Implementation and Design of Fuzzy Supervisory Controller for Mobile Robot Manipulator

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***Abstract*- The Mobile Manipulator Robot (MMR) has many applications in different aspects of the life, for example, grasping and transporting, mining, military, manufacturing, construction and others. The benefits of MMR rise in dangerous place where the human cannot reach such as disaster areas and dangerous projects sites. In this work, the PID controller is combined with Fuzzy Logic Controller (FLC) to structure the Fuzzy Supervisory Controller (FSC) to overcome the drawbacks of PID controller and to obtain the advantages of FLC. Two approaches are suggested for the navigation of Autonomous Mobile Robot (AMR). These are; goal reaching fuzzy control (GRFC) and the obstacle avoidance fuzzy control (OAFC). The hardware implementation of the AMR is performed using AVR ATmega32 microcontroller, two DC motors, light dependent resistor (LDR) and five Infra Red sensors. While, the Laboratory robot arm with some fabrications is used as manipulator arm with a five degrees-of-freedom. Then a microcontroller is employed to implement the proposed controller for MMR. The designed MMR is tested in real environments and give a good navigation.**

***Index Terms*—At Controller Design, Fuzzy Supervisory, Mobile Manipulator Robot, Microcontroller.**

I. Introduction

In recent years, industrial systems with high efficiency and great performance have take advantages of robot technology. More researches and control applications takes interest in the robot which can help people in their daily life, such as office robot, the service robot, the security robot; and so on. Mobile Robot Manipulator (MMR) is one of the interested fields in industrial, medical and educational applications. The main purpose in using these robots is to avoid the human from tedious, difficult and repetitive tasks. In addition, to perform specific tasks in hazard and inhospitable environments that human cannot reach (e.g. working in nuclear reactors) [1]. The motion study of MMR is more difficult than the motion study of manipulators. Combining a mobile base and a manipulator creates redundancy. The redundancy is resolved by decomposing the MMR into two subsystems; the mobile robot and the manipulator [2]. Recently, there are a large number of researchers studied MMR controls. These studies led to different approaches, some of the approaches considered the locomotion as extra joints of the manipulator. In this case, the MMR is regarded as a redundant robot where the redundancy is introduced by the motion of the mobile base [1]. In this work, the locomotion is considered as extra joints of the manipulator. Therefore, each one must be discussed separately and the control system is then designed to both of them.

Many researches have been performed to control the MMR. In 1997, J. H. Chung showed the several issues in MMR and concerned with the modeling and control of MMR. The suitable controllers for the two subsystems have designed, consists of robust adaptive controller for the manipulator and PD controller for the mobile robot [3]. In 2006, A. Ghaffari et al. presented an algorithm for increasing the stability of an MMR is presented based on the optimization of a performance. Considering the interaction between the vehicle and the manipulator and using the genetic algorithm (GA) to minimize the stability criterion cooperating with a neural network [4]. In 2008, M. H. Korayem et al. introduced a robust vision system which was implemented on an MMR to find objects and deliver them to pre-specified locations. A method that is named colour adjacency method was employed in work. Implementation with neural network in MATLAB was used because it is very robust against light changes and can detect objects very quickly [5]. In 2012, J. Jiao et al. proposed a vision based autonomous move-to-grasp approach for a compact MMR. The visual information of specified object with a radial symbol and an overhead colour block is extracted from two CMOS cameras. The mobile platform and the postures of the manipulator are adjusted continuously by vision based control, which drives the MMR approaching the object. When MMR is sufficiently close to the object, only the manipulator moves to grasp the object [6].

FLC is better than the PID controllers with nonlinear systems. On the other hands, more than 90% of the controllers in application today are PID controllers because they are easy to understand and implement. It is costly to replace the PID controller with FLC in all applications. Therefore, one of the attractive solutions is to combine the PID controllers and FLC to structure the Fuzzy Supervisory Controller (FSC) in industrial applications to overcome drawbacks of PID controllers with nonlinear systems [7]. Many papers [8-12] discussed the FSC method. FSC is a multilayer controller with the FLC at the highest level which has the capabilities to tune the PID parameters (K_P, K_I and K_D) under varying process conditions best than classical method (e.g. Ziegler-Nichols) and PID controllers at lowest level.

Two approaches are proposed for the navigation of AMR. These are: Goal reaching fuzzy control (GRFC) and the obstacle avoidance fuzzy control (OAFC). MATLAB Program is used to design and simulate AMR system and it shows good results for navigation and obstacle avoidance tasks, while Proteus Program is used to test the robot manipulator performance. The hardware implementation of the AMR is performed by using AVR ATmega32 microcontroller, two DC motors, circuit of light dependent resistor (LDR) to identify the goal; and five Infra Red sensors. While, the Laboratory robot arm with a five degrees-of-freedom (with some fabrications) is used as manipulator arm. Then, the AMR and robot arm are combined as one system. Microcontroller is employed to implement the FSC for MMR. The designed MMR with proposed controller is tested in real environments and gives a good navigation.

II. Structure of Autonomous Mobile Robot

Figure (1) illustrates the AMR platform. It is equipped with one passive wheel (caster wheel) and two driving active wheels independently. Each active wheel is actuated by a separate DC motor. This independent driving system gives the mobile robot the capability to move in a straight line; turn right or left around its centre; and rotates to the right or to the left.

In this work, the mobile robot is equipped with five Infrared (IR) sensors distributed around the robot body (two in the left, two in the right, and one in the front) to detect the near obstacle and find the distance from the robot to the obstacle. The active range of distance between obstacle and mobile robot for each IR sensor is assumed to be between 0 and 0.8 m. Each sensor is separated from the other by 45^0. The five sensors are labeled as follows:

- Front Sensor (F).
- Right Front Sensor (RF).
- Center Right Sensor (CR).
- Left Front Sensor (LF).
- Center Left Sensor (CL).

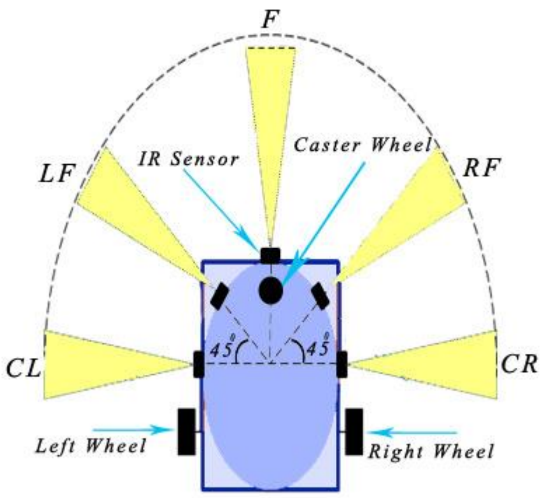


Fig. 1 The Autonomous Mobile Robot Platform

In this work, the AMR is simulated using S-function blocks in MATLAB V-7.14.0.739 (R2012A). A special S-function block was written to create a whole construction of the mobile robot (the robot platform, the robot sensors, and the environment) for online simulation. The complete mathematical model of autonomies mobile robot is discussed in detail in our pervious paper [13].

III. Fuzzy Supervisory Controller (FSC)

The basic structure of FSC is shown in Figure (2). This structure has the form of PID controllers but its parameters are adapted using the FLC. FLC has two inputs: the error e(t) and change of error Δe(t), and three outputs K_P', K_I', and K_D'. This method is defined as multi input multi output (MIMO) systems.

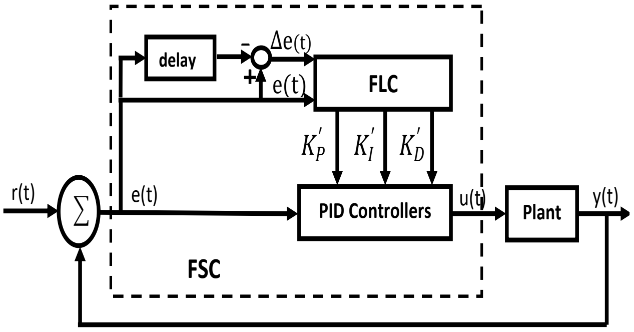


Fig. 2 Basic structure of FSC.

The current error e(t) (which represented the difference between the actual output y(t) and the set point r(t)), and the change of error Δe(t) ;which are used as inputs of FLC block; are obtained according to the following equation:

$$\left.\begin{aligned} e(t) &= r(t) - y(t) \\ \Delta e(t) &= e(t) - e(t-1) \end{aligned}\right\} \quad (1)$$

While The output of FLC generates K_P', K_I', and K_D' vales for tuning PID parameters K_P, K_I and K_D according to the following adaptation equation [11]:

$$K_X = (K_{X_{max}} - K_{X_{min}})\ K_X' + K_{X_{min}} \quad (2)$$

where, subscribe X means P, I, or D.

The range of the PID parameters is chosen by two ways: First, determine the optimal PID parameters, which is obtained previous using Artificial Bee Colony (ABC) optimization algorithm (as discussed in our paper [13]). Second, choose the range of the each parameter around the optimal value as:

$$K_{X_{min}} < K_X < K_{X_{max}}$$

In this work, the model has two PID controllers with six parameters explained in vectors [K_{P1} K_{I1} K_{D1} K_{P2} K_{I2} K_{D2}], the first three parameters represented the parameters of velocity controller while the other three parameters represented the parameters of azimuth controller. Thus, it is required two fuzzy supervisory controllers as discussed in next section.

IV. Simulation, Implementation and Results

A. Simulation and implementation of autonomies mobile robot

Figure (3) illustrates the Simulink of trajectory tracking using FSC. Table (1) illustrates the range of each PID parameter with optimal values.

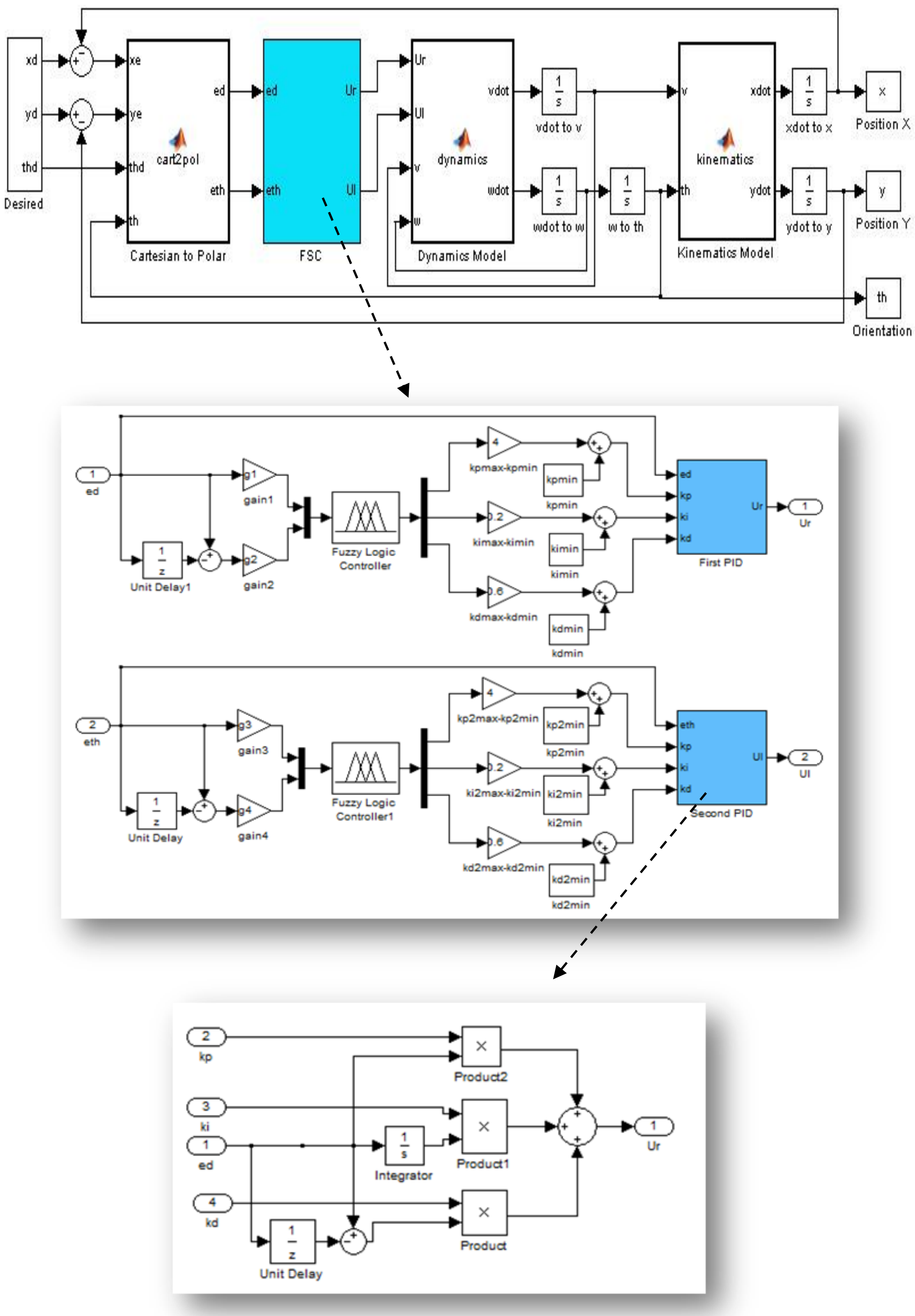


Fig.3 Simulink mode of trajectory tracking using FSC.

TABLE I
OPTIMAL, MINIMUM & MAXIMUM VALUES OF PID CONTROLLER FOR FSC.

PARAMETER NAME	$K_{X_{min}}$	K_X	$K_{X_{max}}$
K_{P1}	98	100.0007	102
K_{I1}	0	0	0.2
K_{D1}	4.2	4.5167	4.8
K_{P2}	198	200	202
K_{I2}	0	0	0.2
K_{D2}	8.7	9.0333	9.3

The inputs of fuzzy controller are normalized in the range [-1, 1] and the outputs are normalized in the range [0, 1] with using external factors to the FSC to give the trajectory required. Scaling factors are optimized based on ABC algorithm, while the same fuzzy controller structure is used for the two supervisory controllers. The input variables (e(t), Δe(t)) has three triangular membership fuzzy sets: Positive (P), Zero (Z), and Negative (N) as shown in Figure (4).

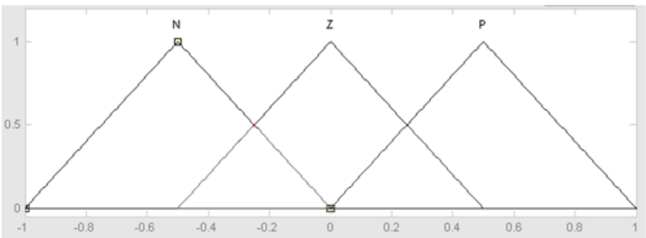


Fig.4(a): Membership Function of Error input for FSC.

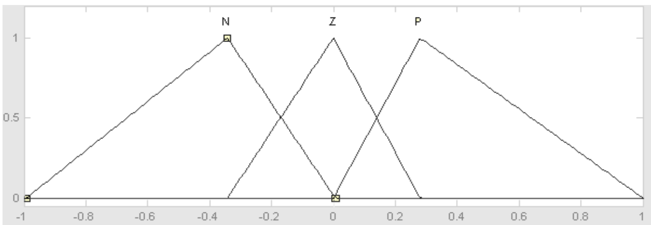


Fig.4(b): Membership Function change of Error input for FSC.

Each output variable (K_X') has three fuzzy sets: Big (B), Medium (M), and Slow (S) as shown in Figure (5). In output FLC, it is assumed that the first and last membership functions have their apexes at 0 and 1 respectively by using triangular membership functions in middle of universes of discourses and trapezoidal membership functions in two edges of universes of discourses.
Mamdani method is used in fuzzy inference system, for example:

If the error is positive and error change is positive Then the K_P' is big and K_I' is big and K_D' is big.

Centre of Area (COA) is used as defuzzification method for each of the output parameter that gets crisp values is used to update PID parameters according to the equation (2). Table (2) illustrates the fuzzy rule of all output parameters.

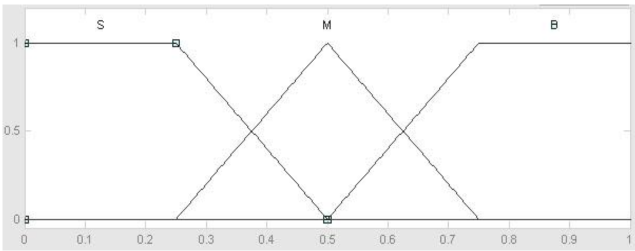


Fig.5 K_X' output for FSC.

TABLE II
FUZZY RULE FOR OUTPUTS PARAMETERS OF FSC

K_X'		e(t)		
		P	Z	N
Δe(t)	P	B	B	M
	Z	B	M	S
	N	M	S	S

Now, the proposed controller is tested to show its ability to reach to specific goal at environment which has obstacles in its way located at random places (this task is called goal reaching with obstacles avoidance). This approach is accomplished by using two controllers, one controller for reaching the goal (it is called Goal Reaching Fuzzy Controller (GRFC)), and the other controller for avoiding collisions with obstacles in its way to goal (it is called Obstacle Avoidance Fuzzy Controller (OAFC)). In this approach, the main task of the AMR is to move toward the goal point using GRFC. During the moving of the mobile robot toward the goal, if it senses obstacles, the mobile robot switches to OAFC. When the mobile robot senses no obstacles by all of the five sensors, then it switches back to GRFC. Figures (6) illustrates a flowchart describes the motion with GRFC and OAFC.
The proposed approach is illustrated in Figure (7). The switching process is accomplished in the switch selector block where OAFC has the highest priority to activate, while the GRFC has the lowest priority.
Depending on the data that is collected from the sensors, the mobile robot computes the location of the target and obstacles and finds the distance from the obstacles, then feeds this information to the SFC. After that, the movement decision (speed and orientation) are used for testing the ability of AMR for goal reaching with static obstacle avoidance in the way toward the target.
The proposed FSC based on PID controllers; which are optimized by ABC algorithm; are used as a motion controller while the two FLC are used for path planning to navigate between static obstacles. One controller used for goal reaching and the other for obstacle avoidance. The mobile robot stops when it reaches the goal point within 0.03 m accuracy of distance between the centre of the mobile robot and the target point.

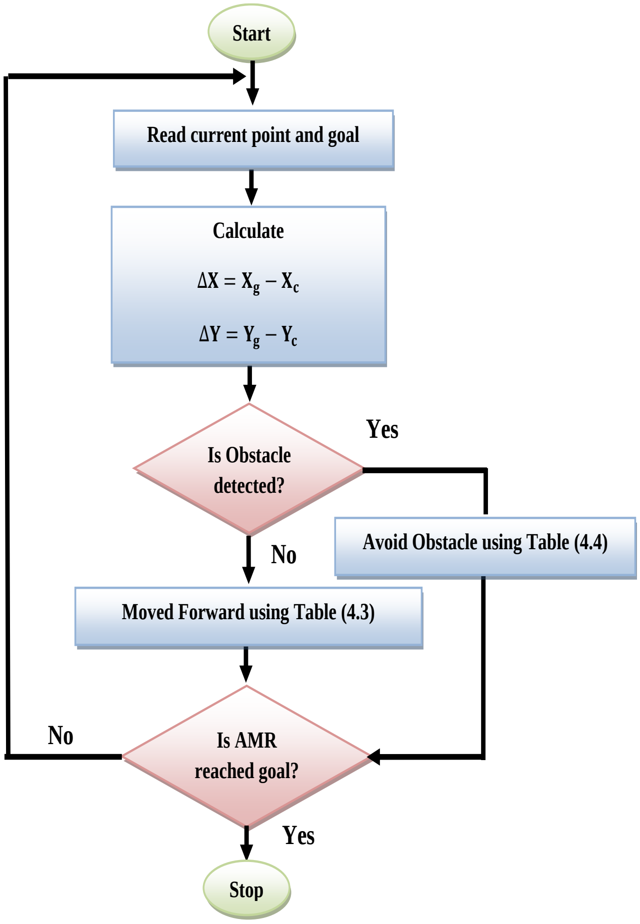


Fig. 6 Flowchart the motion control with GRFC and OAFC

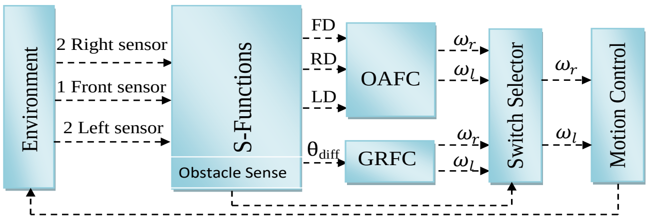


Fig.7 Goal reaching with obstacle avoidance

For the environment shown in Figure (8), AMR travel from point (0, 0) toward point (14, 16), it faces four static obstacles and it can go without hitting obstacles. The total time required equal to 4.5 sec with variable speed and heading angle. The simulation is performed using MATLAB Simulink package.

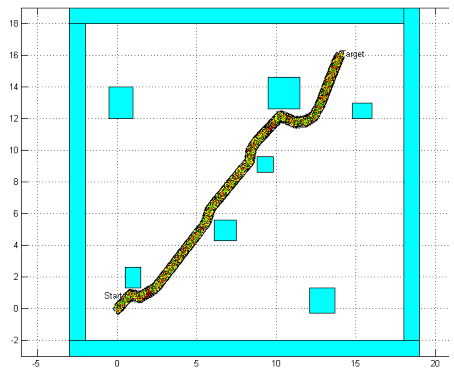


Fig 8 Another example of navigation of the AMR with OAFC & GRFC

Figure (9) illustrates the designed AMR. Figure (10) illustrates the designed AMR navigates in an unknown environment contains obstacles.

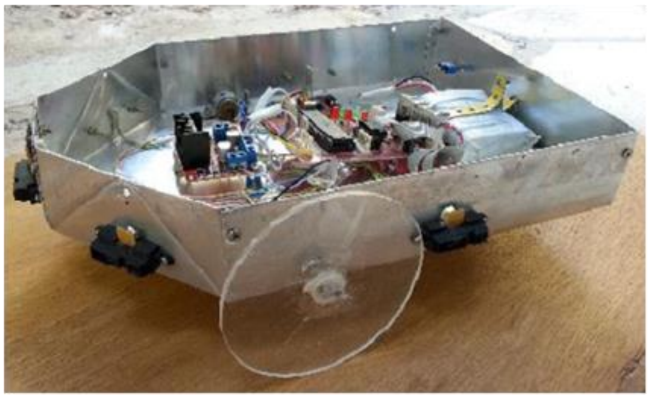


Figure (9): The designed autonomous mobile robot.

(a)

(b)

(c)

Fig 10 The mobile robot navigation

B. Simulation and implementation of robot arm manipulator

In this subsection, the design and implementation of wireless control for the robot manipulator be discussed. Prototype robot manipulator (Lynx-6 or PUMA 560) is used as a case study because it has small size, lightweight, and it is cheap.

Figure (11) shows the robot arm manipulator which is used in this work.

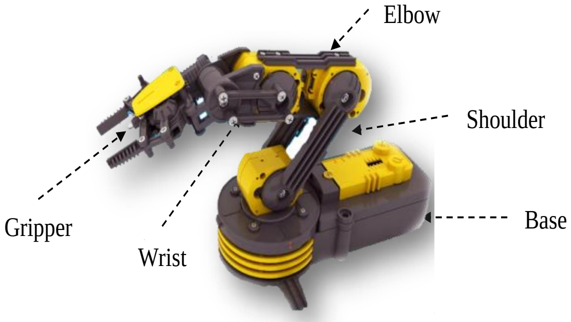


Fig.11 Body of the robot manipulator

To achieve a wireless controller of a robot manipulator using a personal computer (PC), the connection between the robot manipulator and PC is established. This connection is done by using an Arduino Uno board that contents an Atmega328 microcontroller with Bluetooth module. The following hardware items are needed to do this work:

1. Arduino Board “Arduino Uno that contents an Atmega 328 microcontroller ".
2. Bluetooth module "HC-06".
3. Three H bridge "L293D".

The Arduino Uno is tested in virtual simulation of Proteus program for controlling five DC motor using L293D as illustrates in Figure (12).

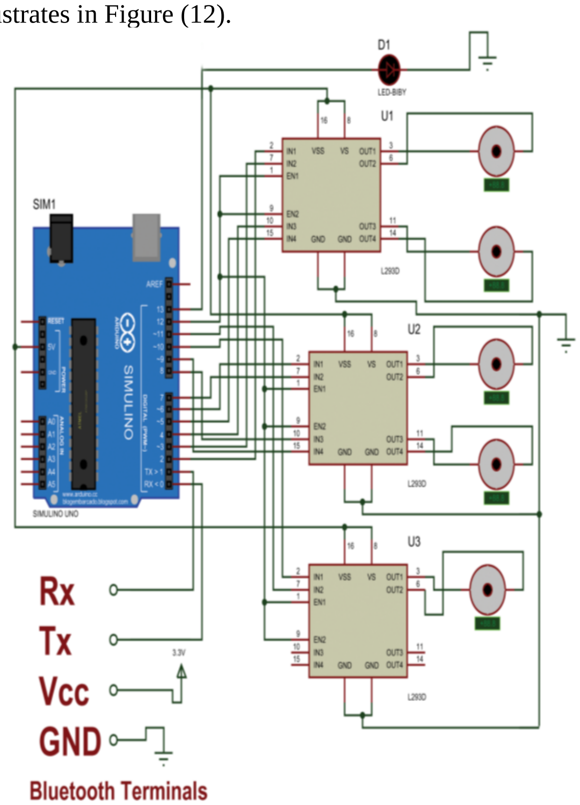
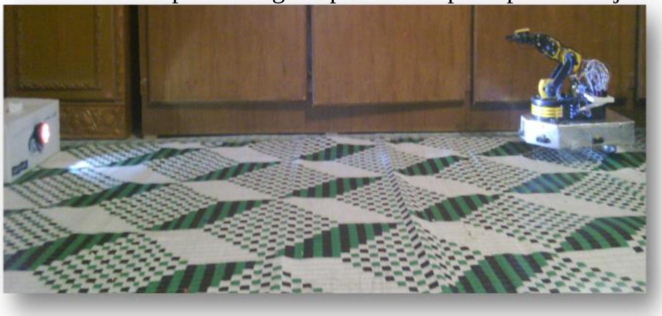


Fig.12 Map design of the robot manipulator

Figure (13) illustrates the tested of the robot manipulator with the mobile robot as a one unit. The MMR transfers for 2m from start point to goal point and pickups the object



(b)

(c)

(d)

(e)

Fig.14 The tested of the MMR in the real environment

V. Conclusion

Main objectives of this work are: applying control techniques like FSC systems to construct the controllers for goal reaching with obstacles avoidance and controlling the robot manipulator to pick up the desired object. The practical aspect was accomplished where a MMR was built as an embedded system included integration of hardware and software in its construction and operation. The hardware of an AMR includes: an AVR ATmega32 microcontroller, two DC motors, LDR sensor, and five IR sensors. The software AMR involves employing C language and Micro C PRO program to create the source code which is then downloaded to the microcontroller in order to perform the required tasks. From the other hand, the hardware robot manipulator includes: five DC motors, three H-Bridge, Arduino Uno, Bluetooth module, and another component.
The simulation results and practical tests show that the MMR is able to avoid the collision with the obstacle and reaching to specific goal, then pick up the desired object by switching between goal reaching task and obstacle avoidance task and using the wireless command for picking up the objects.

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