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Mobile robot navigation based on Fuzzy Cognitive Map optimized with Grey Wolf Optimization Algorithm used in Augmented Reality

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***Abstract*— this work presents a control technique for Mobile Robot Navigation using augmented reality (AR). This navigation technique is based on optimized Fuzzy Cognitive Map (FCM) and AR's Glyphs. AR's symbols are provided by the overhead camera. The patterns are made up of glyphs and a clear path. Six practical test are manipulated to examine the strength of optimizing FCM by a mobile robot for navigation with AR's symbols. The experiment examined the effectiveness of a Grey Wolf Optimization Algorithm (GWOA) in optimizing the FCM. Two practical experiments confirm that AR's Glyphs are an effective symbol for a robot to navigation in an unknown environment. A practical experiment reveals that a robot can use AR to manage its intended movement. Augmented reality, such as the Glyphs and a simplified map, are an effective tool for mobile robots to use in navigation in unknown environments. A prototype system is made to navigate the mobile robot by using AR and FCM.**

Keywords: Augmented reality, Fuzzy Cognitive Map, Grey Wolf Optimization Algorithm, Mobile Robot, Glyph

I. INTRODUCTION

Mobile robots have been recognized in numerous businesses, include mining, military functions, search and rescue missions[1]. In other words, the robot interacts along many tools to simulate environments control navigation, and analyses objects using robot control management [2]. One of the major component of any mobile robot is the ability of localization and navigation [3]. In the mobile robot navigation system, path planning is one of the important tasks [4]. This task divided into two parts: One is path planning in known environments that the mobile robot is navigated based on complete information regarding the environment and the other is path planning in unknown environments that is based on receiving of information via sensors, camera, and other accessories [5]. Diverse methods have been introduced for controlling the robot in the unknown environments. One of these methods is using the augmented reality (AR). AR involves two major operations, tracking, where the direction and position of the relative camera in real-world scenes are calculated, and registration, where virtual objects based on the calculated value from the tracking process are rendered onto the user's view [6]. Research on Augmented Reality commenced since fifty years ago by Azuma [7]. AR has numerous use cases such as Education and training [8-11], medical science [11-13], robotic [14, 15], and so forth.

Fuzzy Cognitive Map (FCM) is based on a fuzzy inference mechanism and a neural network that was developed in 1980 by Kosko [16]. The FCM is a very simple and powerful tool for simulation and analyze of complex systems [17]. The FCM models were developed and employed in most systems such as engineering, politics, etc. [18]. Grey Wolf Optimizer (GWO) is a new meta-heuristic impressed by the hierarchy and searching behavior of gray wolves [19]. GWO is very simple and versatile. The flexibility refers to the relevance of GWO in entirely different issues with not any specific changes within the structure of the algorithm [20]. In the mobile robot navigation of [21], the geometrical modelling of the environment namely " non-human-like" problem, is resolved by new vision-guide navigation method named " NEURO-NAV". The minimum risk method of [22] is based on memory grid technique. Thus the robot can avoid crash with obstacles and the robot is navigated in the right way.

These methods navigate the mobile robot in uncertain environment with rule-base techniques. In the mobile robot real-time navigation method of [23], the problem of using fuzzy logic control with large number of rules is resolved by a new fuzzy control system called Fuzzy Cognitive Map (FCM). In the mobile robot navigation of [24], the intended movement problem is resolved by using visual arrows and a simplified map as spatial Augmented Reality. In the collaboration with a mobile robot of [25], the communication problem between the mobile robot and human is resolved by Augmented Reality Technology. In the [26] exploited the new progress in velocity and precision of optical motion capture to localize the robot, track objects, and extract parameters for moving cameras in the period. In the Robot Path Planning problem of [27], the distance and smooth path issues resolved by GWO.

Our research is novel in that it uses Augmented Reality to provide the control system in uncertain and dynamic

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workspace. AR permits the movement commands for mobile robot with AR symbols. In order to resolve the problems of the previous algorithm as highlighted, (FCM) is used to develop the essential control for movement commands. GWO is used to optimize the FCM. Also for comparing the results, optimization process is done with GA.

The rest of the work is as follows: The mobile robot used in the proposed method presented in section II. Section III introduces the AR and the environment used to control the mobile robot. An overview of the FCM and the main structure of the FCM for controlling the mobile robot described in section IV. Section V presents the GWO, framework and the error function used for optimizing the performance of FCM. Experimental results and discussions are presented in section VI. Finally, section VII concludes the whole work.

II. ROHAN MOBILE ROBOT

In the proposed method, a mobile robot platform namely Rohan was used. The Rohan was designed and manufactured in Robot Makers Company [28]. The Rohan Mobile Robot is a two wheel drive mobile robot platform with two levels. The robot contains two motors, two wheels, and six ultrasonic sensors that give it six directions of surveillance. Our customized, high-quality DC motor has high torque with an integrated encoder and quiet performance. It meets the general requirements of a simple speed controller such PID and fuzzy. It has a bracket for installing Microsoft Kinect (Fig.1). The first control system of this robot is obstacle avoidance in indoor or outdoor environments. Also the Kinect is used to hand gesture recognition in Rohan navigation. The Rohan Mobile Robot wheels are fixed and move only forward or backward in a horizontal plane. Pure rolling is at wheels contact points.

For navigating this mobile robot in environments, a human must be in front of the mobile robot to give the movement command to the robot via Kinect sensors. In the proposed method, we disabled all ultrasonic sensors and detached the Kinect from Rohan to put an augmented reality marker on the robot (Fig.2). To incorporate the mobile robot into this system, a GUI for controlling the Rohan Mobile, Is written in C#. This interface provides a simple platform for proving the functionality of our mobile robot.

III. DEVELOP THE ENVIRONMENT USING AR

A. AR with Graft Library

Computer vision library known as GRAFT by the Aforge.Net in C# program language, is employed to recognize the unique images, estimate the camera position, and show 3D virtual images adjusted to the post of markers[29]. The augmented reality may be the most favourite section in the GRAFT library, where the objects are produced and placed within the environment. Another space of optical glyph's application is in artificial intelligence and robotic technology,

Fig. 1. Original Structure of Rohan mobile platform robot of Robot Makers Company [28].

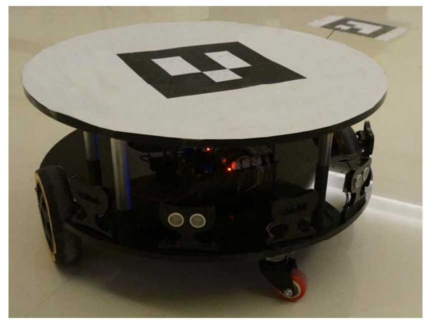

Fig. 2. Put an augmented reality marker on the Rohan Mobile robot instead of Kinect

Where glyphs may provide commands to a robot or help robot to navigate inside some environment. In robotics applications, each glyph may signify a path or order for a mobile robot. Therefore, the important step is to complement the extracted glyph data with a database of glyphs and retrieve the information related to the glyph - ID, name, and other things.

B. Preparing Environment

For developing the environment using AR, we installed a Logitech c930e webcam on the roof of the lab. The Logitech C930e Webcam with 1080p high-definition, H.264 video compression, and a wide 90-degree field of view, C930e was the best choice for image processing and Augmented Reality. In this work the ceiling height of environment is 3 meters and for avoiding radial distortion, the height of camera was changed. And when the camera covered the 3x3 meters of the environment without radial distortion, was fixed. The next step for conversion of distance in pixels to cm was calibrating the camera. With the size of Rohan and distance between the camera and the Rohan we calibrated the camera. After installing the camera, we placed four augmented reality glyphs on the ground and specified the image border. We placed two glyphs on the ground for determining the purpose of the robot movement (Fig.3). Then we extracted some basic parameters for navigating the mobile robot. In this work, we extracted two parameters. First, we determined the coordinates of the markers and secondly, the direction of the marker. In the next phase, we calculated the angle between the mobile robot and the destination. Two angles were defined for moving the robot using the augmented reality route.

- Angle between the robot and the target (Fig.4)
- Angle between front of the robot and the target (Fig.5)

The first parameter for moving the robot towards the target and the second parameter for Non-deviation move. These two angles were the main computational parameters for Determining the direction and movement of the mobile robot. After specifying these parameters, a path was drawn as the optimal route between markers. This road was to specify the desired path for the robots to move in the pilot environment Fig.6. This route is drawn virtual in augmented reality. The aim of this study was to navigate the robot between AR's markers and on the desired path. As shown in Fig.6, each glyph represented a moving command to the specific direction of a mobile robot. The commands include the amounts of the robot's left and right wheel speed. The rate of movement should be based on the movement towards the target and in the specific path. Therefore, we proposed the developed FCM to navigate the robot correctly.

IV. ROBOT MOTION CONTROL WITH FCM

A. *Fuzzy Cognitive Map (FCM)*

FCM started within the last years to control systems including robotics. Although FCM has particular characteristics, such as the ability to represent the causal relation between objects and concepts. This feature enables FCM to be used in technical and complex problems [30]. FCM can be a symbolic causative representation for explaining and modelling advanced systems [31]. In the FCM, the nodes represent the concepts of the system.

These concepts correspond to the characteristic of the scheme. The arrows connect the nodes. These arrows demonstrate the cause-effect relationship between the nodes (Fig. 7) [32]. FCM is based on a direction graph. In the graphs, there are links between variables (nodes) with a direction [33]. The FCM nodes represent the input and output variables. In The FCM, these instructions might describe the effects of input on input, output on output, output on input and even input on output. Each link contains weights that show effect and severity of effect. Initial weights were assign by experts and these values change according to the system condition in the environment. The FCM can train the weights.

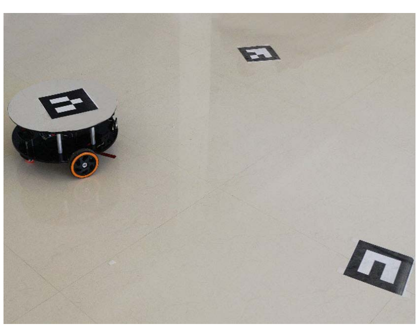

Fig. 3 preparing the environment used augmented reality Markers

One of the methods is AI algorithms such as (GA, PSO...). These weights were obtained from the previous state of the system.

B. *Definition of Navigation Concepts*

In the proposed method, there are five input and four output concepts for setting the robot velocity controls. To improve the robot movement in the environment, we made a little change in the FCM of [23], as described in Table.1. For target direction, we added two new states. They include TLF (Target at left-front) and TRF (Target at the right front). Furthermore, we added the new input concept, namely the target distance. This concept has two fuzzy states, TN (Target-Near) and TF (Target Far).Therefore, there are entirely two input concepts and totally seven fuzzy states. Two output concepts were increase or decrease left wheel speed and increase or decrease right wheel velocity as shown in Table.1.

The target direction for the Rohan is shown in Fig.8. There are five states for these concepts; TL (the target at the left), TLF (the target at the left-front), TF (the target at the front), TRF (the target at the right front) and finally TR (the target at the right). For another concept (the target distance), there are two states, TN (the target- near) and TF (the target far). The distance between the robot and target (d) is calculated by GRAFT library. In addition, this distance is divided into two sections. The d > 50cm called far and d < 50cm named near. The robot velocity according to this parameter changed from high to low. Fig.9 shows the relationship between the forward velocity and the target distance concept.

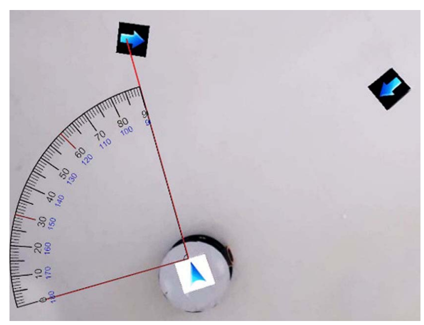

Fig. 4. The angle were defined between the robot and target for moving the robot towards the target

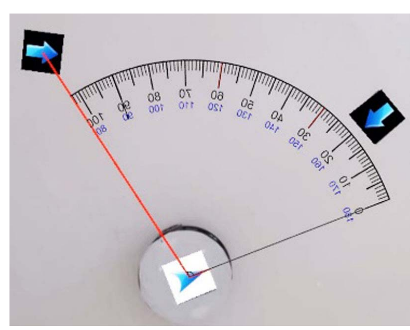

Fig. 5. The angle were defined between the front of the robot and target for Non-deviation move

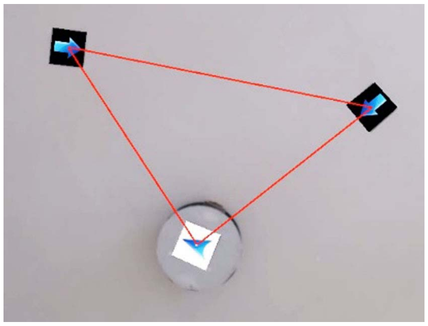

Fig. 6. Draw a visual path as the optimal route for robot navigation via AR

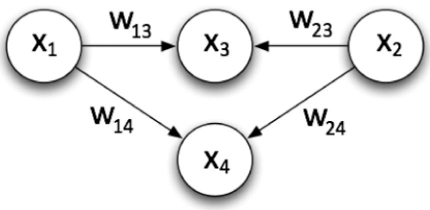

Fig. 7. The FCM graph shows the efficiency and degree of concepts

The primary FCM is shown in Fig.10. This FCM includes seven input concepts and two output concepts from Table.1. The output concepts are applied to the robot's left and right wheels encoders for controlling the linear velocity of the robot. The FCM is developed in two steps. The nine nodes of the FCM make the string. The string includes 81 elements $\{e_{1,1}..e_{1,9};e_{2,1}..e_{2,9};e_{9,1}..e_{9,9}\}$ where $e_{i,j}$ represents the effectiveness of the ith concept on the jth one. The initial weights of links, is defined with the arbitrary amounts that the robot may be moving according to augmented reality commands. These weights are set experimentally based on the robot conditions. For target direction links, we set the wheel velocity in rpm and the target distance links was initially defined using negative (−), or positive (+) amounts.

V. GWO Algorithm for Tuning FCM

The Grey Wolf Optimizer (GWO) [19] is one of the best newly recommended population-based optimization algorithms.

It contains exact parameters which are defined by Users and it is easy to implement. For these reasons, many researchers used this algorithm for solving their problems. However the performance of optimization algorithms is not similar for solving problems[34]. To analyse the performance of the GWO in the proposed method, the FCM was optimized with Genetic Algorithm. Finally the performance of the two optimization algorithm in optimizing the FCM was compared in the proposed method. In the implementation of this algorithm, four types of grey wolves such as alpha, beta, delta and omega were used to simulate the leadership hierarchy in which the three most important steps of the hunt, searching for prey, surrounding prey, and attacking the bait.

The initial steps of grey wolf hunting are tracking, encircling and attack. In the GWO, the fittest solution is alpha (α) and the second and third best solutions are appointed beta (β) and delta (δ), respectively. The other candidates is named omega (ω). To mathematically model the encircling behaviour of Grey Wolves, the following equations are proposed:

$$\vec{D} = |\vec{C}.\vec{X}_p(t) - \vec{X}(t)| \quad (1)$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A}.\vec{D} \quad (2)$$

t demonstrates the current iteration, $\vec{A}$ and $\vec{C}$ are coefficient vectors, $\vec{X}_p$ is the position vector of prey, Furthermore, $\vec{X}$ illustrates the position vector of a grey wolf. The vectors $\vec{A}$ and $\vec{C}$ are ascertained as follows:

$$\vec{A} = 2\vec{a}.\vec{r}_1 - \vec{a} \quad (3)$$

$$\vec{C} = 2.\vec{r}_2 \quad (4)$$

The components of $\vec{a}$ are linearly decreased from 2 to 0 over the iterations. $\vec{r}_1$ And $\vec{r}_2$ are random vectors in (0, 1). In GWO, the first three best solutions are obtained and saved at the beginning. Then the other search agents (ω) are completed to update their positions owing to the position of the best search agents. The following equations are proposed for this purpose:

$$\vec{D}_\alpha = |\vec{C}_1.\vec{X}_\alpha - \vec{X}|, \vec{D}_\beta = |\vec{C}_2.\vec{X}_\beta - \vec{X}|, \vec{D}_\delta = |\vec{C}_3.\vec{X}_\delta - \vec{X}| \quad (5)$$

$$\vec{X}_1 = \vec{X}_\alpha - \vec{A}_1.(\vec{D}_\alpha), \vec{X}_2 = \vec{X}_\beta - \vec{A}_2.(\vec{D}_\beta), \vec{X}_3 = \vec{X}_\delta - \vec{A}_3.(\vec{D}_\delta) \quad (6)$$

$$\vec{X}(t+1) = \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3} \quad (7)$$

In the proposed method the FCM has 9 nodes, therefore there is a string include 81 elements. Two elements of this string must be converted to number.

Table. 1 The input and output concepts of FCM

	Concepts	Number of states	Fuzzy States
Input	Target direction	5	TL,TLF,TF,TR,TRF
	Target distance	2	TN,TF
Output	Wheel speed	2	RVW, LWV

TL, target at the left; TLF, target at the left-front, TF, target at the front; TRF, target at the right front; TR, target at the right; TN, target- near ;TF, target far; RVW, right wheel velocity; LWV, left wheel velocity

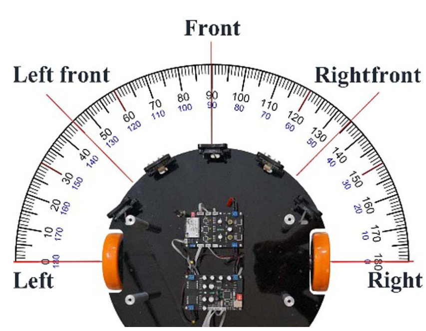

Fig. 8. The target direction concepts of FCM according to position of the Rohan Mobile Robot

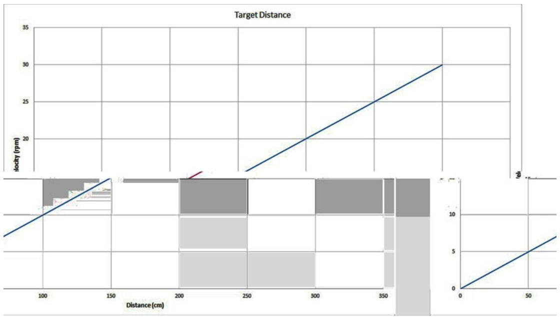

Fig. 9. The relation between robot velocity and distance with target. The robot velocity according to this parameter changed from high to low.

The weight of TN and TF are '+' and '-'. For used these weights in GWO we defined '0' for positive amount and '1' for negative amount.

The aim of the GWO is to find the best weights for the FCM nodes. At each iteration an initial population is generated. The process is repeated until the best solution is founded.

a) Fitnes Function

The significant step in optimizing problems is to select the best cost function which is applied to ameliorate the problems. During tuning of the robot trajectory with GWO, one of two different cost functions is used as Mean of Root Squared Error (MRSE), and Mean of Absolute Magnitude of the Error (MAE) [35] which is shown in Eq.8 and Eq.9.

$$MRSE = E(k) = \frac{1}{N}\sum_{i=1}^{N}\sqrt{(\theta_1^2(i) + \theta_2^2(i))} \quad (8)$$

$$MAE = E(k) = \frac{1}{N}\sum_{i=1}^{N}|\theta_1(i)| + |\theta_2(i)| \quad (9)$$

Where $\theta_1(i)$ and $\theta_2(i)$ are the angles between the right side and the left side of the robot with the destination in an ith sample of trajectory. N is the number of samples; k is the iteration number. GWO algorithm is implemented with the fitness function to optimize the weights of FCM nodes.

The parameters that are used to verify the performance of the FCM in GWO algorithm are shown in Table 2. For the proposed method, two dimensions were defined which are shown in Table 2, that is the left wheel speed and the right wheel speed of the robot. The amount of lower bound parameter was set to 30. This is the minimum speed of the robot wheels in rpm. The amount that is smaller than the speed of the robot may be stopped. The upper bound was set to 100 rpm. Moreover, the number of search agents in this problem was finally set to 9. For the experimental test, the GWO algorithm with one of two different cost functions is processed with 9 search agent and repeated for 10 runs. All the simulations were done by using a GUI program written in visual c#.

VI. RESULT AND DISCUSSION

This exploration introduced an outline of expanded control

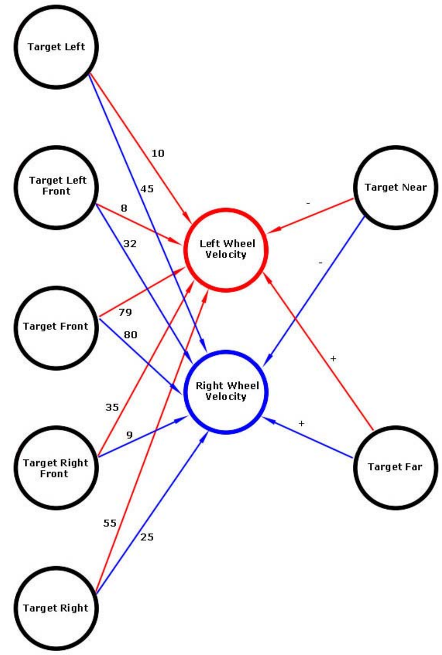

Fig. 10. The initial FCM for the robot navigation

For a mobile robot utilizing FCM using AR under the Microsoft Windows working framework. The framework is uniquely intended for non-master clients for managing the robot utilizing charge, touch screen speed control, and an entirely realistic show for sensor combination. The information from the overhead camera and the Rohan mobile robot is send to the PC and the FCM framework is actualized to improve the execution of the robot in the route. Be that as it may, preceding dialog on the original investigations, is acquired from the Rohan guide test system and a created FCM test system is clarified.

A. The experimental results and comparison of the path shapes

While the program is used for graphical representation of the path using augmented reality, a GUI was designed using Microsoft C# to show the FCM decision productions for robot motion control. The robot displacement from start point to the location A, then to the location B and return to the start point (Fig.6). At the outset, the movement command was set according to the augmented reality. The robot was placed in the environment and navigated with simple commands. It was observed that the robot did not move correctly (Fig.11). This fault occurred due to the following reasons.

- Slippery path
- The inaccuracy of the parameters received by the robot
- Lack of same physical structure engines
- Friction

This navigation is based on movement command. Moreover, FCM is not involved in it. In the next step, the initial FCM was developed. The initial weights of related input variables, i.e., TL, TF, TR, TLF, TRF, are set with the initial amounts of velocity controls LVW, and RWV. The weights of the input and output nodes are set when the robot is at the start location. Accordingly, the FCM is run for generating a motion decision.

The FCM during each cycle changed and examined all Concept weights that were obtained from GWO. This process continues for cycles one after another. Finally, the amounts of LWV and RWV in the FCM are applied to the left and right wheels' actuators, respectively. In Fig. 12, the cycles in which FCM was optimized with the GWO is shown. By using the information in Table 2 as seen in Fig. 12, the robot moves with random numbers created by the GWO algorithm four times. After the iterations were completed, the new weights were replaced by the FCM nodes and the robot moves with these new weights in the environment. The developed FCM model was also run for a case study. The produced values for the project are depicted in Table 2.

The initial population is set in 2 dimensions for left wheel velocity and right wheel speed. The lower bound and upper bound is set to (30,100). The optimization of the FCM process is accomplished in 10 iterations, the values of the FCM decision concept are updated with the final value (Fig.13).

B. Actual results and comparison of the trajectories

Now the trajectory of the robot is compared with the desired trajectory. For this purpose, the trajectory error is calculated. The new function is used to assess the likelihood of the actual trajectory with the desired trajectory pattern. The average of error E for the final position is determined using Eq.10-12:

$$P = \sum_{i=1}^{m} \sum_{j=1}^{n} N_{i,j}(x, y) \tag{10}$$

$$T = \frac{P}{(W_x \times W_y)} \tag{11}$$

$$E = T_d - T_a \tag{12}$$

P is the total values of the path pixels in the image. This route is created by the robot movement. N is the pixel value in the (x, y) coordinate of the picture. T is the mean of the sum of the values of image pixels in picture size. E is the estimated error between the desired path and the actual path.

First based on Hue, Saturation, and Value (HSV), [36] segmented the desired and the actual trajectory of the robot Fig. 14.

Table. 2. The parameters of GWO in proposed method

Parameters	value
Dimension	2
Lb	30
Up	100
Number of search agents	9
Iteration	10

Lb, lower bound; Ub, Upper bound

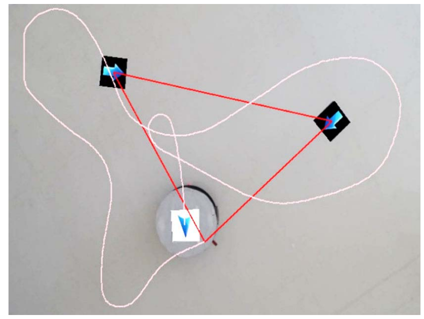

Fig. 11. First robot movement in real environment with simple commands. It was observed that the robot did not move correctly

The results of applied HSV on the images is shown in Fig.15 and Fig.16. Then with Eq.12 the desired trajectory is compared with the actual trajectory path. As observed in Fig. 16, the trajectory at the final step is the same as the desired trajectory. The error between the desired and actual trajectory is E=0.114 and is very similar to the desire trajectory and acceptable. In the proposed method we used the GWO and GA for optimizing the FCM. The GWO and GA in each cycles run four times in the environment. The results for GWO is shown in Table 3. As seen in Table 3, the GWO started optimizing and in four rounds finish its work. This algorithm spent (Total Times=161.12) Seconds to optimizing the FCM. Then reset the movement parameters on the mobile robot and started optimization with GWO. In the second step, the GWO spent 161.748 seconds to optimize the FCM. The average error calculated after each step. In both steps the FCM optimization is acceptable and the average error of final steps shown in Table 3.The average error calculated by Eq.10-12. According to Table 3, GWO provides very competitive results on this test. This expressions that GWO displays a good balance between time and error in this work. The results verify the performance of the GWO algorithm in optimizing the FCM for mobile robot navigation. But to investigate the performance of the GWO algorithm, we compared this work with the GA in the same conditions. All data in the mobile robot and the software set to default. The GA started optimizing. The results shown in Table 4. According to Table.4, in the first Round at the second cycle, the GA fell in local minima.

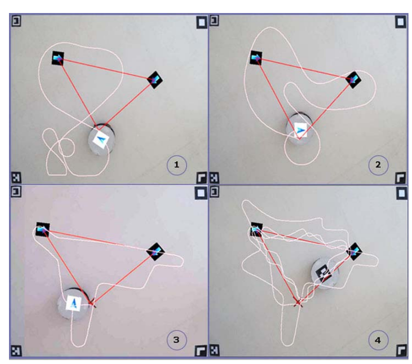

Fig. 12. The four steps to improve the FCM parameters with GWO iteration

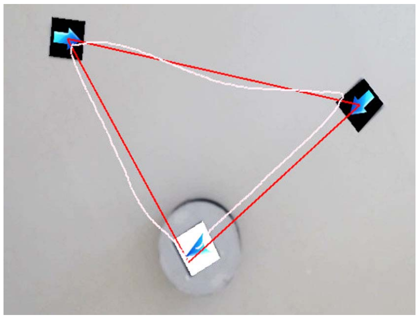

Fig. 13. The final step in the mobile robot navigation with tuned FCM

After reconfigured the GA parameters, in the 4th cycle of Round2 it fell in local minima again. In Round 3 the GA optimized the FCM. The average error (0.136) was acceptable but the spent time was more than the GWO. The Total Times was 229.05, in addition of two uncompleted Rounds. The local minima problem occurred and we had to change the GA parameters. The main limitations and disadvantages of the GA in the proposed method are:

- No warranty of finding best parameters to optimizing. In this work, GA executed in 3 Round and in two Rounds it fell in local minima and after changed the crossover and mutation parameters, optimization was done.
- Time taken for optimizing the problems. Compared with the GWO, the GA took much time in optimization process. This problem is not suitable for navigation the mobile robot.

In this study, the obstacles are not considered and the robot does not use ultrasonic sensors. However, drawn in the fuzzy cognitive map, the obstacles are considered.

VII. CONCLUSION

We have proposed a new control technique for navigating the mobile robot based on developed FCM using augmented reality to enable the movement control of mobile robots in real uncertain environments. The FCM specified input and output concepts for navigation of the mobile robot. In the developed software, we defined movement commands on different AR glyphs.

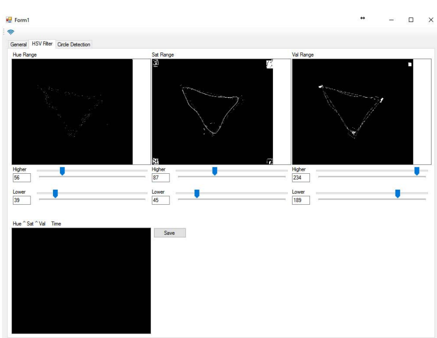

Fig. 14 HSV was applied on actual trajectory path for comparison of the trajectories

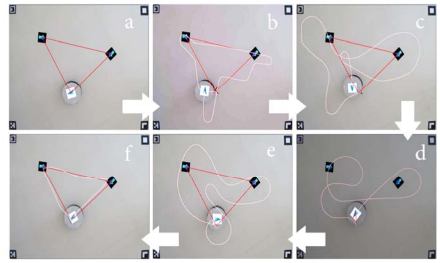

Fig. 15. Images of robot trajectory path (a, desire path; b-e, moving path in GWO iterations, f, actual path moved with the mobile robot in final step)

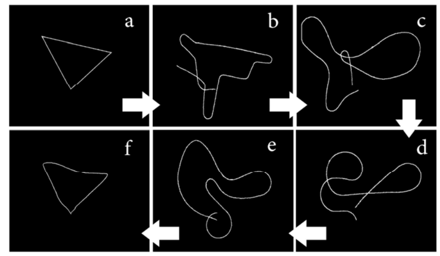

Fig. 16. Results of trajectory path after applied the HSV on images in Fig.15

Table 3. Optimized FCM with GWO

	cycle	Start Point (Second)	A Point (Sec)	B Point (Sec)	Total Time (Sec)
Round1	1	0	20.71	27.42	40.62
	2	40.62	51.87	70.35	88.68
	3	88.68	95.19	110.11	122.10
	4	122.10	135.56	145.16	161.12
	Optimized	0	13.247	24.453	32.075
Round2	1	0	17.255	25.782	39.445
	2	39.445	59.740	72.218	74.608
	3	74.608	99.974	102.540	124.268
	4	124.268	136.281	152.126	161.748
	Optimized	0	8.885	20.827	31.326

The GWO was run in two rounds and calculated arrival time of the robot to the destination A and B in iterations of GWO and in the final step with optimized GWO

Table 4. Optimized FCM with GA

	cycle	Start Point (Second)	A Point (Sec)	B Point (Sec)	Total Time (Sec)
Round1	1	0	31.369	39.248	42.230
	2	LM	LM	LM	LM
	3	LM	LM	LM	LM
	4	LM	LM	LM	LM
Round2	1	0	40.235	63.277	85.109
	2	85.109	107.823	130.738	156.237
	3	156.237	180.987	196.132	219.975
	4	219.975	LM	LM	LM
Round3	1	0	16.369	37.179	58.815
	2	58.815	72.773	92.617	107.591
	3	107.591	130.463	149.125	169.901
	4	169.901	185.644	207.158	229.055
	Optimized	0	14.549	25.733	33.755

The GA was run in three rounds and calculated arrival time of the robot to the destination A and B in iterations of GA and in the final step with optimized GA. LM, local minima

The Grey Wolf Optimization Algorithm was used to train the FCM nodes. The optimized FCM has great execution in actual condition. It also has great capacity to decide the measurement of the robot wheels speed which brings about high probability up to 98% between the actual and desired direction.

The GWO is straightforward and powerful. In compared with the GA, the GWO has good performance to optimize the FCM. It has been shown GWO not only can improve the speed of optimizing process, but also can improve the quality of learning FCMs with more nodes. The software tool is proposed to control the Rohan mobile robot in the environment used FCM and AR. We believe that this proposed method enabled us to control the mobile robot on each environment.

We believe that this combination of Augmented Reality and FCM in the mobile robot control system will help to control the mobile robots in complex environments. In the future works, we want to change the state of the camera to a dynamic position. Moreover, smart glasses will be used to navigate the mobile robot via AR.

We want to use AR without AR's symbols. We want to enhance the navigation algorithm by using Raspberry Pi, Arduino and STM boards on the mobile robot. Ideally, AR's Markers could be moved through the environment and immediately modelled for robot navigation in the uncertain environments. Image processing and optimization algorithms should be explored in order to enhance the performance of the control process.

VIII. REFRENCES

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