Design and Implementation of Hybrid Arm for the Climbing Robot

Mustafa Yahya Hassan
Electrical Eng. Depart.
University of Basrah
Basrah/Iraq

Mofeed Turky Rashid
Electrical Eng. Depart.
University of Basrah
Basrah/Iraq

Ali Hassan Abdulaali
Mechanical Eng. Depart.
University of Basrah
Basrah/Iraq

ABSTRACT
The great development of the robotics design and production make the robots be an important part in the achievement of many of the difficult or dangerous applications to humans, one of these robots are the climbing robots. The design of climbing robots is a major challenge, because the robot has to stick to the walls while the walls are different in terms of roughness. In this paper, the arm of climbing robot has been designed to help robot climbs on coarse surfaces where a gecko arm model is used to achieve linear movement while clinging to the rough wall achieved by using limb has claws as the limbs of cats. A mathematical model has been derived and simulated by MATLAB while the mechanical parts were constructed using plastic materials and motion has been achieved by servo motors, also microcontroller kit used to control the arm and achieving motion synchronization. Several experiments have been performed in order to test the success of the arm of climbing robot.

Keywords
Climbing robot, hybrid arm, gripper device, claws

1. INTRODUCTION
Climbing robots have ability to move vertically on walls which it is useful in military and civilian application, such as surveillance, inspection, window cleaning, disaster relief applications, maintenance of tall buildings, and reach to dangerous places such nuclear facilities which humans can't reach it. The main challenges in achieving climbing on vertical site are the strength of hang on wall which the walls are classified based on their material. The other challenges is the arm dynamics which the performance of climbing depending on arm motion performance [1-4].

There are several types of adhesion method with the capability to climb on various surfaces depended on the design of arm, types of surface, and mechanism to climb. An example of a robot that made from dry adhesive that can climb on flat and smooth walls is stickybot [5-7], which uses polymeric stalks to adhesion to the wall exactly like gecko feet. The researcher developed another type of climbing method that dependent on limb and hook like claw, such as LEMUR II [8], which have four limbs, each limbs include four degree of freedom (4DOF) that autonomously climb on the rock, which was pre-placed on the wall. The disadvantage of LEMUR is that climb on training wall. The robot foot location constrained to special points that arranged randomly on the wall. The CLIBO robot [9], which have four limbs, each limb contain four servomotors (AX-12). It is use hook like claw mechanism for attachment on rough surfaces. The robot design is like the human movement during the climb the rocks or mountains. The CLIBO robot is expensive robot because it has 16 servo motors. Another robot that using claw [10], which using eight hook-like claw divided into two group, four limbs climbs up at the same time that another four limbs attached to the wall. The RiSE [11] that have design like insect, which use 20 motors, six legs, where each leg contain three motors and other two motors for middle and the tail of robot. This robot using microspines that arranged in each leg for reliable and stable hang on the rough surfaces. The GPL model is another type of climbing robot that using single claw in each arm of the robot [12].

In this paper, the hybrid design of the climbing robot arm has been proposed which it is compound from the arm is look like gecko arm while the mechanism of hanging on the wall based on cat claws mechanism. The climbing robot arm has been named CLARC (climb arm with claw). Hook like claw method is suitable for climbing on rough surfaces while the number of servo motors in the joints will be reduced due to the movement mechanism based on the gecko arm movement mechanism. The design starting with modeling of gecko arm movement mechanism, and then the hook is designed to carry a payload suitable to weight of the climbing robot. The mathematical model has been simulated by MATLAB while several experiments are performed in order to test the climbing robot arm.

This paper is arranged as follow: in section 2, the design of the CLARC that based on the gecko feet and cat claw has been discussed. And then, in section 3, the kinematic model and inverse kinematic model are described. The Implementation of climbing robot arm is described in section 4, and finally, the discussion and conclusion about the CLARC are given.

2. DESIGN OF CLARC STRUCTURE
As mentioned earlier that the climbing robot mainly dependent on design of the arm and the mechanism of the movement. Also, it is capability of hang on wall of rough surfaces in order to move vertically. So, in this section the necessary structure suitable for vertical movement and perfect hang on wall will be design.

2.1 CLARC description
The CLARC include three active degree of freedom (3DOFs). All three DOFs are motorized by DC servo motor. The three motors functions are explain as follow:

- For rotation inward and outward of robot body.
- CLARC movement forward direction.
- For hang on wall by gripper device.

The first motor (M1) operates in Z-plane which moves 45° inward and outward. The second motor (M2) operates in Y-plane that moving the CLARC forward direction. The third motor (M3) specialized for gripper device, which operates in Z-plane for make strong hang on the wall.

In Figure 1, the design of the CLARC structure has been described. The structure at point A compound from spring while structure B compound from passive damper, these structures used to make the arm more flexible with small deviation which it is necessary when the robot climbing on the wall. The points C and D added in order to achieving linear movement for the link E, F.

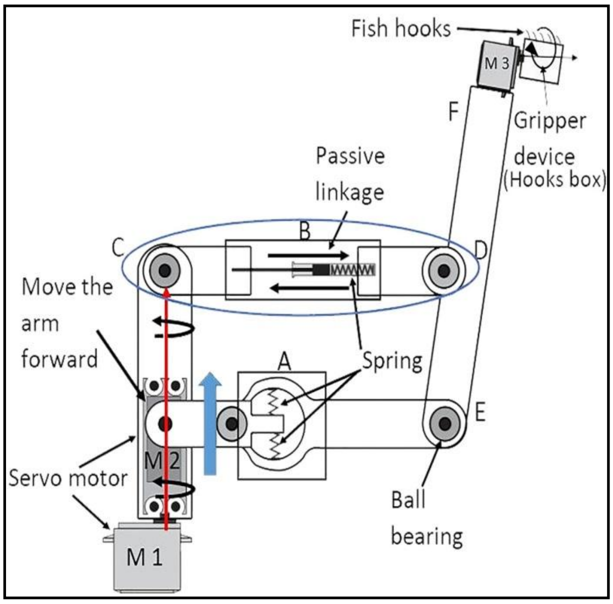


Fig 1: The structure of the climbing robot arm.

2.2 Design of the gripper device

As mention earlier that the CLARC is specialized for rough surfaces, so there is a unique geometric design implemented for hang on wall. The gripper device placed at the end of the link E, F (see Figure 1) and derived by M3, which rotate 45^{o}.

Figure 2 shows all parts of the gripper device. The gripper device is compound from two layers, solid foam material and high density plastic which the thickness of the two layers are 12 mm and 4 mm, respectively. The foam layer have five holes; each hole has diameter of 4 mm while five springs have been used to fix five fish hooks that used for CLARC to hang on the wall as claw. A metal beam is used to fixing all springs in order to making the hooks more fixable and all the hooks interference with terrain of the rough surface, so it is give more reliable and reduce the probability of arm fall.

For each wall surface, there are parameters are describe the roughness value, for example stucco wall, where the root mean square (RMS) of roughness Rq is 141 µm and average roughness Ra is 83 µm [14].

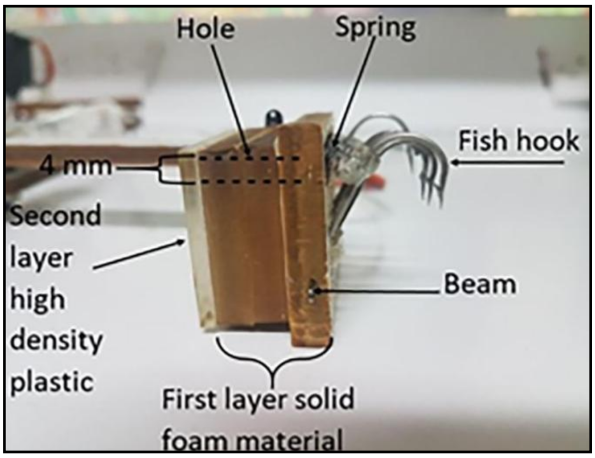


Fig 2: The structure of the gripper device.

3. CLARC KINEMATICS

In order, to design the CLARC, the first step was analysis its kinematics. Where the CLARC move according to mathematic model that described in the following:

3.1 Direct Kinematics

The direct kinematic has been used to determine the displacement of point E in the arm as shown in Figure 3. The motor M1 will move outward making whole arm away from the wall, so no friction will be happen between the CLARC and the wall. Also, the initial angle θ_o can be calculated which is 25.2^{o}.

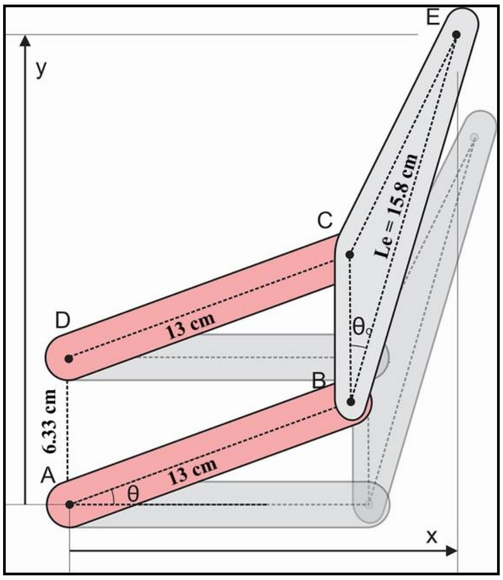


Fig 3: Schematic diagram of CLARC forward motion.

The motor M2 will rotate by θ degree equal to θ_o with respect to link AB and link AD which the two points A and D are fixed, so the two points B and C will move forward in direction Y-axis (see Figure 3). The movement path of link BC is arc path, but the displacement outcome of link BC is straight line. The CLARC motion will be in 3D due to the motion of Motors M1 and M2, but only M2 affected on the forward motion, so the point E displacement will be described in 2D as follow:

$$x = AB * \cos(\theta) + Le * \sin(\theta_O) \quad (1)$$

$$y = AB * \sin(\theta) + Le * \cos(\theta_O) \quad (2)$$

Where θ_o is the initial angle and θ is the angle of the Motor M2.

3.2 Inverse Kinematics

To move the gripper device to the desired position, equation of the inverse kinematics (IK) will be derived. The certain value of θ can be derived from equation 2

$$\theta = \sin^{-1}\left(\frac{y - Le*\cos(\theta_o)}{AB}\right) \quad (3)$$

The angular velocity of motor M2 can be calculated by derive equation 3 as follow

$$\dot{\theta} = \frac{\dot{y}}{\sqrt{AB^2 - (y - Le*\cos(\theta_o))^2}} \quad (4)$$

which can be written as

$$\dot{\theta} = \frac{\dot{y}}{AB*\cos(\theta)} \quad (5)$$

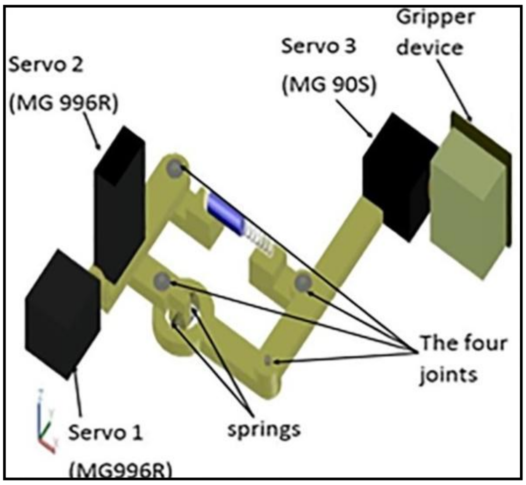
Where $\dot{y}$ is the vertical velocity in mm/s; y is the vertical displacement in mm; θ is the angle of the servo in rad.; and $\dot{\theta}$ is the motor M2 angular velocity in rad/sec.

4. CLARC IMPLEMENTATION

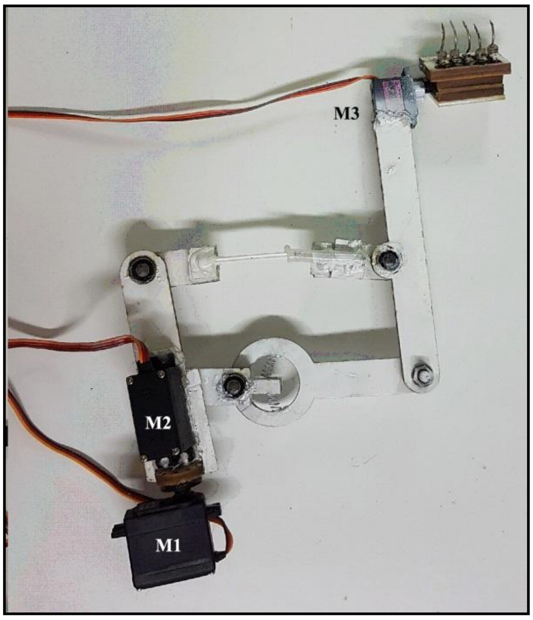
For achieving the mathematical model, the CLARC body has been designed by using AutoCAD as shown in Figure 4 (a). The AutoCAD graphic diagram is used by CNC laser machine in order to making the CLARC parts which the practical mechanical parts are shown in Figure 4 (b). Three dc servo motors are used for CLARC motion achievement M1, M2 is MG 996R. These dc servo motors contain built-in controller, direction control, metal gear operate at 4.8- 6 V, a stall torque 11 kgf.cm (when operated at 6 V), and have operating speed 0.14 s/60º (6 V). M3 is MG90S that have characterized same as MG 996R but the stall torque is 2.2 kgf.cm (6 V) and operating speed 0.08 s/60º (6 V). The weight of the entire arm is 250g. The ball-bearing has been used for each joint for flexible motion and net with screw that polished to be more stable at steady state, also the joints have flexible rotation and efficient without oscillation. All three servo motors are supplied from an external power supply. The ATmega328 microcontroller has been used in main board for controlling three servo motors and achieving synchronization motion.

5. THE EXPERIMENTS AND RESULTS

The design of climbing robot arm has been achieved by mathematical model and then implemented practically, so in this paper the mathematical model has been simulated in order to study the ability to build climbing robot arm, and then testing the climbing arm robot practically in order to examine the ability to use this robot arm in climbing robot.



(a) AutoCAD diagram of the CLARC.



(b) Mechanical parts of CLARC.

Fig 4: CLARC Structure.

5.1 Simulation results

The mathematical model has been simulated by MATLAB in order to evaluate the values of joints angles. Figure 5 shows the relation between the displacement (mm) in y-axis with respect to joint angle θ.

The relation between angular velocity of motor M2 and linear velocity is leaner as shown on Figure 6, so it is easy to control the velocity of CLARC motion.

During the climbing robot arm moving forward, it take arc path with deviation to the x-axis side, the effective of deviation on arm structure can be reduced based on design of mechanical structure that shown in Figure 1, while the transfer of claw from point to the next must be in straight line which can be achieved based on the Equation 1 as shown in Figure 7. When M2 rotate form -60 to 60 will produce maximum deviation which is 55 mm.

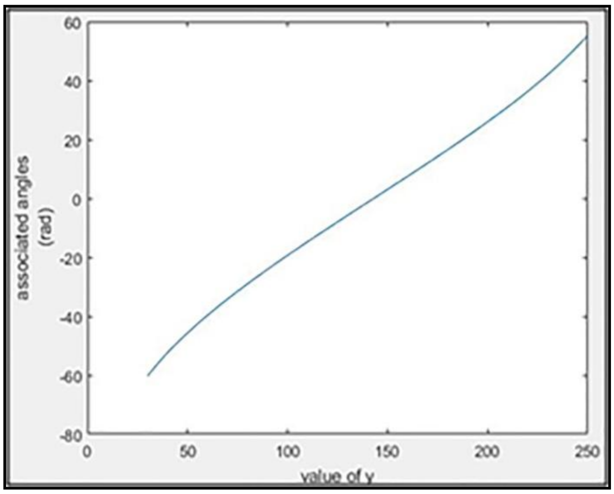


Fig 5: The relation between θ and displacement (mm).

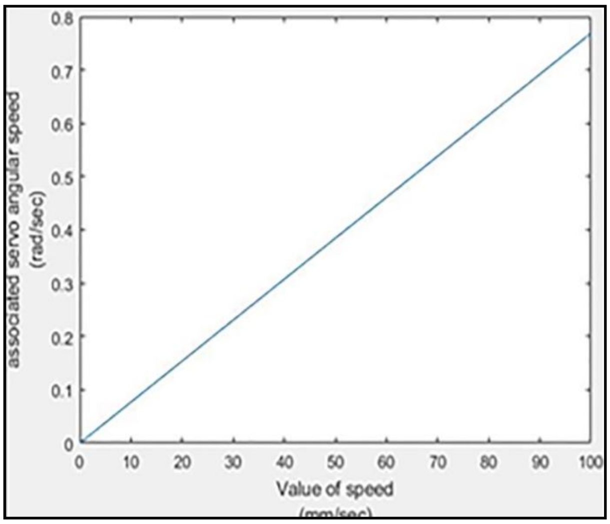


Fig 6: the relation between M2 angular and arm linear velocity.

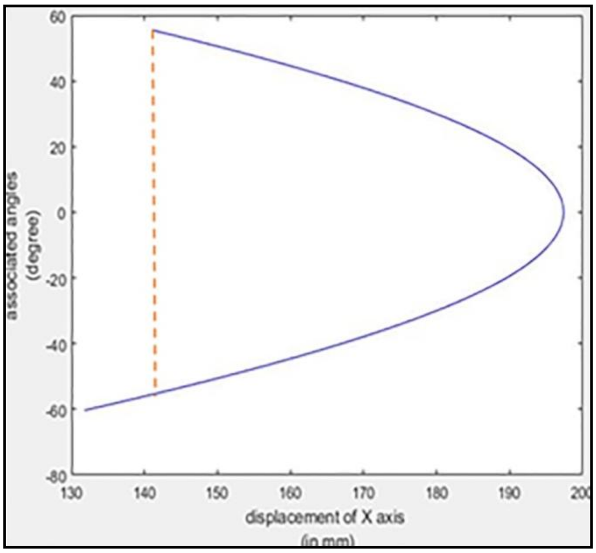


Fig 7: The relationship between the M2 rotation angle and displacement to x-axis.

5.2 Practical Experiments

The microcontroller has been used to control the rotation of each servo motor in order to move the gripper device to a desired position by given a proper degree of (θ). The gripper device has been connected to the motor 3 that set to zero degree as reference position and then rotate 30^o toward the wall which the gripper will hanging on the wall by claws. Some sequences of video frames of arm movement are shown in Figure 8.

(a) M1=M2=M3=0

(b) M2=45^o

(c) M1=45^o

(d) M3=30^o

(e) M2=-45^o

(f) M1=-45^o

Fig 8: Frames sequence describing CLARC movement.

The arm gripper has been tested by performed several experiments in order to evaluate the maximum payload of gripper claw for hang on wall. The maximum payload of gripper claw is 1200 gm when the gripper hangs on wall.

Another experiments have been perform to test CLARC practically which it must suitable for using in climbing robot, the experiments testing the ability of CLARC to carry different payload as shown in Figure 9. The experiment starting by CLARC hanging on the stucco wall, and then the different payloads values have been added which starting with 100 gm and then payload is increased step by step. The maximum payload which can be carried by CLARC is 700 gm before the CLARC is broken. This value is suitable for the climb robot because it is need four CLARC for climbing on stucco wall, so the maximum payload carried by four CLARC is 2.8 Kg (4 * 700 gm).

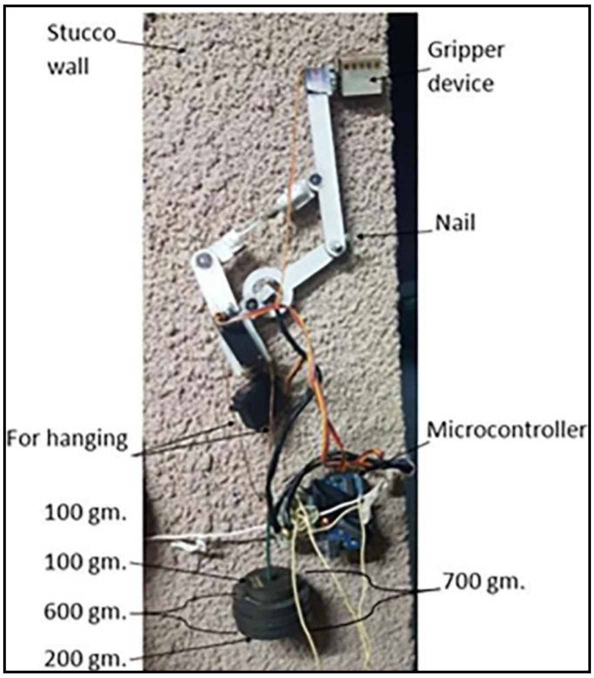


Fig 9: The CLARC experiment for payload testing.

6. CONCLUSIONS

In this paper, the hybrid climbing arm has been designed and implemented in order to employ it in climb robot for rough surface wall. The design has been achieved by emulate the mechanism of hang on that used by some animals like cats, while the dynamic of arm motion is designed based on climbing animals like gecko . This hybrid design achieved several benefits like good hang on wall which seem similar to cat; also it used simple structure with minimum numbers of servo motors. The mathematical model has been derived and simulated by MATLAB (see Figure 7). Several experiments have been performed to test the mechanical design of CLARC (see Figure 8) which the mechanical design modified by using springs as shown in Figure 1 in order to ensure the successfully movement of CLARC. The maximum payload of CLARC has been evaluated by several experiments as shown in Figure 9 which it is 700 gm.

Next step of this project is represented by implementing the climb robot which climbing on rough wall by using four of hybrid climb arm. Also, the performance quality of the hybrid climbing arm can be enhanced by adding conventional control system to the climbing device. This system is sensing the value of surface roughness and then controlling the rotation value of M3 in order to performing perfect hang on wall.

7. REFERENCES

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