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# Path Planning of Mobile Robot Using Fuzzy-Potential Field Method

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***Abstract:*** *This paper deals with the navigation of a mobile robot in unknown environment using artificial potential field method. The aim of this paper is to develop a complete method that allows the mobile robot to reach its goal while avoiding unknown obstacles on its path. An approach proposed is introduced in this paper based on combing the artificial potential field method with fuzzy logic controller to solve drawbacks of artificial potential field method such as local minima problems, make an effective motion planner and improve the quality of the trajectory of mobile robot.*

***Index Terms*— Path Planning, Artificial Potential Fields method, Fuzzy logic, Particle swarm optimization**

## I. Introduction

Many methods and algorithms for path planning have been developed over the past twenty years such as: A* algorithm [1], D* algorithm [2], reinforcement learning [3], potential field methods [4], neural networks [5], and fuzzy logic [6] and each method has its own force over others in certain sides. The artificial potential field (APF) method is widely used for mobile robot path planning. In the artificial potential field method, a mobile robot is considered to be subjected to an artificial potential force. The potential force has two forces: first one is attractive force and second one is repulsive force. In the artificial potential field method, we can imagine that all obstacles can generate repulsive force to the robot that is inversely proportional to the distance from the robot to obstacles and is pointing away from obstacles, while the destination or goal has attractive force that attracts robot to the goal. The combination of these two forces will generate a total force with magnitude and direction, the mobile robot should follow that direction to avoid obstacles and reach to the target in a safe path [7]. Actually the artificial potential field method uses a scalar function called the potential function [8]. This function has two values, a minimum value, when the robot is at the goal point and a high value on obstacles. The function slopes down towards the target point, so that the robot can reach the target by following the negative gradient of the total potential field.

The rest of this paper is organized as follows: Section 2 presents related work in the field of robot path planning. Section 3 discusses representation of the artificial potential fields. Section 4 presents drawbacks and solutions for artificial potential field method. Section 5 discusses the controller of mobile robot. Section 6 discusses the optimization of PID controller by particle swarm optimization algorithm. Section 7 discusses proposed method of fuzzy-artificial potential field method for path planning. Simulation results are described in Section 8 to demonstrate the effectiveness of the proposed method for path planning of mobile robot. Section 9 discusses the conclusions of this work.

## II- Related Work

In this section, we review some of researches in the field of mobile robot path planning methods. Khatib's work [9] defined a potential field on the configuration space with a minimum at the target point and potential hills at all obstacles. The mobile robot in the potential field is attracted to the goal point while being repelled by obstacles in the environment. The robot should follow the gradient of the total artificial potential to goal point while avoiding collisions with obstacles. Chengqing et al. [10] have introduced a navigation method, which combined virtual obstacle concept with a potential-field-based method to maneuver cylindrical mobile robots in unknown environments. Simulation by computer and experiments of their method illustrates accepted performance and ability to solve the local minima problem related with potential field method. A new potential function is proposed by Ge and Cui that function take into consideration of dynamic environments that contain moving obstacles and goals. In this work positions and velocities of robots, obstacles, and goals are considered in the functions of potential field [11]. GNRON problem (goals non-reachable with obstacle nearby), which is a common drawback in most potential field methods, is identified by Ge and Cui [12] and Volpe and Khosla [13]. GNRON problem can be solved using their proposed potential field method. Detailed studies of these local potential methods, their characteristics and their limitations were discussed in [14]. Evolutionary Artificial Potential Field (EAPF) for real-time robot path planning has proposed by Vadakkepat et al. [15]. Combination between genetic algorithm and the artificial potential field method is introduced to derive optimal potential field functions. With the proposed method in this work, the mobile robot can avoid static and dynamic obstacles

## III. REPRESENTATION OF THE ARTIFICIAL POTENTIAL FIELDS

It is assume that the robot is of point mass and Let q represent the position of the robot moves in a two-dimensional (2-D) environment. The position of mobile robot in the environment is denoted by $q = [x\ y]^T$, position of obstacle $q_{obs} = (x_{obs}, y_{obs})$, and position of goal $q_{goal} = (x_{goal}, y_{goal})$.

*A. Attractive Force*

The most commonly used form of potential field functions proposed by Kathib is presented as a parabolic form as shown in Fig. 1 that grows quadratically with the distance to the goal [16].

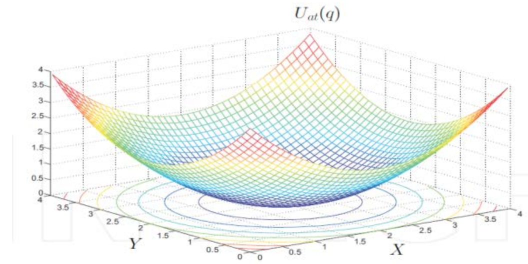


Fig. 1 Attractive Potential Field.

$$U_{att}(q) = \frac{1}{2}\,\zeta\, d^2(q, q_{goal}) \qquad (1)$$

where ζ a is the proportional coefficient of the attractive potential filed function.

$d(q, q_{goal})$ is the Euclidean distance between the robot q and the position of the target $q_{goal}$.

The attractive force on robot is calculated as the negative gradient of attractive potential field and takes the following form:

$$F_{att}(q) = -\nabla U_{att}(q) = -\zeta d(q, q_{goal}) \qquad (2)$$

*B. The Repulsive Potential*

The repulsive force is inversely proportional to the distance from the obstacle. The repulsive potential results from the combination of the repulsive effect of all the obstacles. The representation of repulsive potential field is shown in Fig. 2.

$$U_{rep}(q) = \sum_i U_{repi}(q) \qquad (3)$$

Where $U_{repi}(q)$ represents the repulsive potential generated by obstacle i, where i is no. of obstacles that influence the environment of robot.

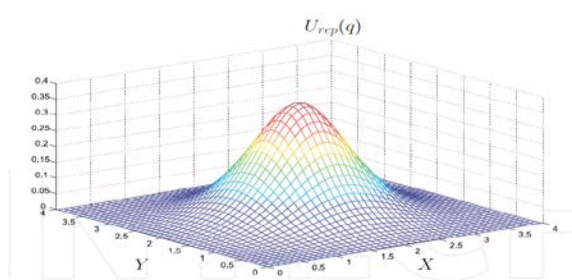


Fig. 2 Repulsive Potential Field

The repulsive function is [17]:

$$U_{rep}(q) = \begin{cases} \frac{1}{2}\eta\left(\frac{1}{d(q,q_{obs})} - \frac{1}{d_0}\right)^2 & \text{if } d(q,q_{obs}) < d_0 \\ 0 & \text{if } d(q,q_{obs}) > d_0 \end{cases} \quad (4)$$

Where q is the robot position and $q_{obs}$ is the obstacle position. $d_0$ is the positive constant denoting the distance of influence of the obstacle. $d(q,q_{obs})$ is the distance between the robot and obstacle. $\eta$ is an a the proportional coefficient of the repulsive potential filed function. The repulsive force is the negative gradient of this repulsive potential fields function.

$$F_{rep}(q) = -\nabla U_{rep}(q) = \begin{cases} \eta\left(\frac{1}{d(q,q_{obs})} - \frac{1}{d_0}\right)\frac{(q-q_{obs})}{d^3(q-q_{obs})}, & \text{if } d(q,q_{obs}) < d_0 \\ 0, & \text{if } d(q,q_{obs}) > d_0 \end{cases} \quad (5)$$

The total potential field is defined as the combination of attractive potential $U_{att}$ and a repulsive potential $U_{rep}$. Then the composition attractive potential with repulsive potential will generate the total potential fields [18]. The total potential fields can be described by:

$$U(q) = U_{att}(q) + U_{rep}(q) \quad (6)$$

The total force that applied to the mobile robot is obtained by the negative gradient of a total potential field which is the steepest descent direction for guiding robot to target point.

$$F(q) = -\nabla U(q) = -\nabla U_{att} - \nabla U_{rep} \quad (7)$$

Where $\Delta$**U** is the gradient vector of **U** at the robot position, the force that effected robot is calculated as the sum of the attractive and repulsive force vectors, $F_{att}$ and $F_{rep}$, respectively.

$$F(q) = F_{att}(q) + F_{rep}(q) \quad (8)$$

## IV. DRAWBACKS AND PROPOSED SOLUTIONS

Artificial Potential Field algorithm suffers from some drawbacks in implementing it for real time applications. The local minima problem is the most common problem, a local minima problem occurs when sum of all forces is zero. The most three conditions in which local minima occur are:

**(1)** When robot, obstacle and target are located on the same line and the obstacle is at the middle of the robot and the target [19]. The diagram in the Fig. 3 below shows this case.

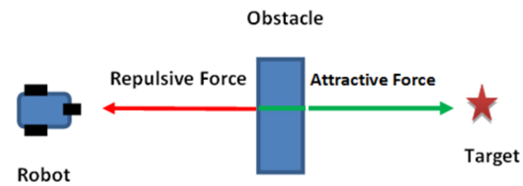



Fig. 3 Robot, obstacle and target are located on the same line

**(2)** When the target is within the effected region of obstacle such that the repulsive force of the obstacle will push the mobile robot away from the goal. This problem is known as "Goals non-reachable with obstacle nearby" [20]. Diagram in the Fig. 4 below illustrates this case.

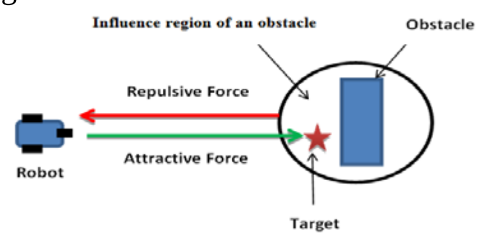



Fig. 4 "Goals non-reachable with obstacle nearby" problem

**(3)** When the mobile robot encounters a complex environment such environment may contain a complex shaped obstacle for example a non-convex (e.g. U-shaped) obstacle, the mobile robot under effect artificial potential field cannot avoid obstacle and reach target [21]. Diagram in the Fig. 5 below illustrates this case.

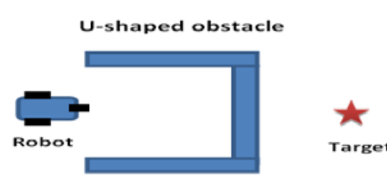



Fig. 5 U-shaped obstacle problem

The problems of (1) and (2) can be solved using the improved artificial potential function method which can be done by modifying repulsive potential function that can overcome the disadvantage of traditional method in the case of the problem (1) & (2). Problem (3) and many other problems of potential field method which related to slowly reaction in complex and dynamic environment can be solved by combining Artificial Potential Field with one of intelligent techniques and in this work fuzzy logic technique is issued with artificial potential field method greatening new approach called "Fuzzy-Artificial Potential Field".

*A. Modified Repulsive Potential Field Function*

As seen in the problem (1) & (2) which occur as the robot approaches the target, that repulsive force $F_{rep}$ increases when robot approach the goal due to presence of obstacle near the target, so the resultant force F at goal is not global minimum, the robot can't reach to the target. It is observed that if the repulsive potential force approaches zero, the mobile robot approaches the target. To solve this problem, it is need to construct a new repulsive potential function which make the target has a global minimal potential force, the modified artificial potential field introduces the distance between the mobile robot and goal into the function of repulsive force between the robot and the target, to ensure the global minimum is at the position of the target [17].
The redefinition of repulsive potential function can be defined by

$$U_{rep}(q) = \begin{cases} \frac{1}{2}\eta\left(\frac{1}{d(q,q_{obs})} - \frac{1}{d_0}\right)^2 d(q,q_{goal})^n, & \text{if } d(q,q_{obs}) < d_0 \\ 0, & \text{if } d(q,q_{obs}) > d_0 \end{cases} \quad (9)$$

where $d(q,q_{obs})^n$ represents the distance between the robot and the goal, where n is a real number greater than 0 . So now when the mobile robot is close to the goal, the attractive potential field is reducing; the repulsive potential field is also reducing accordingly, until the robot reaches the target, then the attractive and repulsive field reduced to 0. The repulsive force is the negative gradient of repulsive potential fields function, and the composition of repulsive forces can be decomposed into two kinds of force. The composition of repulsive forces $F_{rep}$ can be defined as [19]:

$$F_{rep} = -\nabla U_{rep}(q) = \begin{cases} F_{rep1} + F_{rep2} & \text{if } d(q,q_{obs}) < d_0 \\ 0 & \text{if } d(q,q_{obs}) > d_0 \end{cases} \quad (10)$$

Both $F_{rep1}$ and $F_{rep2}$ are the decomposition of $F_{rep}$ , $F_{rep1}$ and $F_{rep2}$ can be described as below:

$$F_{rep1}(q) = \eta\left(\frac{1}{d(q,q_{obs})} - \frac{1}{d_0}\right)\frac{d(q,q_{goal})^n}{d(q-q_{obs})^2} \quad (11)$$

$$F_{rep2}(q) = -\eta\frac{n}{2}\left(\frac{1}{d(q,q_{obs})} - \frac{1}{d_0}\right)d(q,q_{goal})^{n-1} \quad (12)$$

Where $F_{rep1}$ and $F_{rep2}$ are two components of $F_{rep}$. The direction of $F_{rep1}$ points to the robot from the point, which is closest to the robot. The direction of $F_{rep2}$ points to the target from the robot.

## V. MOTION CONTROL OF MOBILE ROBOT

PID control is one of the classical control methods and widely used in the industrial applications. PID controller is considered as a motion controller for controlling movement of mobile robot. In the PID control, the difference between the set point or desired input value **(ref)** and the actual output **(y)** is represented by the **(e)** error signal given by [e(t) = ref(t) – y(t)] , This signal is applied to PID controller to get control signal u(t) as follows [22]:

$$u(t) = K_p e(t) + K_d\frac{de(t)}{dt} + K_i\int_0^t e(t)\,dt \quad (13)$$

$K_P$ = proportional gain, $K_i$ = integral gain and $K_d$= derivative gain.

PID parameters (P, I and D) should be chosen carefully to obtain fast rise time, no steady state error and smaller overshoot. In this paper PID controller parameters are tuned using Particle swarm optimization Algorithm "PSO" to get optimal response of PID Controller. The block diagram of mobile robot control system with two PID controllers is shown in Fig. 6.

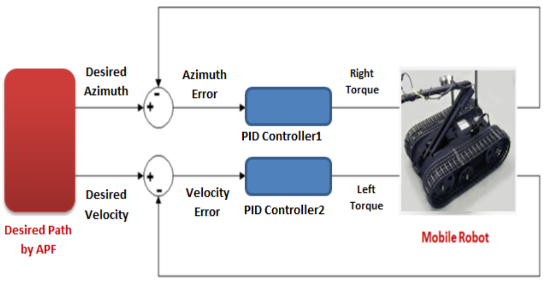



Fig. 6 Block diagram of closed loop system for mobile robot

## VI. PARTICLE SWARM OPTIMIZATION ALGORITHM FOR PID CONTROLLER OPTIMIZATION

Particle swarm optimization (PSO) is optimization method developed by Dr. Eberhart and Dr. Kennedy, the work of PSO resembles behavior of fish schooling and bird flocking [23]. In the PSO algorithm the system is initialized with a population of random solutions and searches for best solution by updating generations. In PSO, the potential solutions, called particles, these particles follow the current optimum particles in the problem space. Each particle keeps track of its coordinates in the problem space which are related with the best solution and that solution called pbest. Particle swarm optimizer is also keeping track another value called the best value that get by particle in the neighbors of the particle. This location is called lbest. When one of particles takes all the population as its topological neighbors, the best value is a global best and it is named gbest [24]. The PSO algorithm is used to find the optimal parameters for the two PID controllers, one for controlling velocity and another for controlling angle of mobile robot. Fig. 7 shows the block diagram of PID-PSO controller for the mobile robot.

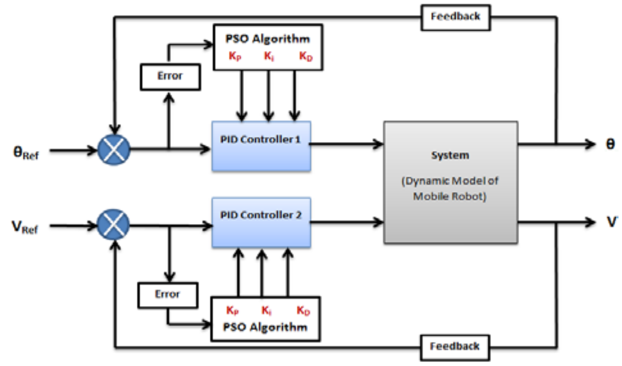



Fig. 7 Block diagram of optimal PID controller for the mobile robot.

The PSO algorithm will be used to tune two PID controllers by searching for their optimal value in the six dimensional search space [i.e. $K_{P1}, K_{I1}, K_{D1}$, $K_{P2}, K_{I2}, K_{D2}$], three dimensions specified for first controller (velocity controller) and another three dimensions for second controller (angle controller), for each controller there are three parameter to be tuned. By doing several experiments using different values for population size and number of iterations, it is observed that the following parameters values of PSO algorithm shown in Table (1) yield acceptable parameters for PID controllers to give a good performance to control the movement of mobile robot.

Table (1)
PSO parameters

| | |
|---|---|
| Size of the swarm | 100 |
| Maximum iteration number | 200 |
| Dimension | 6 |
| PSO parameter $c_1$ | 2 |
| PSO parameter $c_2$ | 2 |
| $W_{max}$ | 0.9 |
| $W_{min}$ | 0.3 |

Mean Square Error MSE criterion has been used as a fitness function to evaluate the performance of the system to compute the acceptable parameters by PSO algorithm. The formula of MES error is shown below:

$$MSE_{total} = \left(\frac{1}{n}\sum_{k}^{n}(e_\theta(k))^2\right) + \left(\frac{1}{n}\sum_{k}^{n}(e_v(k))^2\right) \quad (14)$$

n : represents number of samples, k: sample time. The parameters in the Table (2) give the best (lowest) MSE in order to build the PID controllers

Table (2)
PID controller parameters

| Parameters for PID controller to control velocity | | | Parameters for PID controller to control angle | | |
|---|---|---|---|---|---|
| $K_{P1}$ | $K_{I1}$ | $K_{D1}$ | $K_{P2}$ | $K_{I2}$ | $K_{D2}$ |
| 110.44 | 50.24 | 1.0022 | 60 | 100.59 | 2.213 |

## VII. PROPOSED APPROACH OF FUZZY-ARTIFICIAL POTENTIAL FIELD

A proposed method for path planning of mobile robot is introduced in this paper which is based on combining artificial potential field method with fuzzy logic to improve the performance of artificial potential field method and gives a robust motion behavior capable of navigating the mobile robot in unknown static and dynamic environments. Fig. 8 illustrates the block diagram of the proposed approach. The first block is artificial potential field algorithm block that takes as input the variables: current position of mobile robot (i.e. X-Axis, Y-Axis), sensors readings from three directions (Front, Left, Right) and generates desired angle and velocity. The second block is the fuzzy controller block that takes as inputs the variables: sensors readings from three directions (front, left , right), *Angle_Error* which computed by comparing the angle of the resultant force (i.e. Artificial Potential Field) acting on the robot and current heading angle of mobile robot and has three membership functions :(Negative “N”, Zero “Z”, Positive “P”), and *Velocity_Error* represents the difference between the velocity generated by artificial potential field method and current velocity of the mobile robot and has three membership functions :(Slow, Medium, Fast) and the output of controller are angular velocities of the left "$W\ell$" and right "$Wr$" wheels which then converted to get the desired angle and velocity, each variable of left and right velocity has five membership functions: Zero (Z), Small Positive (SP), Big Positive (BP), Small Negative (SN), and Big Negative (BN). In the 2-D environment, the artificial potential field method is initialized first. The artificial potential field method plans the initial path of mobile robot and starts executing it by following the direction of total potential force (i.e. desired velocity and azimuth). When the fuzzy logic controller detects through mobile robot sensors a collision possibility, the fuzzy logic controller will ignore the initial artificial potential field path and take corresponding actions which represented by changing heading angle and velocity of mobile robot to avoid the collision, until new sensor readings dictate a not-possible collision possibility. Then, the fuzzy logic controller takes into account the initial path that computed by the artificial potential field method. The Artificial Potential Field method is re-invoked every time the environment map is updated. Actually, the fuzzy-artificial potential field method performs sensor fusion from sensor readings into the linguistic variable collision, providing information about collisions in three directions front, left, and right, and then guarantees collision avoidance with static and dynamic obstacles while following the trajectory (i.e. desired velocity and azimuth) generated by the artificial potential field method. The sensors type which equipped on the mobile robot is infrared sensors. Fig. 9 shows the block diagram of the fuzzy inference system. Table (3) illustrates some of rules base of fuzzy controller.

## VIII. SIMULATION RESULTS FOR PATH PLANNING BY USING FUZZY-POTENTIAL FIELD METHOD.

In this simulation we will compare between modified potential field method and fuzzy-potential field method for path planning of mobile robot in the static and dynamic environment.

### *A. Static Environment*

In this environment in which the mobile robot should move from start point (0,0) to target point (6,14) where three static obstacles speared in the environment. Fig. 10 (A) illustrates the simulation of mobile robot by using modified potential field method. Fig. 10 (B) below illustrates the simulation of mobile robot by using Fuzzy-potential field method. Table (4) shows the elapsed time (sec) and path long (m) of mobile robot.

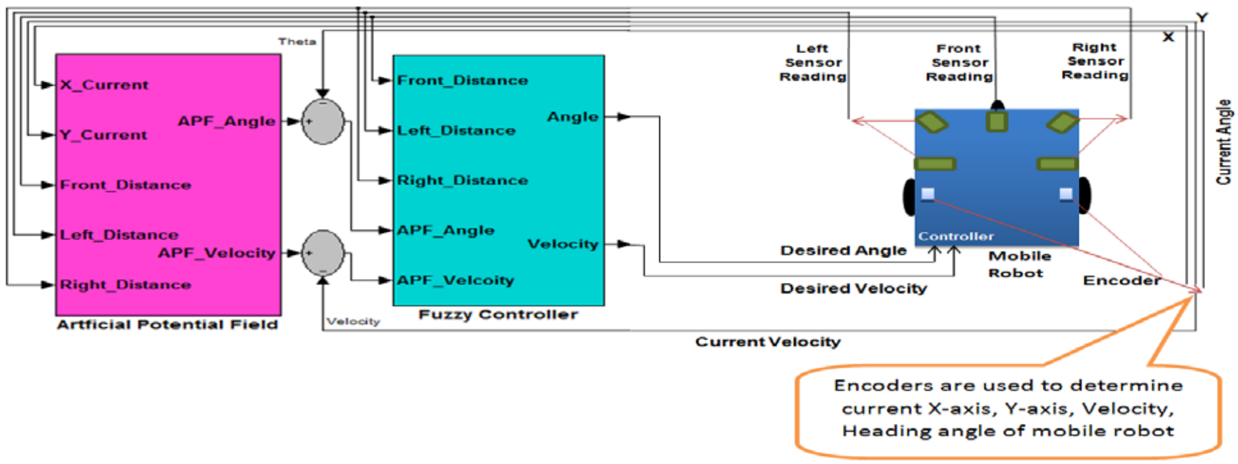



Fig. 8 Block diagram of the proposed approach.

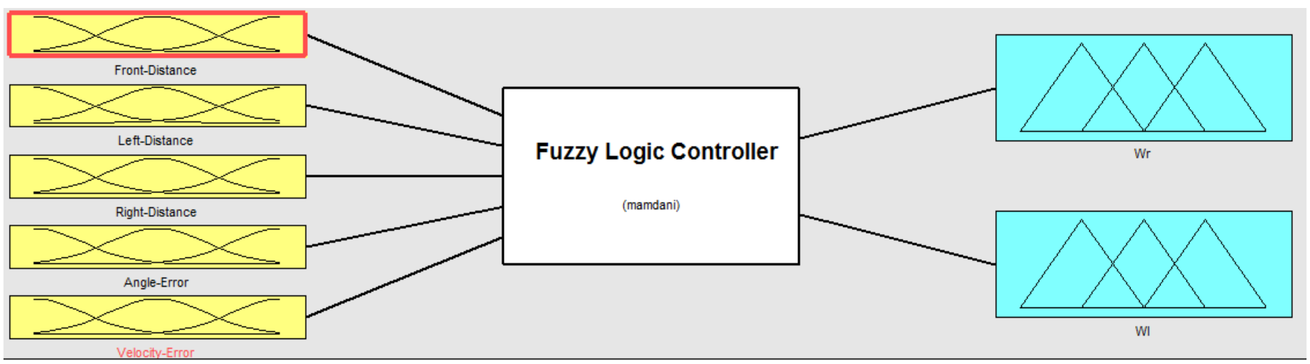
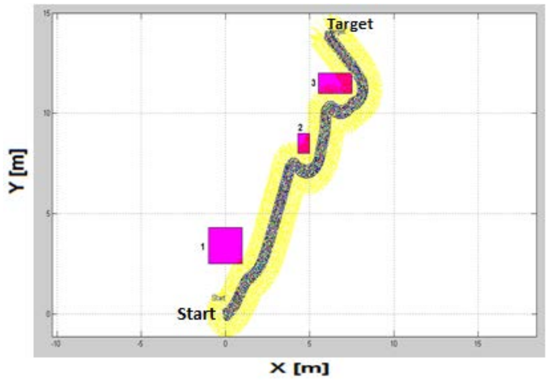



Fig. 9 The block diagram of the fuzzy inference system

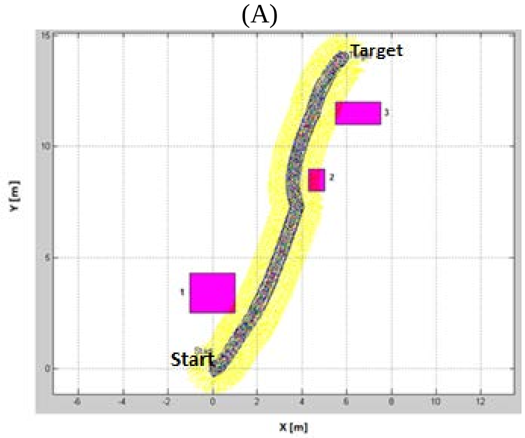
Table (3)

Rules base of fuzzy controller

| No. | Front-Distance | Left-Distance | Right-Distance | Angle-Error | Velocity-Error | Wr | Wl |
|---|---|---|---|---|---|---|---|
| 1 | Not-Possible | Not-Possible | Not-Possible | Negative | Fast | SN | SP |
| 2 | Possible | Not-Possible | Not-Possible | Positive | Slow | SP | Z |
| 3 | Possible | Possible | Not-Possible | Zero | Slow | Z | SP |
| 4 | Possible | Possible | Possible | Zero | Slow | BN | BP |
| 5 | Possible | Not-Possible | Not-Possible | Negative | Fast | SN | SP |
| 6 | Possible | Not-Possible | Possible | Negative | Fast | SP | SN |
| 7 | Possible | Possible | Not-Possible | Negative | Fast | SN | SP |
| 8 | Possible | Not-Possible | Possible | Negative | Fast | SP | SN |
| 9 | Possible | Possible | Not-Possible | Negative | Fast | SN | SP |
| 10 | Not-Possible | Not-Possible | Possible | Positive | Fast | Z | SN |
| 11 | Not-Possible | Not-Possible | Possible | Zero | Fast | Z | SN |
| 12 | Not-Possible | Possible | Not-Possible | Zero | Fast | SN | Z |
| 13 | Possible | Not-Possible | Not-Possible | Positive | Fast | SP | SN |
| 14 | Not-Possible | Possible | Not-Possible | Zero | Medium | SP | BP |
| 15 | Not-Possible | Possible | Possible | Zero | Medium | SN | BP |




(A)




(B)

Fig. 10 The path of mobile robot in static environment.

Table (4)
The elapsed time and path of mobile robot

| | APF | Fuzzy-APF |
|---|---|---|
| Total Elapsed Time(sec) to reach goal | 3.429 | 2.5 |
| Distance of path (m) | 20.5 | 15 |

### *B. Dynamic Environment*

Fig. 11 illustrates the simulation of mobile robot navigation in dynamic environment by using Fuzzy-Potential Field Method as a path planning algorithm In this environment where the robot should move from start point (0,0) to target point (8,14) where many static and dynamic obstacles with different sizes and shapes speared in this environment. Actually mobile robot failed to navigate in dynamic environments by using traditional APF. Table (5) shows the elapsed time (sec) and path long (m) of mobile robot

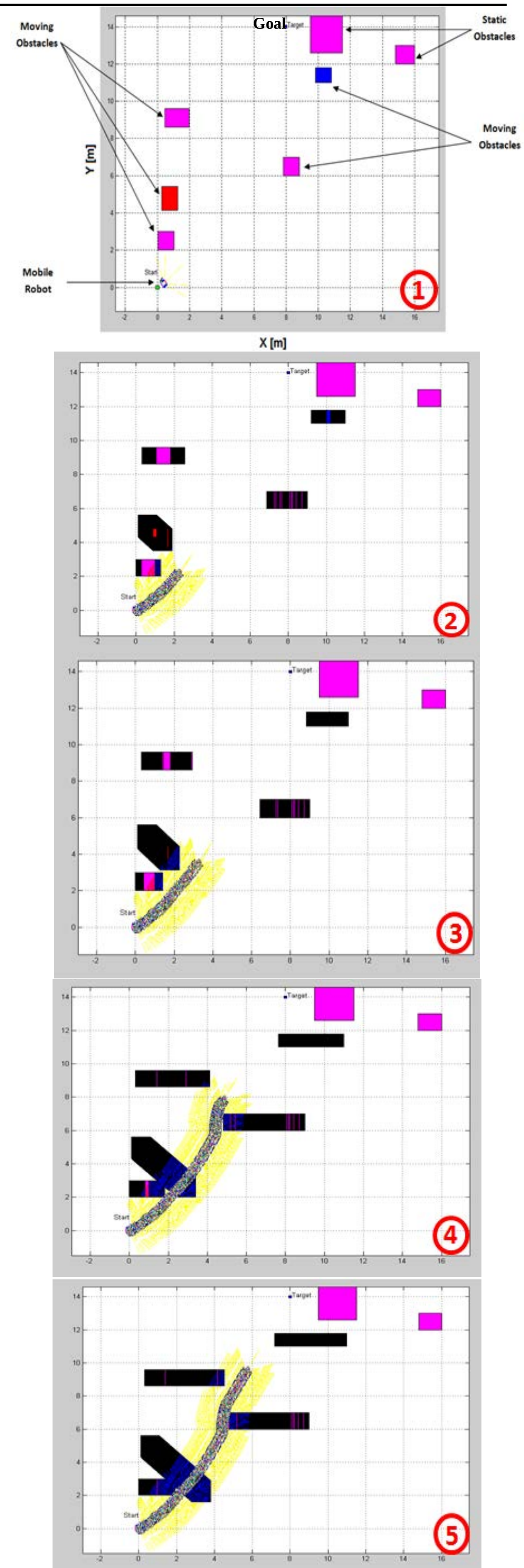



Fig. 11 The path of mobile robot by using "Fuzzy-Artificial Potential Field Method" in dynamic environment.

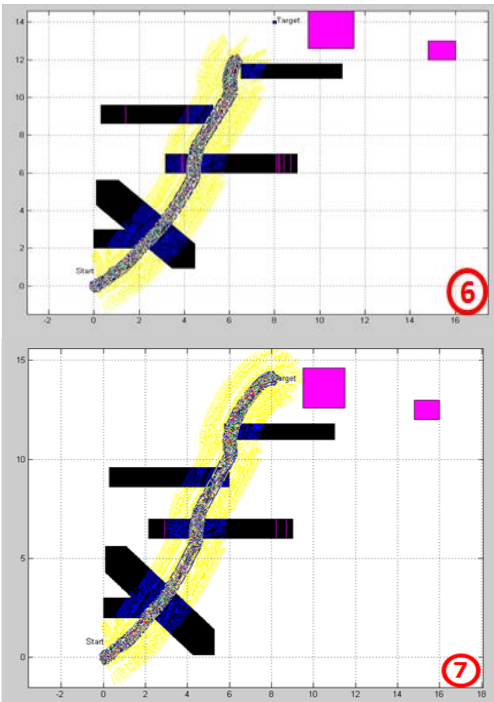



Fig. 11 Continued

Table (5)
The elapsed time and path of mobile robot

| | Fuzzy-APF |
|---|---|
| Total Elapsed Time(sec) to reach goal | 2.48 |
| Distance of path (m) | 15 |

## IX. **CONCLUSION**

The artificial potential field approach provided well-planned paths but sometimes it falls in local minima problems and also very slow to react to the presence of unknown moving obstacles even when a modification of potential functions is made the method still weak and suffer from some problems. The hybrid “Fuzzy-Potential Field Method” allows the potential field to plan the path (by generating desired angle and velocity) and allows the fuzzy controller to implement that path while avoiding collision with obstacles in the environment. The efficiency of the proposed method is demonstrated through simulation in different environments. The mobile robot can generate reasonable trajectories towards the target efficiently with less time and distance in various situations without suffering from the local minima and can navigate in static and dynamic environments.

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