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STUDY OF A MOBILE ROBOT'S OBSTACLE AVOIDANCE BEHAVIOR IN A RADIOACTIVE ENVIRONMENT WITH A HIGH LEVEL OF AUTONOMY

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Abstract- Following the Fukushima tragedy, several robots were designed to investigate areas too radioactive to visit. Monitoring the amount of radiation in the event of a nuclear disaster may be difficult and risky. To assist plant operators, a new system of detection has been created, in particular emergency scenarios, also managers. While moving in an environment contains radioactive sources and keeping an eye on the situation as a source to make this process easier and safer, we must first analyze the system's autonomy, it's a robot built on autonomy and intelligence who navigates in a radioactive environment. When a mobile robot operates in hostile situations (radioactive environments), it appears that it is critical that the ro'ot be equipped with decision-making capabilities that allow it to react to threats that may obstruct its movements (partial breakdowns, unforeseen obstacles), for the development of the various behaviors as well as their coordination, we used fuzzy reasoning. The use of fuzzy logic for behavior design is inspired by the fact that it allows for efficient fusion at the action level while allowing for the use of linguistic rules and concepts.

Keywords: Fuzzy Logic, Obstacle Avoidance, Kalman Filtering, Radioactive Sources.

1. INTRODUCTION

For the past thirty years, there has been a concentrated push in the domains of academia and industry to develop mobile robots that adapt with minimal human interaction. A first generation of robots consisted of devices capable of evolving in well-known environments: these carry out predefined missions (laboratories) or are content to follow a trajectory (handling robots). These robots all have one thing in common: they evolve in an environment that is entirely dedicated to them.

When the environment grows more complex (i.e., partially known, dynamic, etc.), it appears that the robot must be equipped with appropriate decision-making Capabilities For the past thirty years, there has been a concentrated push in the domains of academia and industry to develop mobile robots that adapt with minimal human interaction. A first generation of robots consisted of devices capable of evolving in well-known environments: these carry out predefined missions (laboratories) or are content to follow a trajectory (handling robots). These robots all have one thing in common: they evolve in an environment that is entirely dedicated to them.

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Capabilities For the past thirty years, there has been a concentrated push in the domains of academia and industry to develop mobile robots that adapt with minimal human interaction. A first generation of robots consisted of devices capable of evolving in well-known environments: these carry out predefined missions (laboratories) or are content to follow a trajectory (handling robots). These robots all have one thing in common: they evolve in an environment that is entirely dedicated to them.

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There has been a concerted effort in academia and business over the last thirty years to produce mobile robots that adapt with minimum human input. A first generation of robots consists of devices that may evolve in known surroundings and perform predetermined tasks (laboratories) or simply follow a path (manipulation of robots). All these robots share the same point: they operate in a completely specialized environment.

Artificial intelligence tools may be useful in approaching these dynamic settings. Fuzzy logic [1], genetic algorithms [4], neural networks [2, 3], and other combinations of these methods have all proven to be useful in solving various elements of this problem.

When it comes to a mobile robot operating in environments hostile to humans, radioactive environment (which is our case study), or too far (space exploration), it is essential that the robot is equipped with a tool for decision- making abilities capable of making him react to hazards that could thwart his movements (partial breakdowns, unforeseen obstacles).

The choice of fuzzy logic is justified for a reason that it allows the use of linguistic rules and concepts for design behavior, the networks and potential fields do not take into account the uncertainties in the sensor data.

According to Winston's definition [5] artificial intelligence is defined as the study of computers that allows people to perceive, reason and act.

AI [19] research contributes also to the need to learn more about human brain activity [5-7]. This method comprises employing techniques to solve complex problems based on human and animal intelligence, as well as expressing the attributes connected with intelligence concerning human behavior and how nature responds to people. [8] The major purpose of this research is to assist the robot in navigating its radioactive environment with great autonomy using Fuzzy Logic a type of artificial intelligence (AI) technique developed by Loft Zadeh in 1965 to solve mathematical imprecision problems by supporting human-like but not exact modes of reasoning [9]. Fuzzy logic varies from Boolean logic in that it may simulate a reality of the situation in which there aren't just extreme reactions [7, 10-13]. However, classical logic considers that the values in question are false or true, FL views them to be a question of degree, allowing estimates to be used and even inferred [11]. Silva [14], who describes the idea of difference, gives the example that there are only two forms of difference in Boolean logic. True or false values are allowed in Boolean logic, but in FL the values oscillate between 0 and 1.

Therefore, a significance of 0.5 can mean a half-truth, while 0.9 & 0.1, respectively, represent almost false and true. The true worth of a statement may could be a fuzzy subset of any ordered set (e.g., low, medium, and high) according to this logic [14]. The performance of *R*, *Q* and H algorithms for having to learn using FL has been examined in the navigation control strategy of Romero and Faria [15] concerning mobile robots deflecting obstacles. This assignment was completed by the robot in a good manner. However, no suitable policy of activities for removing impediments during environmental change has been established. This is most likely owing to the MDP (Markov Decision Process) model utilized, according to the authors. Megda et al. [16] describe another study that shows how fuzzy logic may be used as a controller for autonomous robot navigation.

This project seeks to design a mobile robot utilizing the controller proposed by Mamdani [17] to test the effectiveness of the product navigation system. The robots will be able to maneuver in a radioactive environment thanks to a movement system that identifies obstacles in its path and calculates and performs the deviations necessary to avoid colliding with them and achieve their objective of locating radioactive sources. Based on a fuzzy controller concept in confusion with Fuzzy-Kalman filter which would combine the advantages of both concepts. An important limitation of the Kalman filter concerns the assumptions made about its internal model. These assumptions are circumvented by using fuzzy logic in the proposed combined Fuzzy-Kalman formulation, the system parameters were worked out in the Mat Lab software.

4. MATERIALS AND METHODS

2.1. Materials – Mobile Crawler

The crawler mobile robot was chosen for our research because it has a greater hold on the ground than other mobile robots. They are utilized when the ground is disturbed, usually in an outdoor area, and the robot is better balanced when it comes to stairs or other potentially dangerous obstacles. The tracks aid the robot's navigation until it reaches its destination. (Sources of radioactivity) Control is achieved by enforcing a speed differential between the right and left tracks.

The model of the robot used to draw on CATIA as follows:

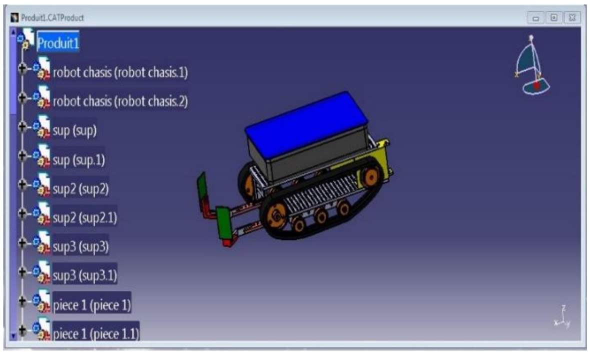

Figure 1. Robot drawn on CATIA with RFID Sensor

The robot contains an AX11 automaton with the use of RFID sensors for the perception of the environment, to avoid collisions with obstacles, we used a fuzzy logic approach with Kalman correction which we modified for the RFID sensor model, as well as an improved Kalman filter to correct the location of the robot. Finally, we offer several Matlab Simulink experiments that we have carried out. The choice of the robot model above comes from its resemblance to the design of the robots developed for the nuclear zones of Fukishima, in particular at the level of the wheels in which the robot can navigate even in rather complicated spaces (with stopovers for example) to keep its balance

2.2. Methods

2.2.1. Navigation by Adopting the Procedures of a Mobile Robot

Below is a flowchart of the general software used to guide the robot on its trajectory and inform it to move away if it encounters an obstacle:

First, some background information about the program will be provided:

The robot moves on a rectangular track, monitoring the condition of the obstacle at each point along the route and calculating the distance taking into account its location as the start and that of the obstacle as the target at the using the formula in the Equation (1).

The distance separates the robot with the obstruction is calculated as distance:

$$D = \sqrt{(u-x)^2 + (v-y)^2} \quad (1)$$

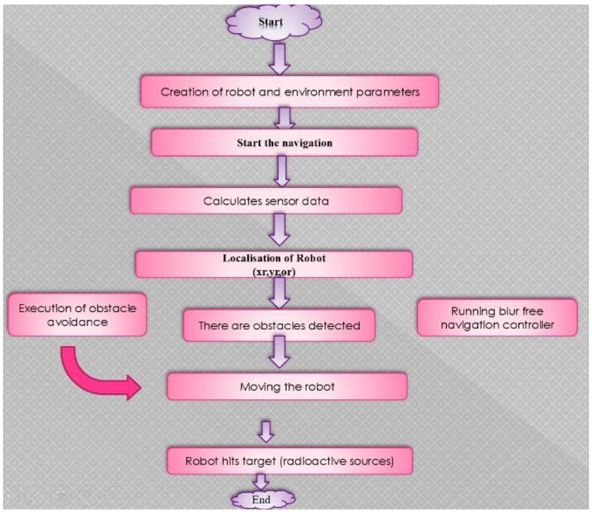

Figure 2. Path to be followed by robot

Knowing that the robot's positions are [x, y] also the coordinates of the obstacle are [u, v].

Robot then compares calculated distance with a predefined value, if 20 is taken as the distance separating the robot from the obstacle, the robot will move away. Following the call to fuzzy logic, we will have as result a new value of distance with a new value of angle, as well as the updated coordinates of locations of the robot (X_r, Y_r).

2.2.2. Development Fuzzy Controller

Using the system developed for navigation control, which used fuzzy logic in conjunction with the Kalman Filter for correction, the robot can detect obstacles in its path, assess the conditions of the surrounding environment (on the basis of sensor readings) and make decisions based on engine performance. By using an FL controller, all inputs to operate the outputs can be deduced at the same time. Because the control is performed consistently, motor responses are smoother, with less jerking and rapid movement, than in Boolean systems.

Sensors giving environmental information are required to solve the obstacle avoidance problem. With a robot outfitted with a radio beacon (RFID), you may navigate while avoiding collisions with objects [09]. To do so, we utilize the distance and direction recorded by a function that analyses data supplied by the RFID of the barrier nearest to the robot as inputs, and the direction and distance to go as outputs. As a result, the output variables will be structured similarly to the input variables.

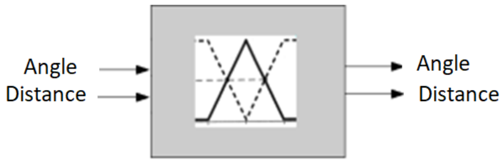

Figure 3. Input/output for fuzzy processing

In the fuzzy system, created by Matlab, as shown in Figure 4.

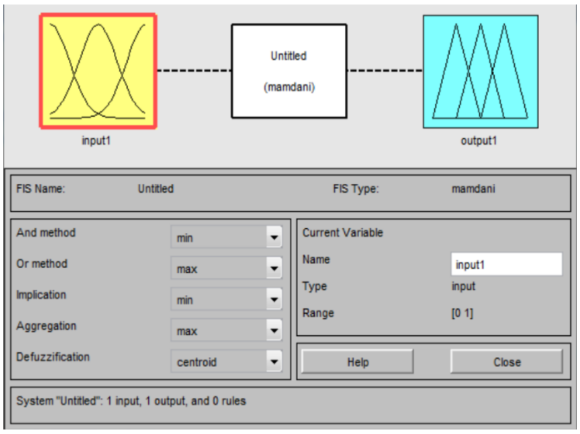

Figure 4. Fuzzy robot system

The input variables were calculated using data from the ultrasonic sensors facing the robot's front on the left and right. The geometric shapes of the Fuzzifier have been defined in Matlab, which corresponds to the specifications of the proposal.

The robot is given an angle value and a distance value in order to move. In our instance, combining the two is not feasible; the actions must be completed one after the other. We decided to turn first, then continue ahead [10]. The environment used to create the relevance function for the controllers input as shown in the Figure 5.

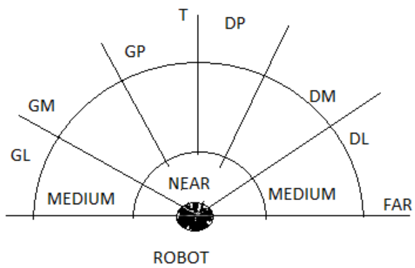

Figure 5. Division of space by the robot [18]

Since this is the robot's primary mission, data of location X (x, y) and desired position X_r (x_r, y_r, r) are the primary inputs to this behavior. Division of space is shown as Figure 6.

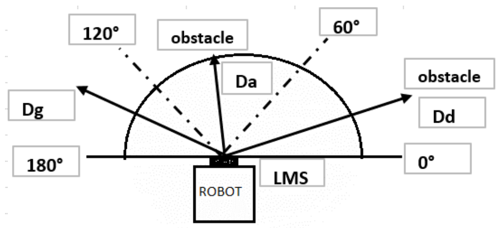

Figure 6. Division of space robot

In this example, there are 2 fuzzy logic inputs (*Derr*, *uh*), *err*: angle error defined as a comparison between the angle we want to get in the target and the current angle detected error of the robot. The term "distance error" refers to the deviation between the robot's desired location and its current location as shown in Figure 7.

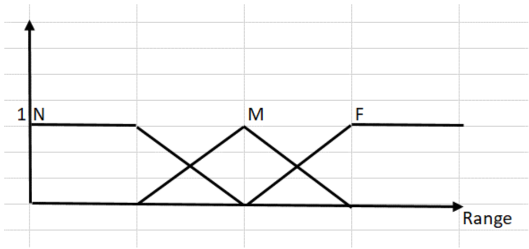

Figure 7. The fuzzy sets for the distance [18]

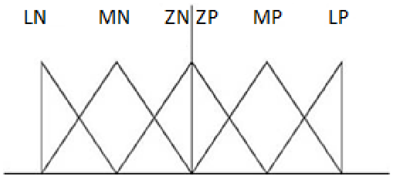

Figure 8. The angle error's membership functions [18]

The form of the fuzzification for orientation is depicted in Figure 8. We calculate the degrees of membership of the sets we just shown once we get data for the nearest barrier. To avoid barriers, we use the following rules as explained on the example below:
- If the obstacle is close to zero and positive, shift to medium and negative.
- Move Near and Medium Negative if the impediment is Medium and Zero Positive.
- If the road is clear, no additional rules are activated:
Move Far and Nearly Positive and Nearly Negative if the obstacle is Largely Positive or Largely Negative or Far.

Table 1. Inference rules

Rules	S1	S2	S3	PMW1	PMW2
1	MP	MP	MP	VN	VP
2	MP	MP	DB	VP	VN
3	MP	MP	ML	VP	VN
4	DB	MP	MP	VN	VP
5	DB	MP	DB	VP	VP
6	DB	MP	ML	VP	VN
7	ML	MP	MP	VN	VP
8	ML	MP	DB	VN	VP
9	ML	MP	ML	VN	VP

With DB (Good Distance); MP (Very Close); and ML (Very Far); V0 (Average Speed); VP (Positive Velocity) and VN (Negative Speed). Two output variables that correspond to the PWM values assigned to the left and right motors, respectively. Two DC PM gear motors drove the crawler wheels on the robot. The H-bridge electrical circuit has been used to connect the respective motors to an 68HC11 microcontroller for control, which can supply the voltage or current required for the motors to function and also makes it easy to change the motor's rotation direction.

2.2.3. Fuzzification

The Defuzzifier in the robot's navigation system is in charge of converting the fuzzy controller's outputs to conventional values, which in this case will be the outputs with the PWM value, which will deliver the motions to the motors.

The centroid approach was chosen as the controller's de-fuzzification method, with the system's final output value determined by the position of the geometry's center of gravity formed in the output fuzzy sets of the inference of inputs. Using *N* as the number of rules, the centroid was determined for each membership function of (1).

As illustrated in Figure 3, a fuzzy logic-based strategy to solving the navigation problem for mobile robots can be used. In a fuzzy system, these rules are applied as follows:
• Input "fuzzification"
• A combination of adhesion degrees
• Incorporation of ruler weights
• Combination of results from several rules
• "Defuzzification" of the resulting output Application: Obstacle avoidance using a fuzzy controller: Autonomous navigation in an unfamiliar environment with obstacle avoidance is an example of fuzzy logic in robotics. This sort of application can be fairly sophisticated, with robustness and performance restrictions that can be met by Using a fuzzy controller is a good idea. The goal is for navigation to be possible while avoiding collisions with objects.

The centroid approach was chosen as the controller defuzzification method, with the system's ultimate output value defined by the position of the geometry's center of gravity formed at the output fuzzification of the input interpretation. Using N as the number of rules, the centroid was determined for each membership function. As illustrated in Figure 3, a fuzzy logic-based strategy to solving the navigation problem for mobile robots can be used. In a fuzzy system, these rules are applied as follows:
• Input "fuzzification"
• A combination of adhesion degrees
• Weights of rulers are taken into account.
• Combination of the outcomes of multiple rules
• "Defuzzification" of the generated output Application, Obstacle avoidance using a fuzzy controller

In robotics, the navigation of autonomous robots in a new environment by deflecting obstacles is an example of fuzzy logic. This sort of application can be fairly sophisticated, with robustness and performance restrictions that can be met by Using a fuzzy controller is a good idea. The goal is for navigation to be possible while avoiding collisions with objects.

4. SIMULATION RESULTS AND DISCUSSIONS

3.1. Prediction, Estimation with Fuzzy Logic

According to the rule base produced, using data inputs that simulated the robot's sensors and outputs.
The results obtained by the robot in the stand, as well as the output values shown in the simulator, were satisfactory and perform exactly the expected behavior in each rule of the controller, leading to the autonomous start of the

robot's motion tests to observe its movement in real world scenarios.

Several experiments were conducted with the robot, with impediments put at various location in the radioactive environment, causing the robot to respond in ways that were inconsistent with the Controller's regulations.

The visuals' behavior reveals that the Matlab-based algorithms developed for the robot produced good results, with similar performance patterns in the settings to which they were applied.

The Figures 9-12 depict the robot's movement in a field, including scanned positions, predicted positions, and estimated positions.

: Real positions

: Predict positions

: Estimated positions

The RFID sensor model presented in [11] is used. We need information on distance and direction because we are using the EKF algorithm, which is why we have chosen this model. The strength of the signal received by the robot'' sensor is used to measure the distance separates a detected RFID with the antenna.

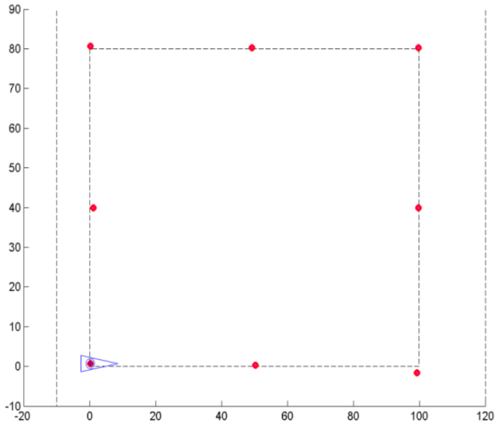

Figure 9. The ground truth of our simulation

We employ as in [11] a simplified approach from [12], assuming that RFID sightings aren'' feasible across walls. The robot moves on a plane and perceives the direction of point landmarks (TAG). The state of the robot is represented by its position and orientation [13] as indicated in the Equation (2):

$$X_t = \left[x_t ; y_t ; \theta_t \right] T \tag{2}$$

The robot'' movement between times t and t+1 is measured using RFID given in the reference of the robot at time t in the Equation (3):

$$X_t = \left[x_u ; y_v ; \theta_u \right] T \tag{3}$$

The prediction stage of the Kalman Filter is used to set this Equation (4).

$$X_{t+1} = AX_t + Bu \tag{4}$$

In this technique, we consider the robot'' state as a combination of the average robot location and the correlation. This distribution will continue to evolve until the robot completes its journey.

Below are the different stations when moving the robot, assuming that the robot must make this rectangular path in order to reach its target and detect radioactive sources.

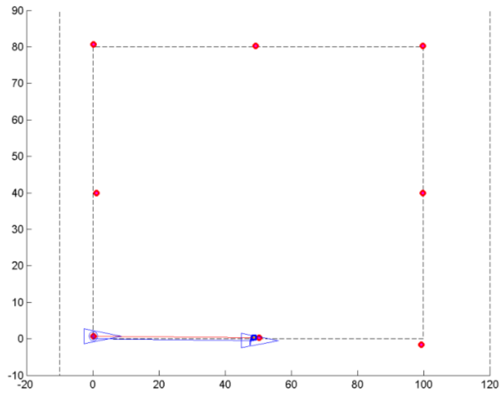

Figure 10. Start navigation of robot

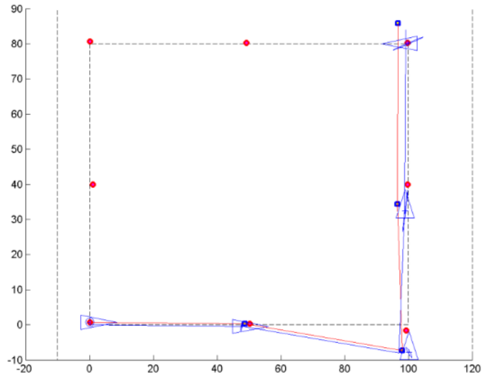

Figure 11. Step 3 –The predicted positions

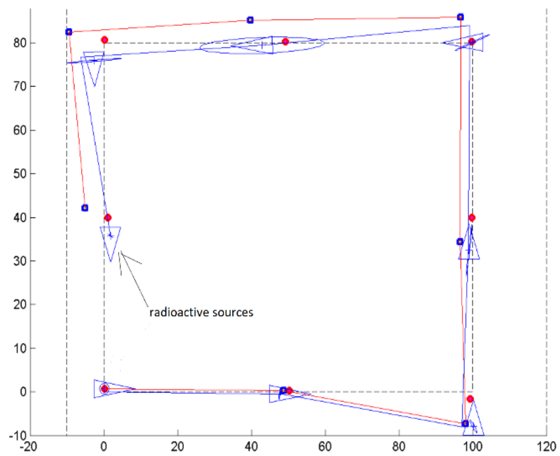

Figure 12. Arrival of the robot at his target

A message should be sent to the user informing him of the existence of a radioactive source [20].

In Figure 13, we present the different phases of EKF filtering. First, the ground truth constitutes the positions we want the robot to follow. These positions are shown by the green dots. After applying the displacement model, the robot positions become erroneous (The dots in red). We consider that the noise on the displacement is Gaussian white, in other words, its probability density is Gaussian. Finally, we show that the use of EKF filtering allows to reset the position of the robot. More concretely, the estimated position becomes closer to the ground truth (see the triangle in the simulation).

The curve below shows the error in the x, y coordinates of each position. The red curve that of the positions estimated after EKF is closer to the ground truth, which validates our simulation.

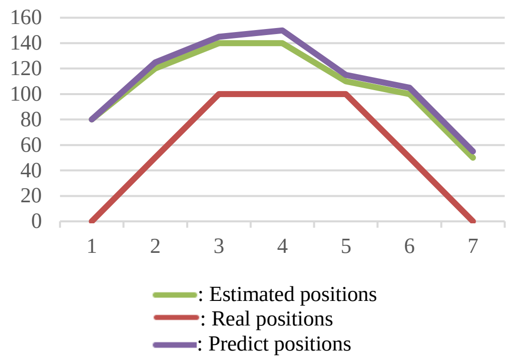

Figure 13. Variation of true, prediction and estimated position

After knowing the distance separates the robot with the obstacle, the following formula is used to calculate the locations after the deviation.

$$d = 1;\ u = 2;\ v = 3;\ \theta = \frac{\pi}{4}$$

New coordinates are calculated as follows:

$$x = \frac{u-d}{\sqrt{1+(\tan\theta)^2}} \quad (5)$$

$$y = \frac{v-d}{\sqrt{1+(\tan\theta)^2}} \quad (6)$$

In Equation (5), we calculate the new position x-axis of the robot after deviation, and in the Equation (6), we calculate the new position y-axis

3.2. Combination EKF and Fuzzy Logic

In this part we will try to combine Fuzzy logic and Kalman Filtering in order to create a function that will detect the obstacle and anticipate it as well as return to the old trajectory.

: Real positions
: Obstacle
: Robot away from the obstacle
: Robot back on track

We can clearly see the movement of the robot as shown in Figure 19. In this simulation, the robot locates itself and updates its position while avoiding obstacles. Thus, when we put an obstacle (point in red surrounded by a circle in green), the robot puts update its leadership with the fuzzy logic method in order to avoid the obstacle. Then he continues in according to the estimated positions.

This combination is essential especially in an indoor environment where the robot does not control the obstacles that may face it.

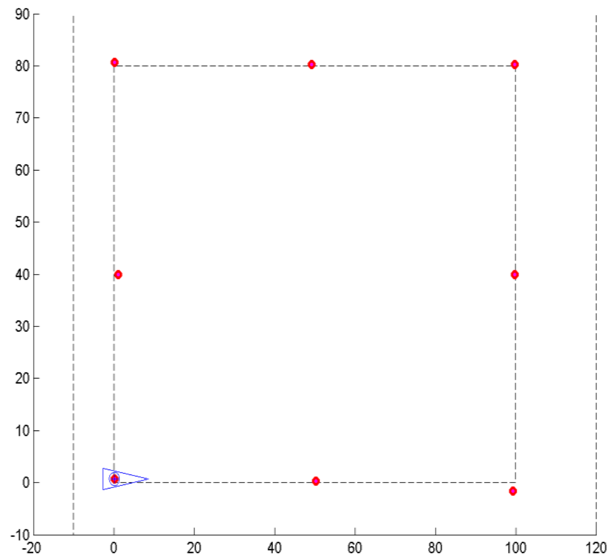

Figure 14. The ground truth of our simulation with Kalman Filter

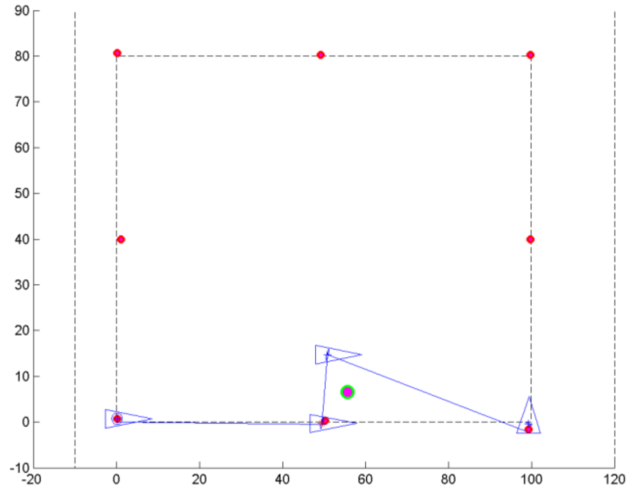

Figure 15. Step 2 -–Navigation robot with Kalman Filter for correction

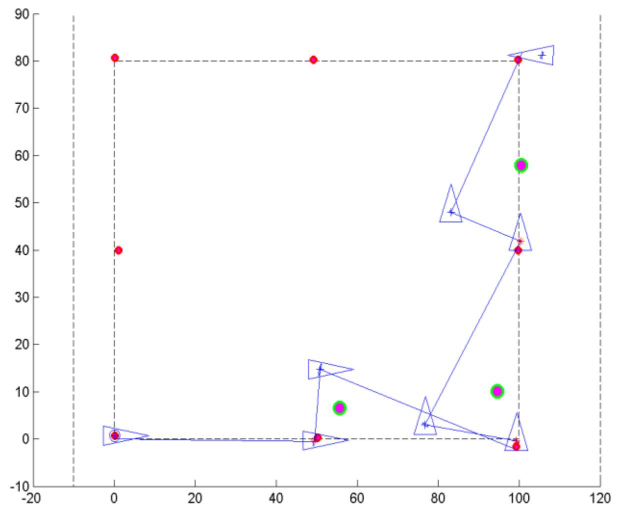

Figure 16. Step 3 -–Navigation robot with Kalman Filter for correction

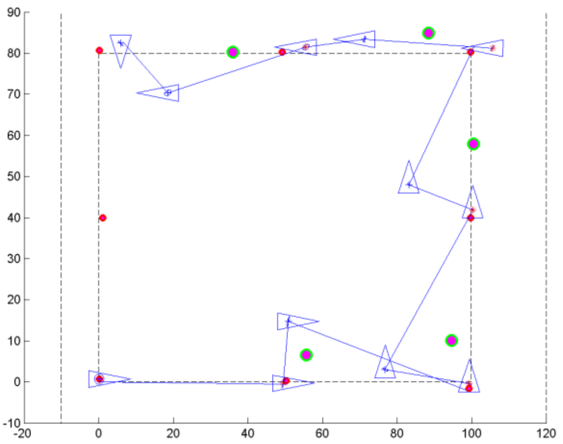

Figure 17. Step 4 –Navigation robot with Kalman Filter for correction

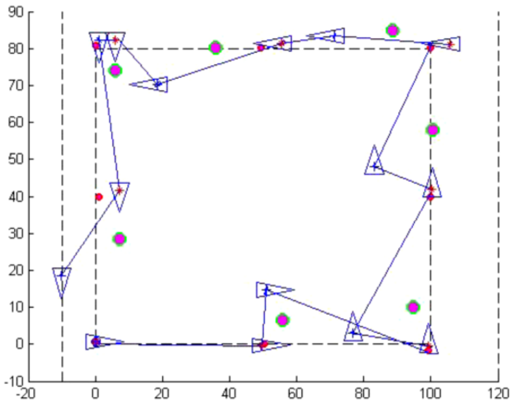

Figure 18. Robot navigation steps deflecting obstacle (people) by bold disks surrounded by a green circle with KF correction

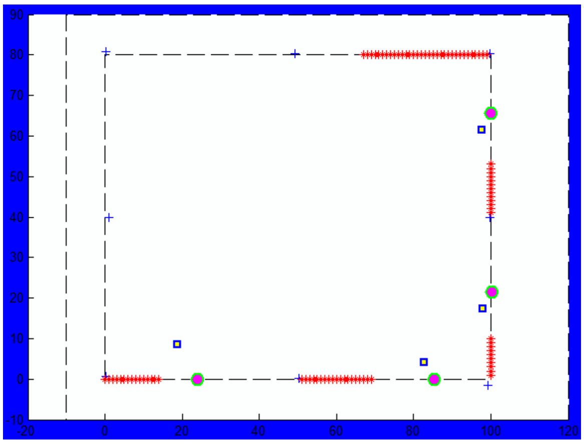
Figure 19. Real-time robot movement [18]

4. CONCLUSION

This article explains how to control the navigation of a mobile robot with route correction using fuzzy logic combined with a Kalman Filter. Obstacle avoidance behaviors are managed using this strategy.

It has been established that the system'' level of autonomy allows for guided navigation for

As a result, an implementation for such purpose is sought. Simulations using Matlab Simulink have given positive results, enabling the robot to be equipped with intelligence.

The robot'' autonomy should allow it to help and protect humans from the impacts of radioactive rays. We recommend integrating a radioactive detector (the Geiger Muller radioactive counter) on the robot in future studies and observing the communication between the detector and the robot.

All of the data were analyzed and compared to suggested goals and the intended behavior elicited.

In an intelligent navigation system, the fuzzy controller used in the study was a virtual simulation. It seems that such an application produces answers to non-standard exams, which is problematic.

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