent vehicles. However, the mobile robot is an appropriate tool for investing optional artificial intelligence problems relating to world understanding and taking a suitable action, such as, planning missions, avoiding obstacles, and fusing data from many sources[1,2,3,4,5,6,7,10,11].

A robotic vehicle is an intelligent mobile machine capable of autonomous operations in structured and unstructured environment, it must be capable of sensing (perceiving its environment), thinking (planning and reasoning), and acting (moving and manipulating). But, the current mobile robots do relatively little that is recognizable as intelligent thinking, this is because:

- Perception does not meet the necessary standards.
- Much of the intelligence is tied up in task specific behavior and has more to do with particular devices and missions than with the mobile robots in general.
- Much of the challenge of the mobile robots requires intelligence at subconscious level.

To reach target without collisions while avoiding all possibly encountered obstacles is a dream in robot application systems. Thus, the intelligent system must have the capability to achieve target localization and obstacle avoidance behaviours. More, current intelligent system requirements with regard to these behaviours are real-time, autonomy, and intelligence. Hence, to acquire these behaviours while answering IAV requirements, the intelligent autonomous mobile robot must be endowed with recognition, learning, decision-making, and action capabilities.

The next focus research is how to be more “autonomous” and “intelligent”. Researchers attempt to design robots which are able to navigate by themselves in a real environment, and therefore, these should be able to learn and make intelligent decisions while performing all tasks. In other words, this intelligent navigation must treat and transmit knowledges, which constitutes the key of a certain kind of a best planning. Reproduce this kind of intelligent navigation is, up to now, a human ambition in the construction and development of intelligent machines, and particularly autonomous mobile robots.

The classical approaches to solve navigation problems of these robots don’t response or sometimes is very hard to answer all requirements such as real time, autonomy, and intelligence. The problem is articulated around the ability to achieve all tasks without collision but in efficient manner. The robot must reach its target with less energy, short time, big

safety, and must have a good precision in execution. These robots must be endowed with perception, data processing, recognition, learning, interpreting and action abilities.

The key of intelligence is to acquire these faculties to treat, produce and reproduce, and transmit all necessary knowledges. This key constitutes the integration of neural networks, expert systems, for example, and all possible integrations of hybrid intelligent systems.

This paper deals with the intelligent navigation control of IAV in an unknown environment. The aim of this paper is to develop an IAV combining Expert Systems (ES) and Fuzzy Logic (FL) for the IAV stationary obstacle avoidance to provide them with more autonomy and intelligence. Artificial intelligence, including Fuzzy Logic (FL) and Expert system (ES), 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.

These technologies (ES and FL) are 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_ES *approach* allowing recognizing 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.

The aim of this work is to develop a fuzzy-expert navigation approach able to provide mobile robot with more autonomy and intelligence. The ability must solve the following problems: recognition, learning, decision, thinking, and mission execution.

The use of these technologies (FL, ES) improves the learning and adaptation capacities related to variations in an environment where information is qualitative, imprecise, or incomplete. More, these theories are able to bring the machine behaviour near the human one in thinking, reasoning and acting.

The proposed approach FL_ES 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 developments and research.

II. THE THEORY OF IAV

The theory and practice of IAV are currently among the most intensively studied and promising areas in computer science and engineering which will certainly play a primary goal role in future. These theories and applications provide a source linking all fields in which intelligent control plays a dominant role. Additionally, Intelligent Autonomous Vehicles (IAV) are becoming more and more interesting for

underwater, terrestrial, and space applications. These mechanical systems are constructed to respond any traditional working as in construction and agriculture. Previously, certain industrial operations required human skills may be tedious and exceptionally hardly ever. Above all, repetitive operations can result in reductions in quality control, as in visual inspections tasks. Also, these repetitive actions may be hazardous health risks as exposure to unsafe materials like radioactive and high pressure in underwater applications. So, the presence of human workers in these environments may be perilous which need the necessity to be replaced by intelligent systems, these systems can move, react, and carry out tasks in various environments by themselves like human.

Cognition, perception, action, and learning are essential components of such-systems and their use is tending extensively towards challenging applications (service robots, micro-robots, bio-robots, guard robots, warehousing robots). Many traditional working machines already used e.g., in agriculture or construction mining are going through changes to become remotely operated or even autonomous. Autonomous driving in certain conditions is then a realistic target in the near future.

A robot is a "device" that responds to sensory input by running a program automatically without human intervention. Typically, a robot is endowed with some artificial intelligence so that it can react to different situations it may encounter.

Today, robotic occupies special place in the area interactive technologies. It combines sophisticated computation with rich sensory inputs in a physical embodiment that can exhibit tangible and expressive behaviour in the physical world. In this regard, a central question that occupies some research group pertains to the social niche of robotic artefacts in the company of the robotically uninitiated public - at -large: "what is an appropriate first role for intelligent human-robot interaction in the daily human environment? The time is ripe to address this question Robotic technologies are now sufficiency mature to enable interactive, research has demonstrated the development of effective social relationship. Anthropomorphic robot design can help prime such interaction experiment by providing immediately comprehensible social cues for the human subjects.

Technology has made this feasible by using advanced computer control systems. Also, the automotive industry has put much effort in developing perception and control systems to make the vehicle safer and easier to operate, to perform all tasks in different environments, the vehicle must be characterized by more sever limits regarding mass volume, power consumption, autonomous reactions capabilities and design complexity.

Particularly, for planetary operations sever constraints arise from available energy and data transmission capacities, e.g., the vehicles are usually designed as autonomous units with: data transfer via radio modems to rely stations (satellite in orbit or fixed surface stations) and power from solar arrays, batteries or radio-isotope thermo electric generators (for larger vehicles).The environment force prevents the robot from

moving and turning towards obstacles by giving the user the distance information between the robot and the obstacle in a form of force. This force is similar to the traditional potential force field for path planning of mobile robot. However, the environment force is different from the potential force in some aspects. First there is no attention on a goal since we assume that the goal position is unknown. Secondly, only obstacles in the “relevant” area (according to the logical position of the interface) are considered, i.e. the obstacles that are far, or in the direction opposite to the movement of the robot are not relevant. In this context, a full range of advanced interfaces for vehicle control has been investigated by the researchers.

III. THE IAV REQUIREMENTS

The history of autonomous mobile robotics research has largely been a story of closely supervised, isolated experiments on platforms which do not last long beyond the end of the experiment. Autonomous robots which work without human operators are required in robotic fields. In order to achieve the necessary tasks, autonomous robots to be intelligent and should decide on their own action. When the autonomous robots decide its action, it is necessary to plan optimally depending on their asked missions. In the case of a mobile robot, it is necessary to plan a collision-free path minimizing a cost such as a time and distance [16, 17, 18].

To detect all possible obstacles, the robot is supposed to have vision system (camera). To operate in certain dynamic environments, the use of two or more sensors can guarantee to deliver acceptably accurate information all of the time. Thus the redundancy can be useful for autonomous systems as in human sensory systems. 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 obstruction in its way and answering to autonomy requirements such as: thermal, energy, Communication Management, Mechanical design, etc. To evaluate the performances of vehicles one must answer to all factors to be embedded with robot when it executes its mission, this is summarized in how to perform all tasks, such as:

A. Intelligence

A robotic system capable of some degree of self-sufficiency is the primary goal of Intelligent Autonomous Vehicles IAV. Thus, the robot must achieve his task with more autonomy and intelligence. Also, the vehicle reacts to unknown static and dynamic obstacles with safety not to endanger itself or other objects in the environment. Near Safety, the reliability is taken into account in the field of robotics; it is the probability that the required function is executed without failure during certain duration.

B. Navigation

Navigation is the ability to move and on being self-sufficient. The IAV 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.

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 the; mobile robots because it is essential that the mobile robots have 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.

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. The main work is to find an optimal path to navigate intelligibly avoiding obstacles. This example shows the way on which the scene of navigation is decomposed. The figure 2 illustrates one model of navigation where the polygonal model is used for the navigation.

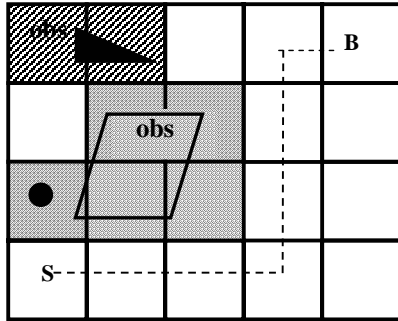


Fig. 1 an example of square cellule grid navigation

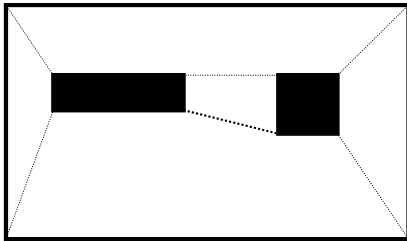


Fig. 2 an example of polygonal model of navigation

Many researches which have been done within this field, some of them used a “visibility graph” to set up a configuration space that can be mapped into a graph of vertices between which travel is possible in a straight line. The disadvantage of this method is time consuming. At the opposite, some researches have been based on dividing the world map into a grid (explained before) and assign a cost to each square.

A grid model has been adopted by many authors, where the robot environment is divided into many squares and indicated to the presence of an object or not in each square [6, 9]. Path cost is the sum of the cost of the grid squares through which the path passes. A cellular model, in other hand, has been developed by many researchers where the world of navigation is decomposed into cellular areas, some of which include obstacles. More, the skeleton models for map representation in buildings have been used to understand the environment’s structure, avoid obstacles and to find a suitable path of navigation. These researches have been developed in order to find an efficient automated path strategy for mobile robots to work within the described environment where the robot moves.

The method of search for visibility graph is one of the oldest methods for path planning without collision. They are Lozano-Perez and Wesley whom introduced the idea of the search for visibility graph. Brooks and Lozano Perez introduced the configuration of curvilinear path planning. The most efficient exact roadmap construction algorithm is due to Canny who reduced the complexity of Lozano-Perez’s earlier algorithm from double exponential to single exponential in the degrees of freedom of the robot. Canny’s Silhouette method

projected configuration space obstacles into lower dimensional representations and traced their projections until a roadmap was computed. Canny’s planner relies on mathematical results from semi-algebraic sets and is purely theoretical. His algorithm is both formidably complex and too slow to have practical application. A modified version of the algorithm capable of path planning in practice was later implemented, but was computationally limited to three or fewer degrees of freedom. In order to make use of environmental models mobile robots always must know their current position and orientation in their environment. Therefore, the ability of estimating their position and orientation is one of the basic preconditions for the autonomy of mobile robots.

The methods for position estimation can be roughly divided into two classes: *relative* and *absolute* position estimation techniques. Members of the first class track the robot’s relative position according to a known starting point. The problem solved by these methods is the correction of accumulated dead reckoning errors coming from the inherent inaccuracy of the wheel encoders and other factors such as slipping. Absolute position estimation techniques attempt to determine the robot’s position without a priori information about the starting position. These approaches of the second class can be used to initialize the tracking techniques belonging to the first class.

The coverage problem has been defined the maximization of the total area covered by a robot’s sensors. The problem of coverage can be considered as static or more generally as dynamic problem. The static coverage problem is addressed by some algorithms which are designed to deploy robots in a static configuration, such that every point in the environment is under the robots sensor shadow (i.e. covered) at every instant of time. Clearly, for complete static coverage of an environment the robot team should be larger than a critical size (depending) on the environment size, complexity, and robot sensor ranges).

Navigation system based on the animal behaviour has received a growing attention in the past few years. The navigation systems using artificial pheromone are still few so far. For this reason, some scientists have presented a research that aim to implement autonomous navigation with artificial pheromone system. By introducing artificial pheromone system composed of data carriers and autonomous robots, the robotic system creates a potential field to navigate their group. They have developed a pheromone density model to realize the function of pheromones with the help of data carriers. They intend to show the effectiveness of the proposed system by performing simulations and realization using modified mobile robot. The pheromone potential field system can be used for navigation of autonomous robots and in a transportation network system. But for single robot navigation, we will be obliged to build the path for the robot using the data carriers and this is very costly and it waste time. The parameters must be optimized other wise the error will be increased.

C. Reliability

In the literature it is given by: reliability is the probability, that the required function is executed without failure during certain duration. It depends on the system design.

D. Safety

We can define the safety of an autonomous mobile robot as the ability of a system not to endanger itself or other objects in the environments. This is to ensure the security of an IAV and how does react to unknown static and dynamic obstacles.

E. Autonomy

The degree of autonomy has some of the most significant and varied long-term consequences for system's design: the higher the overall system's autonomy, the less the human involvement and sophisticated processing inside the system. Such autonomy increases the need for multiple sensory modalities, translation between external requests and internal processing, and the internal computational model's complexity detailed characterization systems are relatively low-autonomy systems, because their intent is to simply deliver sensory information to a human user or external program. Event detection requires far more autonomy because the definition of interesting events must be programmed into the system, and the system must execute more complex queries and computations internally to process detailed measurements and identify events. Perhaps more than any other dimension, autonomy is most significant in moving us from embedding instruments to embedding computation in our physical world.

F. Modalities

Truly autonomous systems depend on multiple sensory modalities. Different modalities provide noise resilience to one another and can combine to eliminate noise and identify anomalous measurements.

G. Complexity

Greater system autonomy also entails greater complexity in the computational model. A system that delivers data for human consumption leaves most of the computation to the human consumer or to a centralized program that can operate based on global information. A system that executes contingent on system state and inputs over time must execute a general programming-language that refers to spatially and temporally variable events.

IV. MAPPING AND COGNITION OF ENVIRONMENTS

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 some types of navigation, it is more advantageous to use an implicit one. In the intelligent robot behavior, this environment model map has an important role to play. So, building a map of the sensory input space is more interesting especially we give this subdivision by the following points:

A. Geometrical level

This task consists on the "cartographer work". The flat earth model viewable area of the world as an ideal planner surface S defined by the points of contact of the objects projected into the ground. Considering the point of map $S(x, y)$ down on the surface S , this point is the intersection of the line (x, y) with surface S , this is how the projection is given into the flat earth model and shadow projection.

B. Topological level

This one 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. In addition to determine a valid safe path grid-mapped environment, an intersection of parallel horizontal and vertical lines is the key of digital field analysis, which is the way to interpret safety and danger areas. We mention below this organization, the obtained grids are homogenous in dimensions.

C. Semantic level

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: we affect number one (01) if grid is free otherwise it is zero (00).

D. Path planning

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. So, path planning 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.

Often, a path is planned off-line for the robot to follow, which can lead the robot to its destination assuming that the environment is perfectly known and stationary and the robot can rack perfectly. Early path planners were such off-line planners or were only suitable for such off-line planning.

However, the limitations of off-line planning led researchers to study on-line planning, which rely on knowledge acquired from sensing the local environment to handle unknown obstacles as the robot traverses the environment.

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, behavior-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 path-planning 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. There are three basic levels of path planning and execution:

The planner

A global path planner uses priori knowledge (a map) to plan a plausible road.

The navigator

A local path planner, uses the plan of the planner a guide, but provides more precision routing according to obtained terrain information locally.

The pilot

It is the execution of simple vehicle movement routines. Path planning is one of the key issues in mobile robot navigation. Path planning is traditionally divided into two categories: global path planning and local path planning.

In global path planning, prior knowledge of the workspace is available which means that the robot navigates in known environment. Local path planning methods use ultrasonic sensors, laser range finders, and on-board vision systems to perceive the environment to perform on-line planning in this case a prior knowledge of the environment is not necessary and the robot navigate in an unknown environment.

V. THE PROPOSED FUZZY LOGIC AND MOTION DESIGN

Today, researchers have at their disposal, the required hardware, software, and sensor technologies to build IAV. More, they are also in possession of a computational tool such as FL and ES that are more effective in the design and development of IAV than the predicate logic based methods of traditional Artificial Intelligence.

Fuzzy Logic FL and Expert System ES are well established as useful technologies that complement each other

in powerful hybrid system. Hybrid intelligent systems are now part of the repertoire of computer systems developers and important research mechanisms in the study of Artificial Intelligent. The integration of ES and FL has proven to be a way to develop useful real-world applications, and hybrid systems involving robust adaptive [8].

In order to reach a goal, learning vehicles rely on the interaction with their environment to extract information. By another way, ES and FL have been recently recognized to improve the learning and adaptation capacities related to variations in environments where information is inaccurate, uncertain and imprecise.

In order to reach a target, learning robots rely on the interaction with their environments to extract information. By another formulation, FL and ES have been recently recognized to improve the learning and adaptation capacities related to variations in environments where information is imprecise, uncertain, or incomplete for example. Particularly, the use of this integration (FL and ES) is necessary to bring IAV behaviour near the human one in recognition, learning, decision-making, and action. Thus, several integrations of FL and ES based navigation approaches have been developed. The interest in FL_ES stems from the wish to understand principles leading in some manner to the comprehension of the human thinking and to build machines that are able to perform complex tasks requiring massively parallel computation. Essentially, this approach deals with cognitive tasks such as learning, adaptation, generalization and optimization.

A. Robot control

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.

Conventionally, mobile robots are controlled through an action selection mechanism that chooses among multiple proposed actions. This choice can be made in a variety of ways, and action selection mechanisms have been developed that demonstrate many of them, from strict priority schemes to voting systems.

In order to make use of environmental models mobile robots always must know their current position and orientation in their environment. Therefore, the ability of estimating their position and orientation is one of the basic preconditions for the autonomy of mobile robots.

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.

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.

When the robot is far from its objective only the mobile base moves; thus avoiding obstacles if necessary. When the objective is close to the robot, both mobile base and arm move and redundancy can be used to maximise a manipulability criterion. The partial results obtained with the real robot consolidate the results of simulation. The work does not propose an autonomous path planning and navigation of the mobile arm but assistance to the user for remote controlling it.

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. Experimental comparisons with the vector field histogram method (VFH) for example show that the proposed method usually produces smoother albeit longer paths to the goal.

Some approaches have shown that how soft computing methodologies such as fuzzy logic, genetic algorithms and the Dempster–Shafer theory of evidence can be applied in a mobile robot navigation system. The navigation system that is considered has three navigation subsystems. The lower-level subsystem deals with the control of linear and angular velocities using a multivariable PI controller described with a full matrix.

The position control of the mobile robot is at a medium level and is nonlinear. The nonlinear control design is implemented by a backstepping algorithm whose parameters are adjusted by a genetic algorithm. The authors proposed a new extension of the controller mentioned, in order to rapidly decrease the control torques needed to achieve the desired position and orientation of the mobile robot. The high-level subsystem uses fuzzy logic and the Dempster–Shafer evidence theory to design a fusion of sensor data, map building, and path planning tasks. The fuzzy/evidence navigation based on the building of a local map, represented as an occupancy grid. The path planning algorithm is based on a modified potential field method.

This paper presents the design of a preference-based fuzzy behaviour system for navigation control of robotic vehicles. In this algorithm, the fuzzy rules for selecting the relevant obstacles for robot motion are introduced. Also, suitable steps are taken to pull the robot out of the local minima. Particular attention is paid to detection of the robot's trapped state and its avoidance. One of the main issues in this case is to reduce the complexity of planning algorithms and minimize the cost of the search.

The performance of the proposed system is investigated using a dynamic model of a mobile robot. Simulation results

show a good quality of position tracking capabilities and obstacle avoidance behaviour of the mobile robot. The missing point that this work does not deal with it is the navigation of a mobile robot in a dynamic environment.

B. Expert System

An ES is a computer program that functions, is in a narrow domain, dealing with specialized knowledge, generally possessed by human experts. ES is able to draw conclusions without seeing all possible information and capable of directing the acquisition of new information in an efficient manner.

C. Fuzzy Logic

Logic has long been beset with the often-muddled distinction between inferences made in a meta-language from statements in an object-language, on the one hand, and on the other hand, the formation in the object language itself of an implicative combination of its own statements. Both the need for this distinction and the difficulty of keeping to it becomes more acute in the fuzzy environment.

Fuzzy models can obviously be made to work very well indeed. The big advantage of a fuzzy model is that it is relatively simple to construct and is in itself a simple structure. It does not require the modeller to have a deep mathematical insight, but relies more on intuition and experience of the process. Its greatest value must be, therefore, in those areas where such qualitative process knowledge is predominant and essential for understanding.

The theory has shown that the fuzzy models can be successfully constructed; the overall concept needs a considerably more detailed investigation before its true worth can be evaluated. Many of the successful application of fuzzy logic have shown the importance of rule based fuzzy control. Control is meant in the most general sense: it includes actual closed loop control, expert systems, and all kinds of man-machine systems where the decision of the human 'component' is supported or modified by the conclusion obtained by the application of approximate reasoning on the set of available rules.

Zadeh's original idea of constructing relations from the rules, and the simplified computational techniques (both the one invented by Mamdani and the methods applied in some of the Japanese applications) can be interpreted as approximate computation of the 'graph' expressing the true nature of the system modelled. This 'graph' is mapping which maps the fuzzy power set of the input universe to the fuzzy power set of the output universe, where all the rules can be considered as approximate 'points' of the mapping.

In order to understand this interpretation, let us first think about the system itself. In a deterministic (although fuzzy) system there must be a mapping roughly:

$$R : X \rightarrow Y \quad (1)$$

X is input of fuzzy system and Y is output, and which

expresses the true connection of input and output (R denotes the fuzzy power set). Application of fuzzy control is more successful compared to the traditional linear and other control methods where this connection cannot be expressed analytically at all. In well defined cases, an expert system approach can lead to good results, logically; a kind of case based reasoning is applied. If the system and the available knowledge are defined, i.e. fuzzy, the expert system must be replaced by a fuzzy rule based control system-this is what was proposed by Zadeh. The fuzzy rules containing linguistic terms as values for the variables represent fuzzy cases and are typical 'fuzzy points' of the graph of R . The graph in this one explaining is nothing else but a plastic expression for the mapping. Rules in the form

$$\text{IF } X \text{ is } A \text{ then } Y \text{ is } B \quad (2)$$

Can be considered as fuzzy points of the fuzzy function. R in this sense a mapping of the input space X to the set of all fuzzy subsets of the output Y . if $R(S)$ stands for the fuzzy power set of S , the precise definition of the mapping is

$$R : R(X) \rightarrow R(Y) \quad (3)$$

So it is supposed that the mapping from input to output is inherently fuzzy. If the membership functions in use have necessary single point i.e. cores with cardinality one, the fuzzy mapping defines always a classic mapping from core to core. This interpretation of the fuzzy mapping points to the importance of the resolution principle. The mapping can be decomposed into an infinite number of α -cuts (for every $\alpha \in [0,1]$), and every cut can be general shape rule with its α -cuts and the α -cuts of the whole rule in the $X * Y$ space. If the interpretation is accepted that every

$$\text{IF } \dots \text{Then} \quad (4)$$

Rules stands for a fuzzy point of the fuzzy mapping R , the next step is to clarify how well a set of rules, i.e. a set of fuzzy points can describe the hypothetical mapping. If the analogy is taken from ordinary functions, the curve of an arbitrary function can be approximated better and better, e.g. by a polynomial function, if more and more points of the function are known. A polynomial of degree n has maximally $(n-1)$ local optima, so a curve with many turns (increasing to decreasing or opposite) needs a polynomial with a high degree for an appropriate approximation. An n th degree polynomial need $(n+1)$ points to determine it, i.e. for $(n-1)$ turns, $(n+1)$ points are needed. This analogy makes it clear that in general, more rules mean more exact approximation of the fuzzy mapping from input to output. These considerations point out the importance of the denseness of rule bases.

Also, fuzzy logic can be viewed as an attempt to bring together conventional precise mathematics and human-like decision-making concepts. More, the fuzzy logic proves to be a robust tool to solve all one imprecise problem. Fuzzy logic can be a valid approach solving control problem in a wide range of applications. In particular, embedded architectures are likely to use fuzzy logic in the future for dedicated

applications.

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.

D. Fuzzy Logic Controller

To build intelligent systems that are able to perform complex 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 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. This is the reason why FL is closer to human thinking and natural language than classical logic [9].

Acknowledging the environment structure and interacting with it involves abstract appreciations of natural concepts related to the proximity, degree of danger...The implied natural language is represented through fuzzy sets. These ones involve classes with gradually varying transition boundaries. In effect, human reasoning is not based on the classical two-valued logic because this process involves fuzzy truths, fuzzy deduction rules; this is the reason why FL is closer to human thinking and natural language than classical logic. Our fuzzy model, treaded in this conception is presented in Fig. 3

Where: A_1 : the direction of the robot. D_1, D_2 : intermediate distance between current position, intermediate position and visual point (see the Fig. 4). The membership labels for distance D_1 and D_2 , see the Fig. 6, are defined as:

C_p : current position, I_p : intermediate position, I_v : intermediate visual position, V_p : visual position. The membership functions of direction A_1 are presented in Fig. 7 where fuzzy labels are defined as: LDS: Left Danger Small, RDS: Right Danger Small, LDB: Left Danger Big, RDB: Right Danger Big. the membership labels of distance D_f are defined as (see the Fig. 8): C_p : current position, I_d : intermediate danger, V_p Visual point. The membership functions of direction A_f are presented in Fig. 9, where fuzzy labels are defined as: RSS: Right Safety Small, RSB: Right Safety Big, LDS: Left Danger Small, RDS: Right Danger Small, LSS: Left Safety Small, LSB Left Safety Big, LDB: Left Danger Big, RDB: Right Danger Big.

The direction A_1 is calculated by:

$$A_1 = \tan^{-1}(Y_g, -Y_1) / (X_g - X_1) \quad (5)$$

Where The $P_1(X_1, Y_1)$, $P_i(X_i, Y_i)$, and $P_g(X_g, Y_g)$ are the coordinates of respectively to initial point, intermediate and

visual point (we calculate point to point until the visual point become the target ones, see the figure 5). The vehicle must learn to decided A_f and D_f 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 Fig.10.

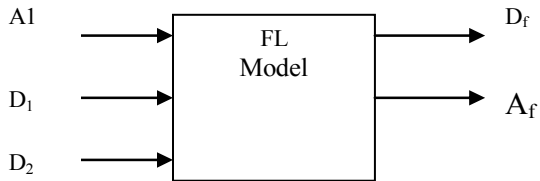


Fig. 3 fuzzy model

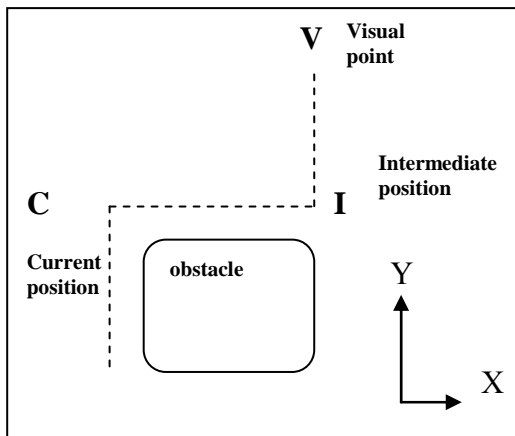


Fig. 4 Robot obstacle mode avoidance

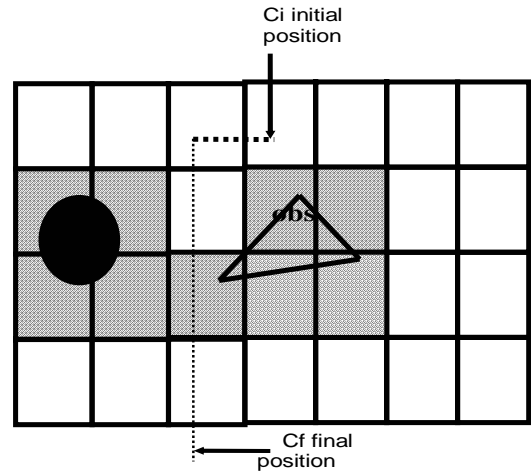


Fig. 5 example of the navigation finding an optimal path

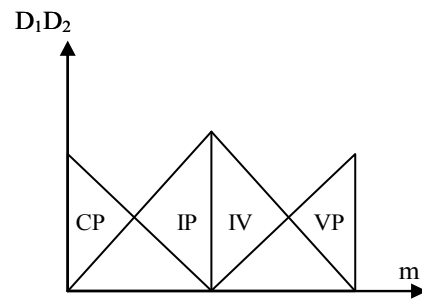


Fig. 6 Memberships function of distance D_1 and D_2

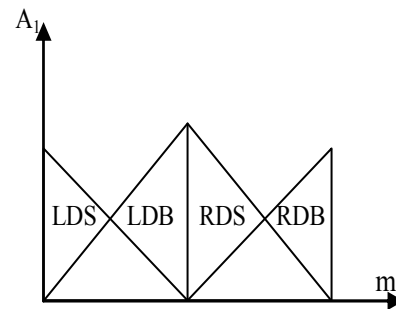


Fig. 7 Memberships function of direction A_1

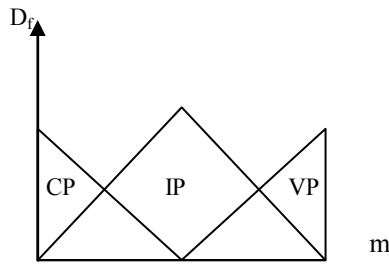


Fig. 8 Memberships function of distance D_f

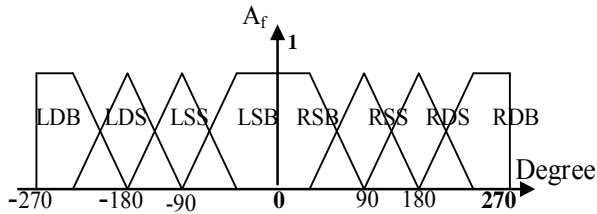


Fig. 9 Memberships function of direction A_f

If ((A1 is LDB)and(D1is Cp)) then ((Df is Cp) and (Af is LDS))
 If ((A1 is LDS)and(D1is Cp)) then ((Df is Cp) and (Af is LDB))
 If ((A1 is RDB)and(D2is Ip)) then ((Df is Ip) and (Af is LSS))
 If ((A1 is RDS)and(D2is IP)) then ((Df is Vp) and (Af is LSB))

Fig. 10 Rule inference

It is the same principle repeated for RDS, RDB,RSS,RSB, it depends on the position of robot. 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.

If x and y are taken to be two linguistic variables, fuzzy logic allows these variables to be related by means of fuzzy conditional rules of the following type **IF** (x is A) **THEN** (y is B). Where (x is A) is the premise of the rule, while (y is B) is the conclusion. The premise defines the conditions in which the conclusions define the actions to be taken when the conditions of the premise are satisfied. More specially, the degree of membership of the premise is calculated and through application of a fuzzy logic inference method to the conclusion, it allows the output y to be determined. In general in a fuzzy conditional rule “**IF** premise **THEN** conclusion” is made up of a statement in which fuzzy predicates P_j of the general form are combined by different operators such as the

fuzzy operators AND . To apply an inference method to the conclusion, it is first necessary to access the degree of membership of the premise, trough assessment of the degree of membership of each predicate P_j in the premise. In our case, the principle of the technique consists in verifying for every degree membership functions.

Defuzzification is the output of the fuzzy system, it is a decision-making logic (written in a formula) adopted for the compute of the real value of the output. The final decision (*defuzzification*) is achieved to give the output of fuzzy controls and to converts the fuzzy output value produced by rules. The system must decide how to give the right output using fuzzy logic from a fuzzy linguistic formulation. The generation of rules operates itself according to the distribution of the training whole in fuzzy linguistic terms. The final decision (defuzzification) is accomplished to convert input of the fuzzy system after treatments with the inference rules.

The final decision (defuzzification) is achieved to give the output of fuzzy controls and to converts the fuzzy given by :

$$G = \frac{\text{the sum of } (\mu_i * \beta_i)}{\text{the sum of } (\mu_i)} \quad (6)$$

Where : $1 \leq i \leq m$, m : number of rule, B : centroid of the backend membership function correspond for each rule. μ : factor of membership correspond for each rule.

This intelligent task uses the fuzzy linguistic terms and calculates for each degree of membership functions under expertise of an expert system ES. An ES is a computer program that functions, is in a narrow domain, dealing with specialized knowledge, generally possessed by human experts.

The expert system represents a good part of activities of the Artificial intelligence that makes call to knowledge on the domain treaty, these systems are capable to reach human expert performances for various types of tasks (diagnosis, conception in restraint domains). In our case, the principle of the technique consists in verifying for every degree membership function a whole of rules, or each rule is the shape: **IF** <cond> **THEN** <name of the stain>, Where <cond> is a combination of predicates translating the spatial relations between the primitive of the unknown shape (if the logic used by the ES is the one of predicates).

VI. SIMULATION RESULTS

Assume that path planning is considered in a square terrain and a path between two locations is approximated with a sequence of adjacent cells in the grid corresponding to the terrain. The length $A(\alpha, \beta)$ from cell “ α ” to its adjacent cell “ β ” is defined by the Euclid distance from the center cell “ α ” of one cell to the center cell “ β ” of another cell. Each cell in this grid is assigned of three states: *free*, *occupied*, or *unknown* otherwise. A cell is *free* if it is known to contain no obstacles, *occupied* if it is known to contain one or more obstacles. All other cells are marked *unknown*. In the grid, any cell that can be seen by these three states and ensure the

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 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. The detection of the three states is done by the different color of pixels of those belonging to the area obstacle.

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.

As an example: the environment set up is shown in the figure 11. The path is found by figuring all the fuzzy squares. 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 12. 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 13, figure 14, figure 15, figure 16, figure 17, and figure 18. The figure 19 shows the robot closes to the target.

For unwalkable space, we compute the total size of free cells around danger (obstacle) area. This total may be at least greater or equal than to the length of architecture of robot. This is ensure the safety to our robot to not be in collision with the obstacle, and that the path P has enough security SE to attend it target where it is given by $P \pm SE$ (S is size of security). For walkable space the robot reaches its target with

the following steps illustrated in this algorithm:

Algorithm Of Work:

Begin

Start set up environment

Initialization

Move

IF {the target is Reached? } DO End task

ELSE

Begin

L1 : If {the obstacle is detected?} DO

Begin

Change the direction.

Move

Target is attended.

End task.

Else Goto L1.

End.

End.

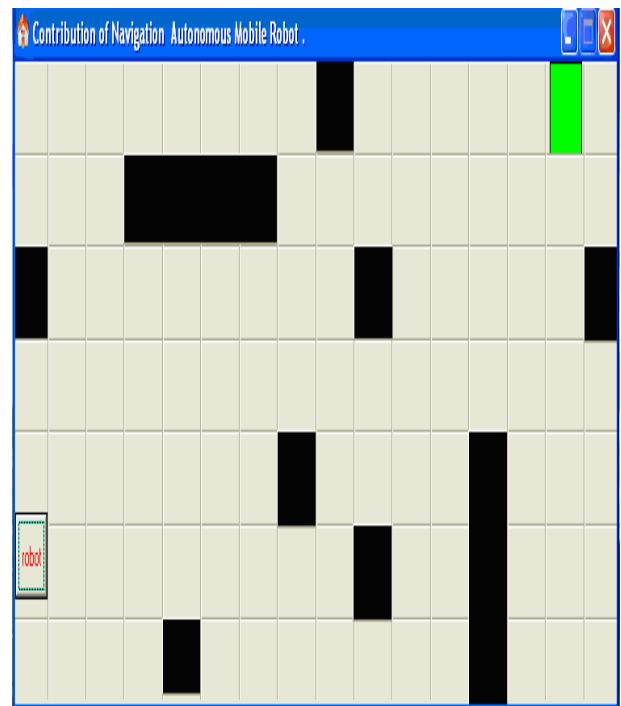


Fig. 11 assumed initial environment set up.

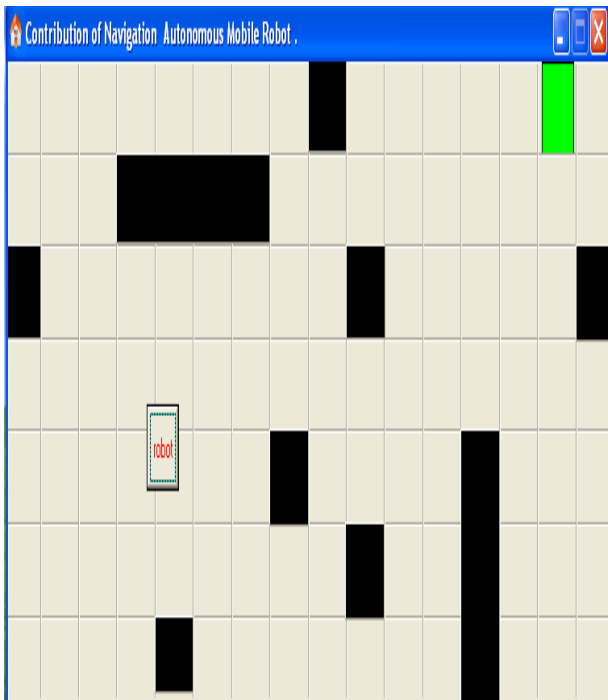


Fig. 12 intermediate position: robot moves



Fig. 14 intermediate position: robot in half way
First obstacle situation

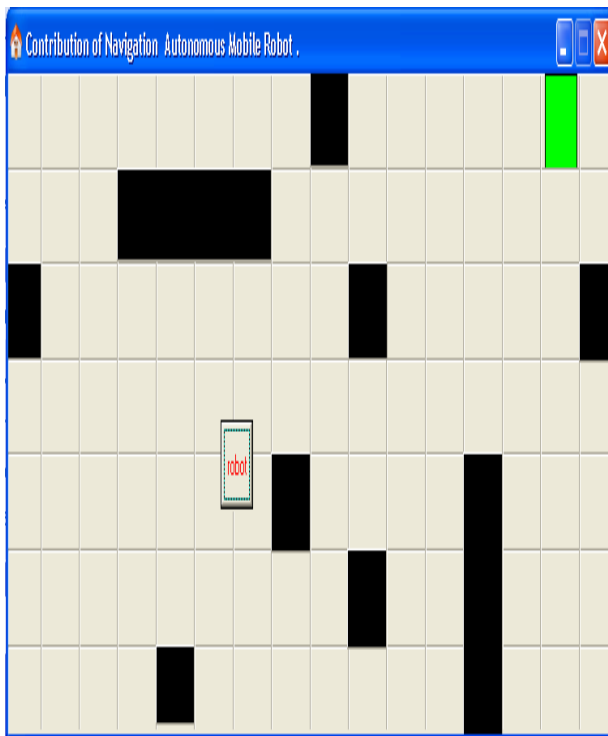


Fig. 13 intermediate position: robot in half way
First obstacle situation

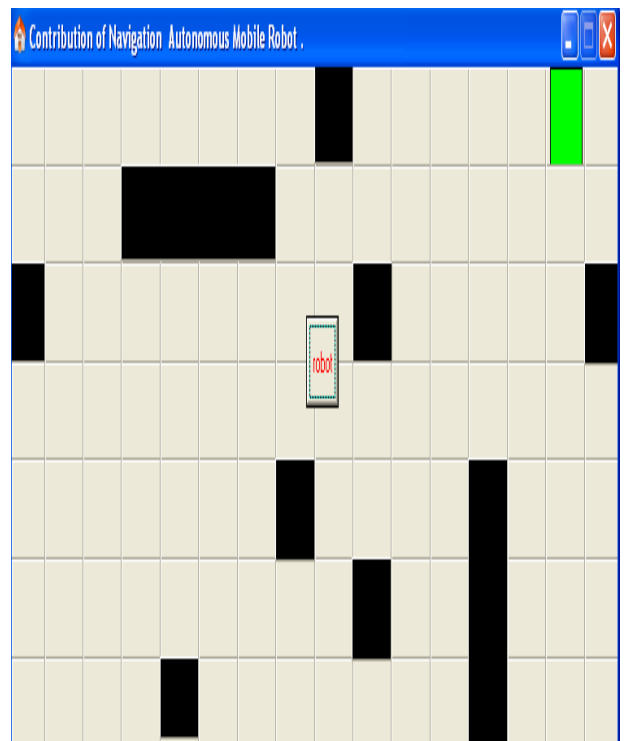


Fig. 15 intermediate position: robot in half way
Second obstacle situation

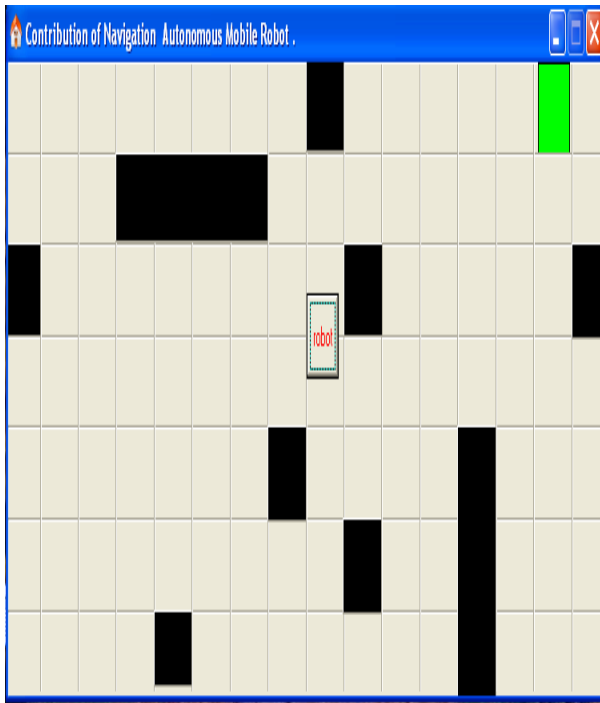


Fig. 16 robot recognizes the obstacle (robot must avoid this obstacle)
Second

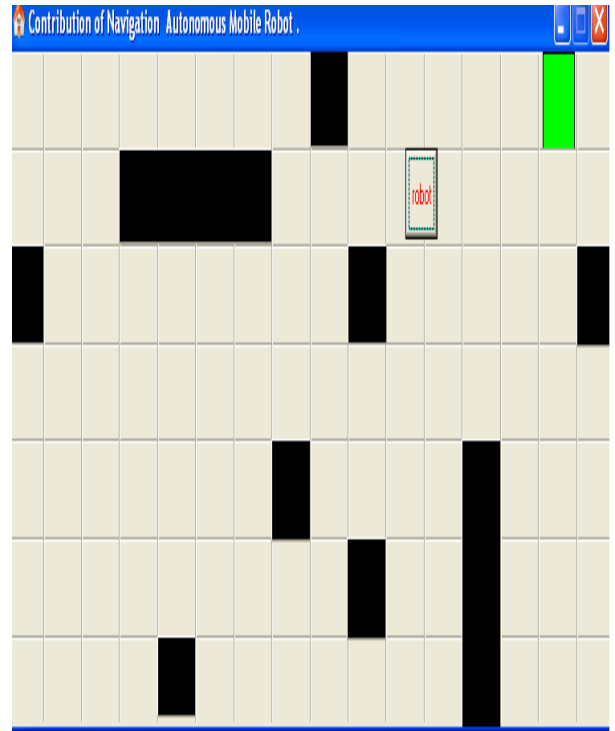


Fig. 18 robot in security self: far from obstacle

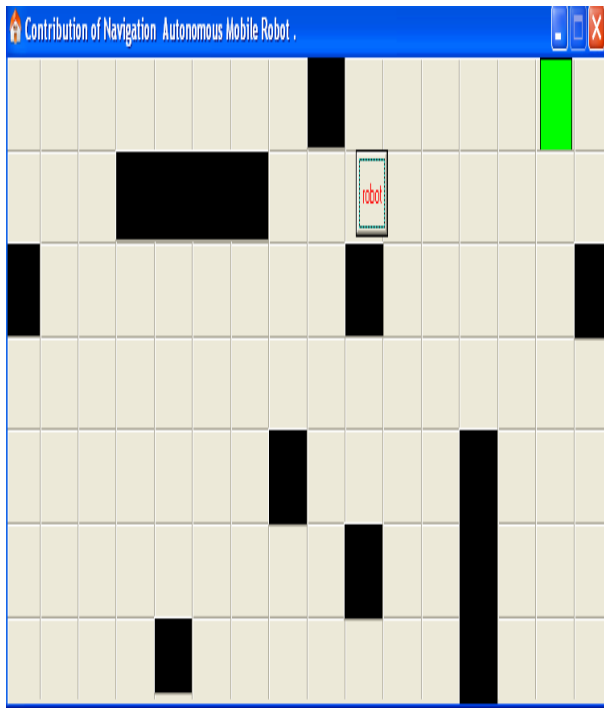


Fig. 17 the task fuzzy reasoning and inference: robot avoids the obstacle

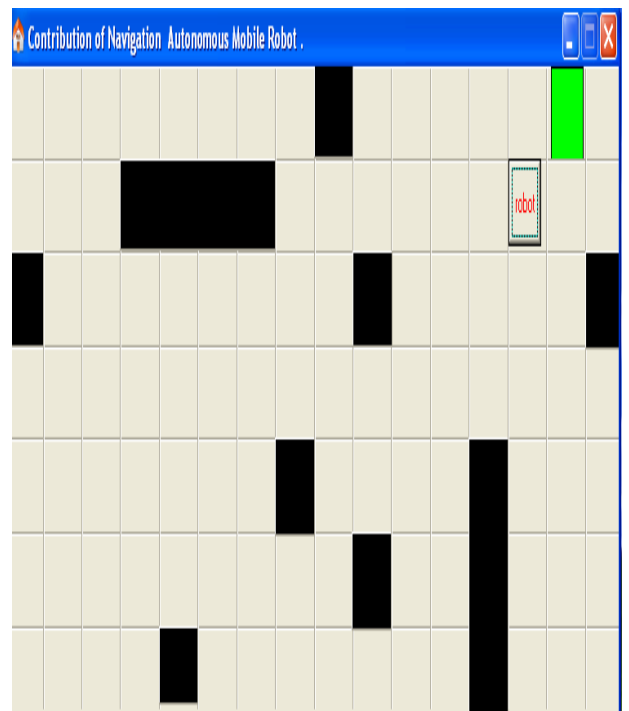


Fig. 19 Final position: robot approaches target

VII. CONCLUSION

The theory and practice of IAV are currently among the most intensively studied and promising areas in computer science and engineering which will certainly play a primary goal role in future. These theories and applications provide a source linking all fields in which intelligent control plays a dominant role. Cognition, perception, action, and learning are essential components of such-systems and their use is tending extensively towards challenging applications (service robots, micro-robots, bio-robots, guard robots, warehousing robots).

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 our simulation in several environments where the robot succeeds to reach its target in each situation and avoids the obstacles capturing the behaviour of intelligent expert system. The proposed approach can deal a wide number of environments. This navigation approach has an advantage of adaptivity such that the IAV approach 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. Hence; the results are promising for next future work of this domain.

REFERENCES

- [1] B. P. Gerkey and M. J. Mataric, "Principled Communication for Dynamic Multi-Robot Task Allocation", *Experimental Robotics VII, LNCS 271*, Springer-Verlag Berlin Heidelberg, 2001, pp.353-36.
- [2] S. Saripalli, G. S. Sukhatme, and J. F. Montgomery, "an Experimental Study Of The Autonomous Helicopter Landing Problem", *the Eight International Symposium on Experimental Robotics*, July 2002, pp. 8-11.
- [3] B. P. Gerkey , M. J. Mataric, and G. S. Sukhatme, "Exploiting Physical Dynamics for concurrent control of a mobile robot", *In Proceeding of the IEEE International Conference on Robotics and Automation (ICRA 2002)*, Washington, DC , May 2002, pp. 3467-3472.
- [4] D. Estrin, D. Culler, and K.Pister, *PERVASIVE Computing IEEE*, 2002, pp. 59-69.
- [5] T. Willeke, C. Kunz, and I. Nourbakhsh, "The Personal Rover Project: The comprehensive Design Of a domestic personal robot", *Robotics and Autonomous Systems (4), Elsevier Science*, 2003, pp.245-258.
- [6] A. Howard, M. J. Mataric, and G. S. Sukhatme, "An Incremental Self-Deployment Algorithm for mobile Sensor Networks", *autonomous robots, special Issue on Intelligent Embedded Systems*, 13(2), September 2002, pp. 113-126.
- [7] L . Moreno, E.A Puente, and M. A. Salichs," World modelling and sensor data fusion in a non static environment : application to mobile robots", in *Proceeding International IFAC Conference Intelligent*

- Components and Instruments for control Applications*, Malaga, Spain, 1992, pp.433-436.
- [8] L. R. Medsker, hybrid *intelligent systems*, Kluwer Academic Publishers, 1995.
- [9] W. Pedrycz " Relevancy of fuzzy models", *Information Sciences* 52 (1990), pp.285-302.
- [10] K. Schilling and C.Jungius," Mobile robots for planetary exploration", in *proceeding second international conference IFAC*, Intelligent Autonomous.
- [11] S. Florczyk, "Robot Vision Video-based Indoor Exploration with *Autonomous and Mobile Robots*", WILEY-VCH Verlag GmbH & Co. KGaA, 2005,Weinheim.
- [12] O. Hachour and N. Mastorakis, "IAV: A VHDL methodology for FPGA implementation", *WSEAS transaction on circuits and systems*, Issue5,Volume3,ISSN 1109-2734, 2004, pp.1091-1096.
- [13] O. Hachour AND N. Mastorakis, "FPGA implementation of navigation approach", *4th WSEAS international multicongference robotics, distance learning and intelligent communication systems (ICRODIC 2004)*, in Rio de Janeiro Brazil, October 1-15 , 2004, pp2777-2784.
- [14] O. Hachour AND N. Mastorakis, "Avoiding obstacles using FPGA –a new solution and application", *5th WSEAS international conference on automation & information (ICAI 2004)* , *WSEAS transaction on systems* , issue9 , volume 3 , Venice , Italy15-17 , November 2004 , ISSN 1109-2777, pp2827-2834.
- [15] O. Hachour AND N. Mastorakis, "Behaviour of intelligent autonomous ROBOTIC IAR", *IASME transaction*, issue1, vol.1, ISSN 1790-031x WSEAS, January 2004,pp 76-86.
- [16] O. Hachour,"The proposed Genetic FPGA Implementation for path planning of Autonomous Mobile Robot", *International Journal of Circuits, Systems and signal processing*, ISSN: 1998-4464, Issue 2, Vol. 2, 2008, PP151-167.
- [17] O. Hachour, path planning of Autonomous Mobile Robot", *International Journal of Systems Applications, Engineering & Development*, Issue4, vol.2, 2008, pp178-190.