Al-Khwarizmi Engineering Journal, Vol. 9, No. 1, P.P. 9-18 (2013)

Al-Khwarizmi Engineering Journal

Design of Robotic Arm Control System Mimics Human Arm Motion

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(Received 14 May 2012; accepted 6 November 2012)

Abstract

This paper presents a control system to make the robotic hand mimic human hand motion in real time and offline mode. The human hand tracking system is a wearable sensing arm (potentiometers) used to determine the position in space and to sense the grasping task of human hand. The maskable sensing arm was designed with same geometrical arrangement of robotic hand that needs to be controlled. The control software of a robot was implemented using Visual Basic and supported with graphical user interface (GUI). The control algorithm depends on joint to joint mapping method to match between the motions at each joint of portable sensing arm with corresponding joint of a robot in order to make the robot mimic the motion.

Keywords: *Robotic Arm, Control****,*** *human hand tracking.*

1. Introduction

Teleporting of a robot through human hand motion plays an important role in many fields such as medicine, space exploration, military, nuclear environment, construction and many other fields. A large number of interfaces concerning robot control using hand motion such as vision based system by tracking markers placed at a dorsal side of human hand using cameras to estimate the 3D position of hand to control the robot were proposed [1, 2]. EMG (electromyography) signals which are measured using non-invasive electrodes are placed at specific locations of human arm and represent the activity of human arm muscles due to motion to drive the robot [3]. Micro-Electro-Mechanical Systems (MEMS) was used to estimate the 3D position and orientation of human hand by integrating inertial sensors such as gyroscope, accelerometer and magnetometer [4]. Electro-mechanical devices (potentiometer and metal parts), are worn by the operator arm to sense the motion of arm [5].

This paper presents a method to control the robot motion using a built sensing arm that can be gripped by human hand to determine the position and orientation of human hand and to sense the grasping task performed by human hand finger.

2. The Experimental Work

The system consists of four parts: sensing arm, interface circuit, robotic arm and control software, Fig.1.

A. Sensing Arm

A wearable arm Fig.2, is used to measure the 3D position of human hand (Within the workspace of sensing arm), and to sense the grasping of a hand finger. The sensing arm has the same degrees of freedom DOF of robotic arm, which is 4 DOF that needs to be controlled. It was made from four metal parts and four potentiometers (1M Ω) sensing arm joints, base, shoulder, elbow, wrist, and push-button switch for finger joint.

The principle of operation of each sensing arm joint (except finger joint) depends on the voltage divider. So, when the operator mask the sensing arm and move his hand, this motion will make each joint (except finger joint) rotate with a specific motion. Therefore, the resistance of each joint varies, so, the output voltage of each potentiometer will change according to the voltage divider principle and represents the measuring of joint rotation. Finger joint was implemented using a push-bottom switch which is connected with the ground.

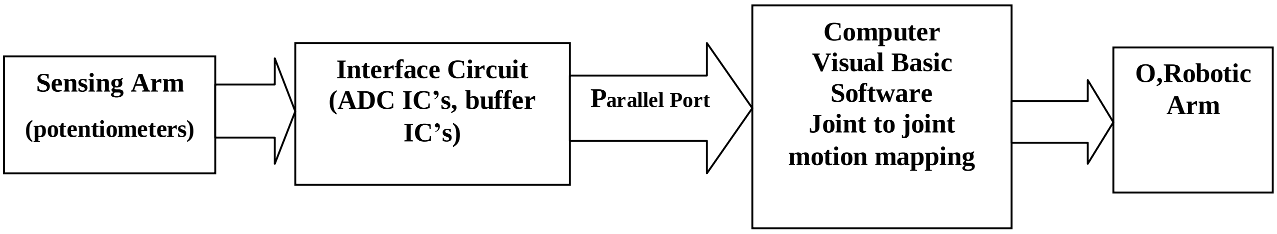

Fig. 1. Control System Block Diagram.

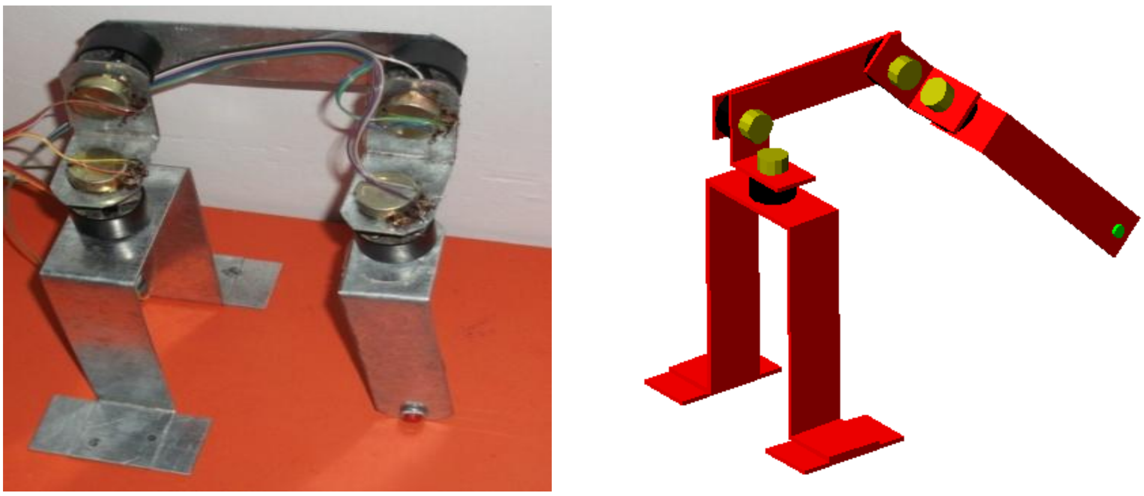

Fig. 2. Sensing Arm

B. Interface Circuit

The analog voltage of each sensing arm joint (potentiometer) must be converted to the digital form before sending them to the computer via parallel port. Therefore, the interface circuit ,Fig.3, consists of four ADC IC's (0804LCN) [6], one for each sensing arm (except finger joint) joint. Additionally, four Buffer IC's (74Ls245) [7] are used to protect the computer from any harmful signals. The finger joint of sensing arm is connected directly to the parallel port without using ADC and buffer IC. The analog voltage of sensing arm base joint is converted to the digital voltages of 4-bits and are sent via pin(2),pin(3),pin(4),pin(5) of parallel port. The analog voltage of sensing arm shoulder joint is converted to the digital voltages of 3-bits and are sent via pin (6), pin (7), pin (8) of parallel port. The analog voltage of sensing arm elbow joint is converted to the digital voltages of 3-bits and are sent via pin (15), pin (13), pin (12) of parallel port. The analog voltage of sensing arm wrist joint is converted to the digital voltages of 2-bits and are sent via pin (10), pin (11) of parallel port. While, the push-button switch of a finger joint of sensing arm is connected between the ground and pin (9) of parallel port. The LEDs are used as an indicator to simplify a programming task.

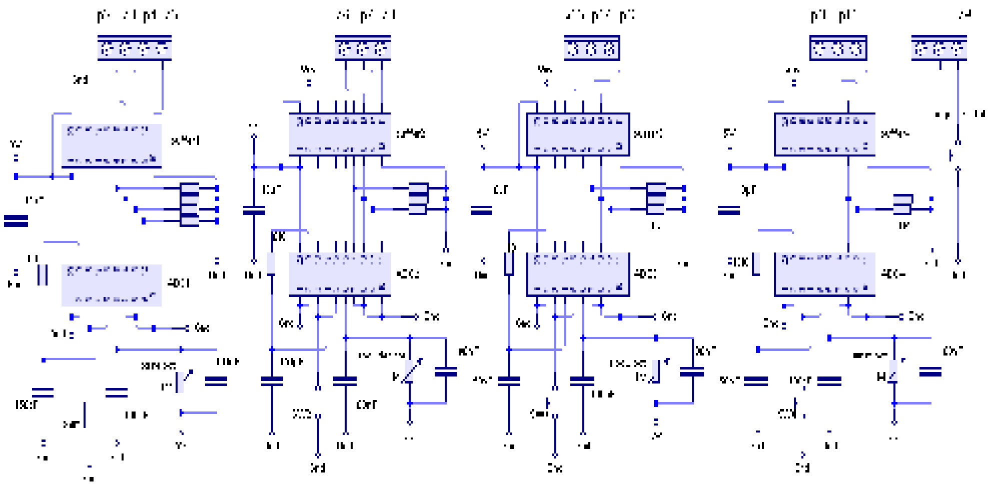

Fig. 3. Interface Circuit

C. Robotic Arm

The PhantomX Pincher AX-12 Robot Arm, Fig.4&5, consists of four joints plus a gripper. There are seven servo motors (AX-12 Dynamixel) used to actuate robot joints; one servo for base joint, two servos for shoulder joint, two servos for elbow joint, one servo is for wrist joint and one servo for gripper joint. Each servo motor has its own ID number and can rotate (300° through 1024 steps). The robot is supported with USB2Dynamixel interface circuit to connect the robot with computer through USB port, additionally, it is supported with SDK software to use it with different programs such as MATLAB, Visual Basic, LabVIEW , etc.

Fig. 4. Robotic Arm

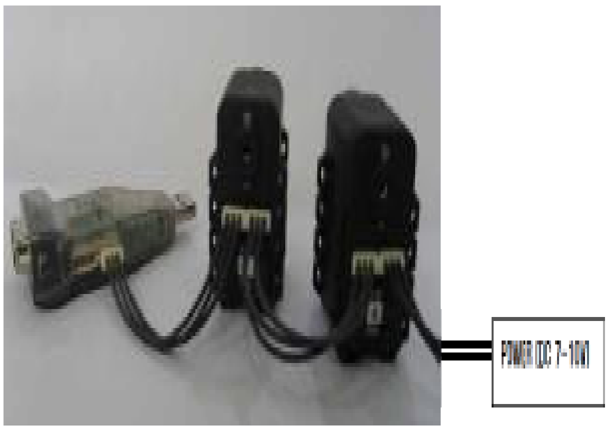

Fig. 5. AX-12 Dynamixels Network

D. Control Software

The control algorithm of a robot reads the decimal value of status and data bus of parallel port and extracts the binary value of pin(2,3,4,5), pin(6,7,8) ,pin(9) pin(9 , pin(10,11) and pin(15,13,12) . The control algorithm uses (IF. .Else) instructions to match between the digital values of sensing arm joints with corresponding joint's motion of a robot in a manner to make the robot mimic the motion of sensing arm. For example, when the base joint of sensing arm rotates (90º) , the base joint of a robot also rotates (90°) to mimic this motion, and when the operator pushes the switch of a finger joint of sensing arm, the robot's two fingers are closed to perform the grasping task. The software was supported with offline control to repeat the motions of a robot (during the real time control), Fig.6.

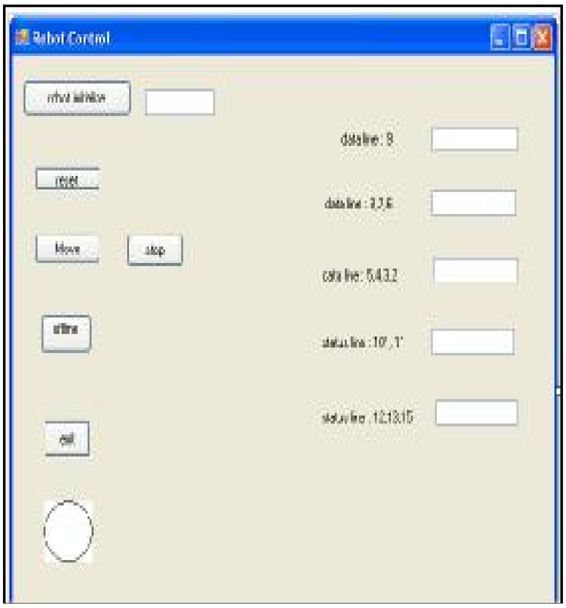

Fig. 6. (GUI) of Control Software.

3. Results

When the sensing base joint rotates (CW) with angle (-90º) with respect to the reference point, the digital output of this motion is (1111_b) . In the same manner, when sensing arm rotates (CCW) with angle (90º) with respect to the reference point, the digital output of this motion is (0001_b).Calculating the step of rotation for each digital output within (0111_b to 1111_b) is shown in table 1,and Fig.7 & 8:

$\Theta_s = \frac{90°-0°}{8} = 11.25°$, and $\Theta_r = \frac{512-204}{8} = \sim 39$ step (for robot)

And to calculate the step of rotation for each digital output within (0111_b to 0001_b):

$\Theta_s = \frac{90°-0°}{6} = 15°$, and $\Theta_r = \frac{820-512}{6} = 51$ step (for robot).

Table 1,
Sensing Arm and Robot Base Joint Motion.

Ө	**Sensing Base Digital Output**	**Sensing Base Rotation Angle**	**Robot Base Motion**
Θ_1	0111_b	0°	512+(0*51)=512
Θ_2	0110_b	15°	512+(1*51)=563
Θ_3	0101_b	30°	512+(2*51)=614
Θ_4	0100_b	45°	512+(3*51)=665
Θ_5	0011_b	60°	512+(4*51)=716
Θ_6	0010_b	75°	512+(5*51)=767
Θ_7	0001_b	90°	512+(6*51)=~820
Θ_8	0000_b	105°	512+(7*51)=869
Θ_9	1000_b	-11.25°	512-(1*39)=473
Θ_{10}	1001_b	-22.5°	512-(2*39)=434
Θ_{11}	1010_b	-33.75°	512-(3*39)=395
Θ_{12}	1011_b	-45°	512-(4*39)=356
Θ_{13}	1100_b	-56.25°	512-(5*39)=317
Θ_{14}	1101_b	-67.5°	512-(6*39)=278
Θ_{15}	1110_b	-78.75°	512-(7*39)=239
Θ_{16}	1111_b	-90°	512-(8*39)=204

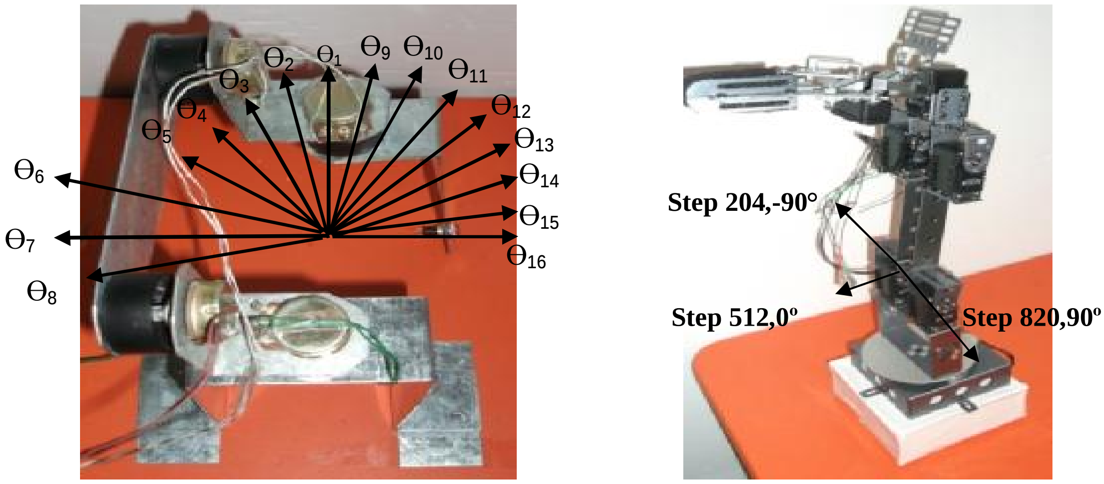

Fig. 7. Range of Sensing Arm and Robot Base Joint Motion.

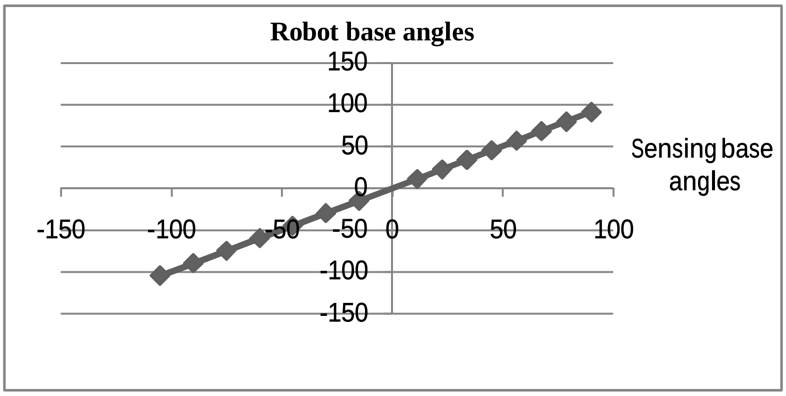

Fig. 8. Sensing Arm and Robot Base Angles.

For shoulder joint, the digital value (001) was chosen as a reference point, so, the rotation angle for this position is considered (0°). Now, to rotate down with rotation angle (-90º), the digital output of sensing shoulder will be (101) . To calculate the rotation angles within (111 - 000)), table 2 and Fig.9 &10:

$\Theta_s = \frac{90°-0°}{4} = 22.5°$ and $\Theta_r = \frac{780-512}{4} = 67$ step (for robot).

Table 2,
Sensing Arm Shoulder Joint Motion.

Θ	Sensing Shoulder Digital Output	Sensing Shoulder Rotation Angle $\theta i = 45 - 22.5i$, $i = 1,7,1$	Robot Shoulder Motion $512 + i67$, $i = -1,6,1$
Θ_1	000_b	22.5º	512-(1*67)=445
Θ_2	001_b	0º	512+(0*67)=512
Θ_3	010_b	-22.5º	512+(1*67)=579
Θ_4	011_b	-45º	512+(2*67)=646
Θ_5	100_b	-67.5º	512+(3*67)=713
Θ_6	101_b	-90º	512+(4*67)=780
Θ_7	110_b	-112.5º	512+(5*67)=847
Θ_8	111_b	-135º	512+(6*67)=914

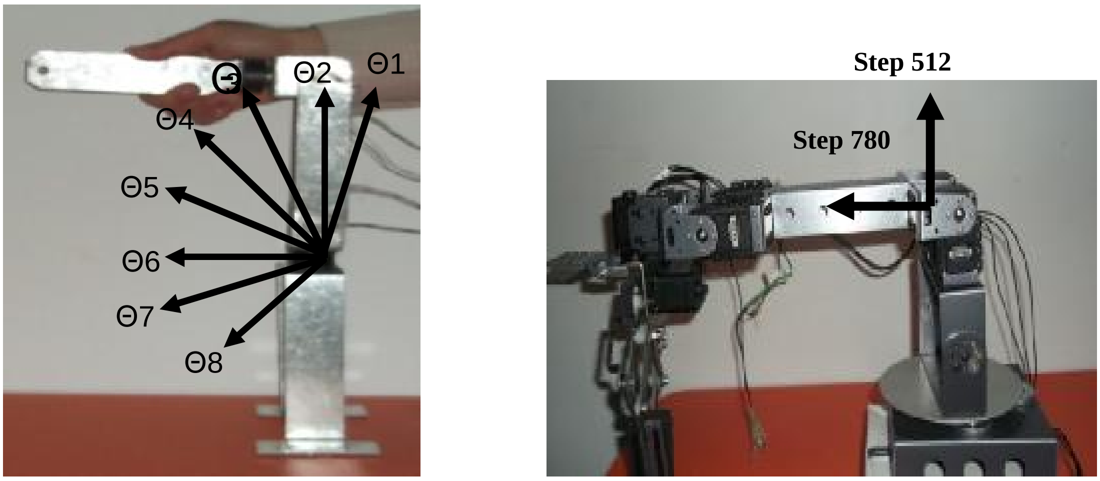

Fig. 9. Range of Sensing Arm and Robot Shoulder Joint Motion.

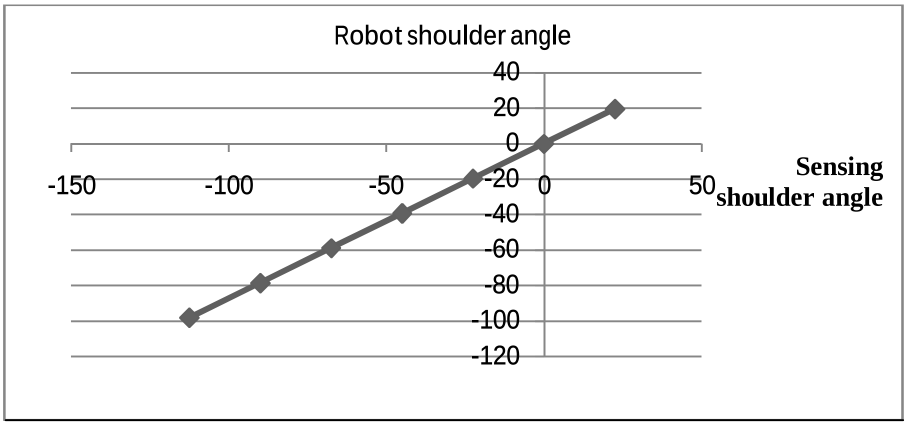

Fig.10.Sensing Arm and Robot Shoulder Angles.

There are eight digital outputs due to sensing arm elbow joint (000 to 111). The digital output (001) was chosen as a reference point with a rotation angle (0°) and when the joint rotates up with angle (90º), the digital output is (101),table 3 and Fig .11 &12.

$\Theta_s = \frac{90°-0°}{4} = 22.5°$ and $\Theta_r = \frac{512-204}{4}$=77 step (for robot).

Table 3,
Sensing Arm and Robot Elbow Joint Motion.

Θ	**Sensing elbow digital output**	**Sensing elbow rotation angle** $\theta i = 135 - 22.5i$, $i = 0,7,1$	**Robot wrist Motion** $512 - i67$, $i = 6,-1,-1$
Θ_1	111	135°	512-(6*77)=50
Θ_2	110	112.5°	512-(5*77)=127
Θ_3	101	90°	512-(4*77)=204
Θ_4	100	67.5°	512-(3*77)=281
Θ_5	011	45°	512-(2*77)=358
Θ_6	010	22.5°	512-(1*77)=435
Θ_7	001	0°	512+(0*77)=512
Θ_8	000	-22.5°	512+(1*77)=589

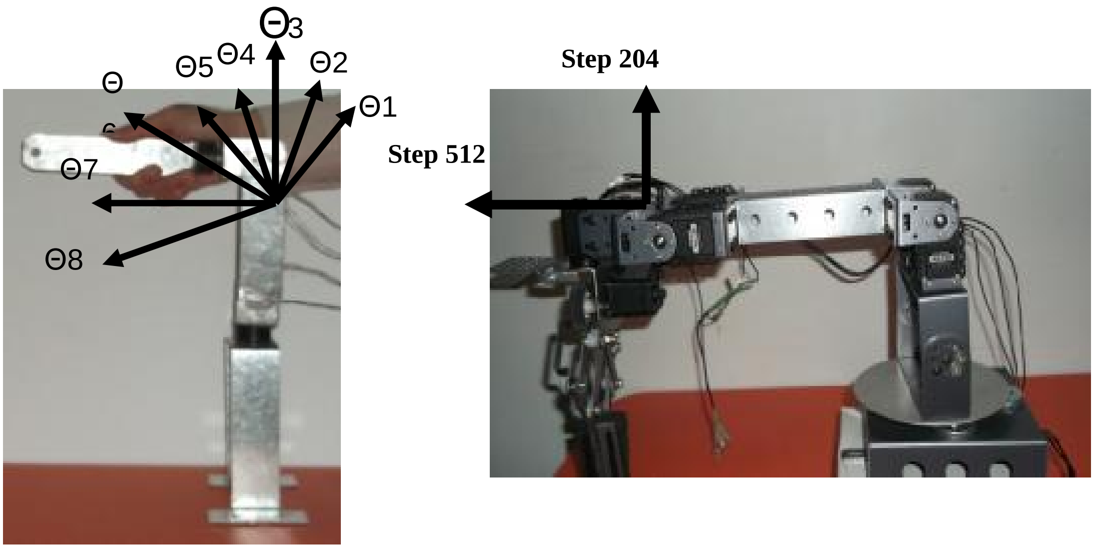

Fig. 11. Range of Sensing Arm and Robot Elbow Joint Motion.

For wrist joint, there are four digital outputs (00_b to 11_b). The digital value (10_b) was chosen as a reference point, below are the results of motion, table 4 &5 and Fig 12 &13 :

Table 4,
Sensing Arm and Robot Wrist Joint Motion.

Ө	**Sensing wrist digital output**	**Sensing wrist rotation angle**	**Robot wrist motion**
$Ө_1$	10_b	0°	512
$Ө_2$	11_b	-45°	666
$Ө_3$	01_b	45°	358
$Ө_4$	00_b	90°	204

Table 5,
Sensing Arm And Robot Two Fingers.

Sensing switch	**Robot fingers motion**	**Robot fingers status**
Pressed (0_b)	700	Close
Released (1_b)	600	open

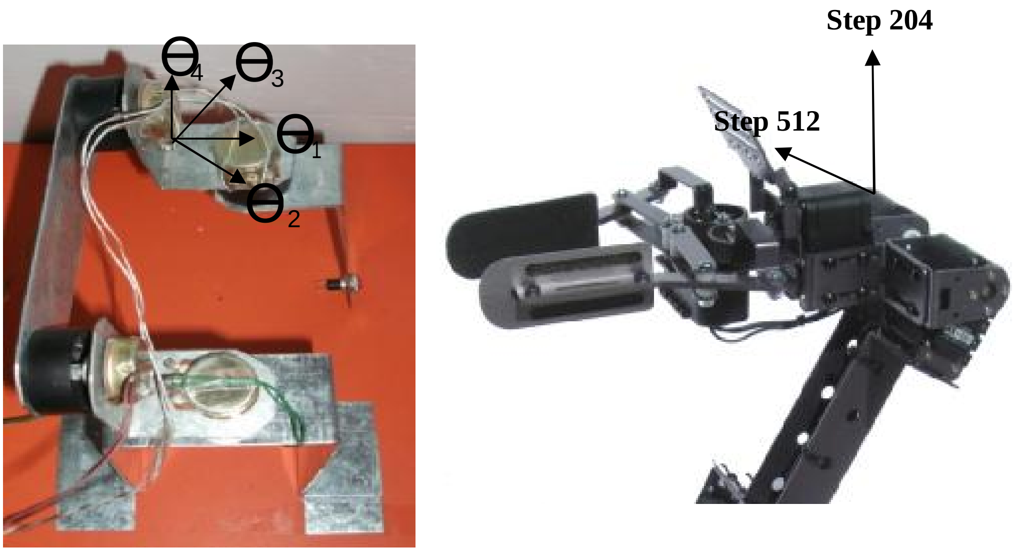

Fig. 12. Range of Sensing Arm and Robot Wrist Joint Motion

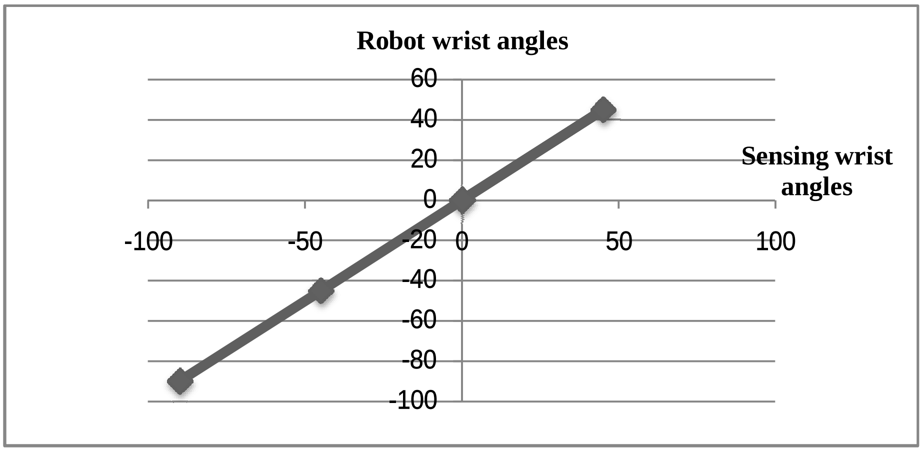

Fig. 13.Sensing Arm and Robot Wrist Angles.

4. Conclusion

This paper presents a real time and offline (teaching) control of robotic hand. The control system depends on (If. Else) , instruction to map directly between sensing arm and robot joints,Fig.14. The system achieved a good response time of robot control (~ 1 second) and high repeatability. The dimensions were chosen to cope with geometrical dimensions of a real robot because they affect on the results of motion. The type of potentiometer affects on the analog to digital conversion performance through the noise that may occur due to bad manufacturing of a potentiometer.

Fig. 14.Samples of Robot Motion.

5. References

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تصميم نظام تحكم لذراع انسان الي يحاكي حركة ذراع الانسان

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الخلاصة

يعرض هذا البحث نظام تحكم لذراع إنسان آلي، لمحاكاة حركة ذراع الإنسان بالوقت الحقيقي والوضع الغير متصل. لقد تم تصميم وبناء نظام المتابعة لحركة يد الانسان من خلال نظام تحسس لتحديد الموقع والاتجاه في الفضاء وكذلك عملية المسك والالتقاط ليد الإنسان. لقد استند في تصميم نظام التحسس على الهيكل الهندسي لمتابعة حركة ذراع الإنسان المراد السيطرة عليها . نُفِذت خوارزمية التحكم بذراع الإنسان الآلي بواسطة برنامج ألفيجوال بيسك بواجهة رسومية للمستخدم . اعتمدت خوارزمية السيطرة على طريقة خارطة مفصل لمفصل لمطابقة حركة كل مفصل لذراع التحسس وذراع الانسان ليتم محاكاتها من قبل ذراع الإنسان .