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Robot Manipulator Control Using Absolute Encoder and Electromyography Signal

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***Abstract*—Many robots have been being developed based on the characteristics of the human body. Robots that mimic the motion of a human arm have many practical applications. The author built a robot manipulator which is controlled by a human left arm and studied its effectiveness. This robot had two joints and one gripper attached to the end-effector. Two joints worked based on the information from two absolute encoders operating as movement sensors on the operators' left elbow. The gripper picked up and released objects based on the electromyography (EMG) signals from the flexor muscle of left hand. The first joint provided for flexion and extension and the second joint was for supination and pronation rotation. Both of the encoders produced three bits of data resulting in eight combinations. The resolution for the first encoder was approximately 7° and the second was 10.5°. The gripper mode depended on the amplitude of EMG signal. The gripper picked up the object if the signal was bigger than the threshold value and it released the object if the signal was smaller than that threshold value. The threshold used was 100 µV. The result showed that this control design successfully operated the robot joints using human arm movement and the contraction of the flexor muscle controlled the gripper well. This system can be further developed by increasing the resolution of the sensors and flexibility of the mechanical structure.**

Keywords-human arm; robot manipulator; encoder; EMG

I. INTRODUCTION

As robot technology improves, robots are able to replace human labour to perform difficult and dangerous tasks. Academics who conduct research in extreme environments can use robots collect data safely reducing the risk to human investigators.

Robots are also being developed for building construction projects. Specific jobs with high risk can be done using robots instead of endangering human construction workers. Daniel Schmidt in [1] surveyed the range of climbing robots used for maintenance and inspection of vertical structures. He discovered that although many robots were created to do these tasks; they were limited to specialized functions. The challenges in creating climbing robots are to make them light, small and fast.

Underwater robots also have a role in scientific research. A walking underwater robot [2] has been created that is able to use arms and legs for walking on the seabed. This robot named CRABSTER200. It uses six legs and the front two legs can be transformed into manipulators. The degree of freedom, dimensions, motion range, joint structure and mass were developed according to certain specifications.

Medical robots help doctors during surgery. Robots are developed to carry out minimally invasive diagnosis and interventions so improving efficiency, safety, pain, speed and post-operative recovery time. [3]. There are still many challenges to be overcome in developing effective medical robots. But reducing the cost of surgery and ensuring patient well-being are very important issues to be addressed.

Robots that work in collaboration with humans or *cobot* are utilized in many fields including industry, medicine and tourism. Cobots, designed for the assembly line worker, must be ergonomic, safe produce quality goods and not compromise productivity. Andrea Cherubini [4] developed a human-robot manufacturing system for homokinetic joint assembly. The result showed that although the collaboration between human and robot took longer to insert six balls in the joint assembly, than doing the job manually the cobot reduced the operator load by approximately 60%.

Assistive robots are also being developed to help people with special needs. Recently, two types of biosignals, electromyography (EMG) and electroencephalography (EEG), are being used widely to control these. Rechy-

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Ramirez [5] reviewed the development of these biosignals in control systems and noted that. design of bio-control systems requires four stages: data acquisition-segmentation, feature extraction, classification and control. There are several challenges in the implementation of EMG and EEG control systems. First, there are many methods to classify the EMG and EEG signals proposed by academic community, but developing this technology to produce commercial applications for simple tasks has yet to be achieved. Second, most EMG and EEG control systems have only been tested in a laboratory setting. However outside the controlled conditions of the laboratory EMG and EEG signals are harder to detect. Electrooculography (EOG) signals are also being studied to establish the communication between the human eye and machines using blinking and gaze motion. The EOG signals are linear to the gaze angle as reported by Rusydi [6]. An EOG based control robot has been developed by Rusydi [7].

Robots are also created to imitate human or animal movement. In [8], a snake arm robot was constructed that demonstrated flexibility-stiffness and actuation. In another project [9], a flexible robot arm using flexible pneumatic cylinders and ultrasonic sensors for human wrist rehabilitation was developed. In last few years, academia and industry have focused attention on human-robot interaction, improving robot perception, reasoning, learning, manipulation and navigation. Human-aware navigation has been classified according to comfort, naturalness and sociability motion [10].

Prosthetic organs are being developed to assist disabled people in daily activities. Non-linear ankle dynamics have been modeled using an artificial neural network and the relationship between the foot and walking configurations has been determined by an empirical model of the ground reaction force [11].

As cobots are bound to play an increasing role in so many areas, developing effective biocontrols is essential. This research is a significant advancement toward achieving this as it combines both encoders and EMG signals. A robot manipulator controlled by a human left arm was constructed. This project was selected as a manipulator controlled by a left arm would be invaluable for a right arm amputee to perform tasks requiring two arms. Human elbow movement was replicated by two joints. Two absolute encoders were used to calculate the joint movements. A gripper was attached to the end-effector of the robot and controlled by EMG signals.

II. THE EMG SIGNAL

The EMG signal is a biosignal corresponding to muscle contractions [12]. Many methods have been developed to classify the EMG signal, such as bayessian [13], neural network [14], fuzzy [15] and support vector machine [16].

In this research, EMG was used to detect muscle contraction. Two muscle locations were investigated to determine the best electrode position. The amplitude of EMG produced by wrist extensor and wrist flexor were studied. Five participants relaxed and contracted these muscles for approximately two second each. The experiment was repeated five times. Fig. 1 shows the investigated muscle positions.

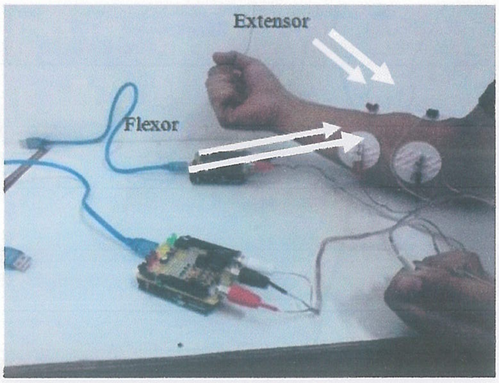

Figure 1. Electrode position for flexor and extensor muscle.

III. ENCODER

Modelling the arm movement was a challenge in this research. The previous papers [17] and [18] used Inertial Measurement Unit (IMU) sensor to detect the Euler angle of the hand movement. The problem of using the Euler angle for the hand movement patterns was the callibration to the reference point of the movement.

In this research, two encoders were used to sense the elbow movement. The positions of the two encoders were maximised to detect the angle of flexion/extension and supination/pronation rotation of the left hand. Fig. 2 illustrates the encoder positions. The first encoder determined the flexion/extension movement and the second encoder was used for supination/pronation.

Both of the encoders were typically designed three bit absolute encoders. The possibile states were 000, 001, 010, 011, 100, 101, 101, 110 and 111. The shape of the encoder for the flexion/extension measurement was different from that of the encoder for the supination/pronation. The enocder structures in Fig. 3 were estabilished after a prelimanary study of hand kinesiology.

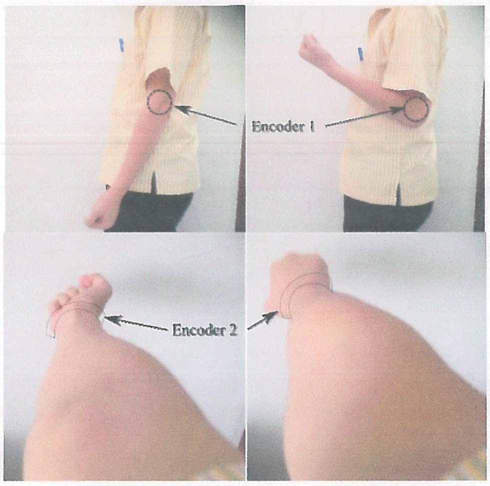

Figure 2. The encoder positions.

Three photodiodes were used to detect the encoder state. These photodiodes captured the light from three Light Emiting Diodes (LEDs) facing them. The signal produced by photodiodes was determined by intensity of the light received from the corresponding LED. The design of photodiodes is shown by Fig. 4.

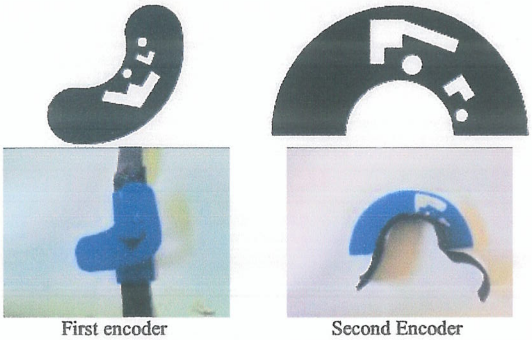
First encoder   Second Encoder

Figure 3. The encoder design.

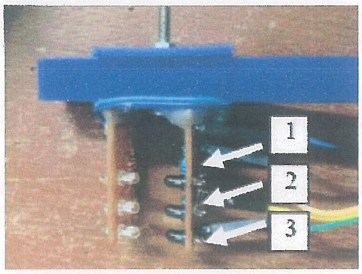

Figure 4. Three photo diode

IV. ROBOT ARM

The robot manipulator had two joints and a gripper attached to the end-effector. These two joints together reproduced the elbow movement of the human arm. The first joint was for the flexion and the second joint was for the internal rotation. Fig. 5(a) illustrates the robot arm design. The hand function, was simulated by the gripper to pick up and release objects. The two joints were controlled by the encoders and the gripper by the EMG signal. The first joint movement is illustrated in Fig. 5(b). The robot rotated about Z_1-axis for the flexion movement. The second joint movement is shown in Fig. 5(c). The robot rotated about Z_2-axis for supination/pronation.

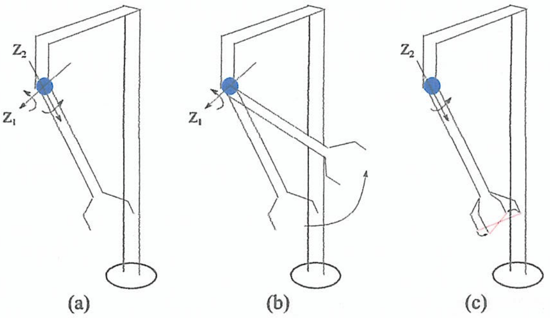

Figure 5. The robot manipulator movement.

Fig. 6 shows the robot manipulator. The first joint was driven by a Pro MG995 servo motor and the second joint was manipulated by a FreeTech FR0115M servo motor. The gripper used the same motor type as the first joint.

Figure 6. Robot manipulator.

V. METHOD

Fig. 7 shows the control scheme of the robot manipulator. Two encoders were connected to an Arduino microcontroller. The output of the microcontroller was a Pulse Width Modulation (PWM) signal. Two microcontrollers were used.

The first microcontroller processed the data from the two encoders. It converted the analog signal from the photodiode to the digital signal. The states determined by the three photodiodes converted to angle of the motor. The second received the signal from EMG and processed it to control the gripper. The EMG signals were classified into contraction and relaxation mode.

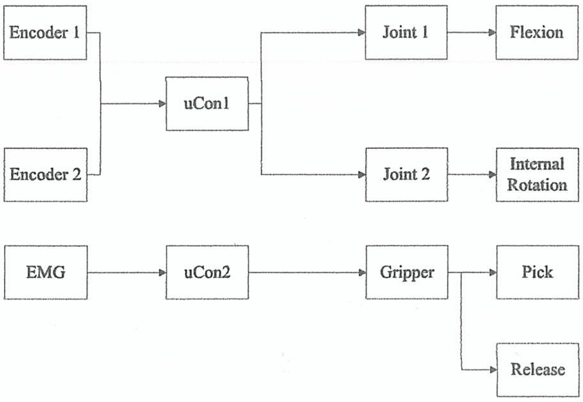

Figure 7. Control scheme of the robot manipulator

VI. RESULT AND DISCUSSION

The first encoder was designed to detect flexion angles between 0° to 50°. The second encoder angle was used to detect the pronation/supernation angle from 0° to 73.5°. Table I shows the degree of eight states for the first joint encoder and the second joint encoder. The encoders were attached as shown by Fig. 8.

TABLE I. THE DEGREE OF EIGHT STATES

Binary code	**First Encoder**	**Second Encoder**
000	0°	0 °
001	7 °	10.5 °
010	14 °	21 °
011	21 °	31.5 °
100	28 °	42 °
101	35 °	52.5 °
110	42 °	63 °
111	50 °	73.5 °

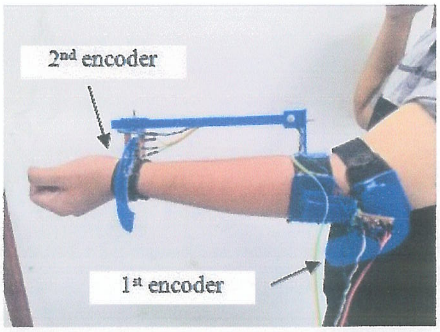

Figure 8. Two encoder sensor systems attached to human left arm.

The signals from the three photodiodes were tested for each or the eight states. The result is shown inTable II. Based on the signals obtained, it was decide to define two conditions for the photodiode. If the encoder blocked the light to the photodiode the binary code was 0 and the photodiode output was higher than 900mV. When the light was not blocked by the encoder but was received by the photodiode the binary code was 1 and the photodiode ouput lower than 800mV.

TABLE II. PHOTODIODES OUTPUTS

Binary Code	**Photodiodes Encoder 1 (mV)**			**Photodiodes Encoder 2 (mV)**		
	1	*2*	*3*	*1*	*2*	*3*
000	932	926	953	932	913	947
001	904	913	226	932	910	670
010	954	529	965	931	545	955
011	964	533	697	927	526	705
100	500	960	983	517	903	925
101	508	957	577	515	908	584
110	520	647	961	490	510	952
111	517	520	548	499	522	562

Five human subjects participated in this research. Their EMG signals from flexor and extensor wrist muscles were investigated. Fig. 9 shows an example of EMG signals from one of the subjects. The results showed that the flexor muscle produces bigger signals than the extensor muscles. This muscle was chosen to control the gripper. A threshold value was set to differentiate when the subjects hand was picking up an object and when it was releasing. If the EMG signal was bigger than 100mV, the robot gripper also picked up an object. If the EMG signal was lower than 100mV, the gripper released.

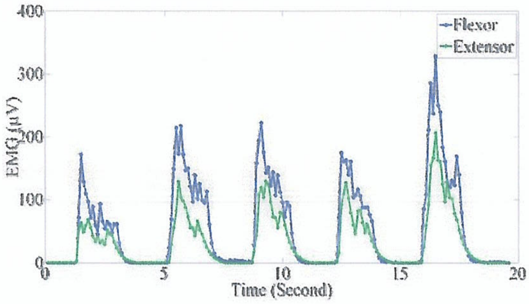

Figure 9. EMG signal.

All the systems were integrated as shown by Fig. 10. This robot followed the human left arm movement well.

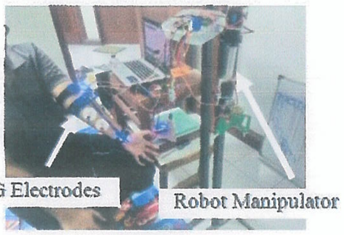

Figure 10. The integrated robot manipulator with two encoders and EMG sensor.

VII. CONCLUSION

A robot manipulator controlled by a left human arm was designed in this research. The result showed that the encoder could detect hand movement but with limited resolution. The EMG signal was able to differentiate between: relaxed and contracted muscles but more work is required to replicate contractions of differing strength based on EMG signal.

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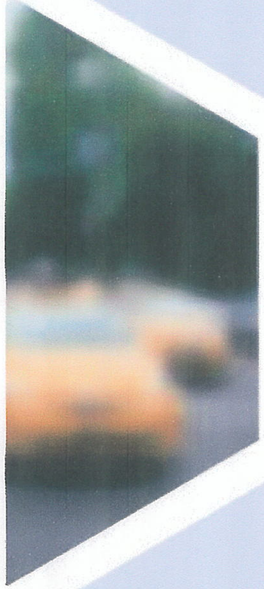

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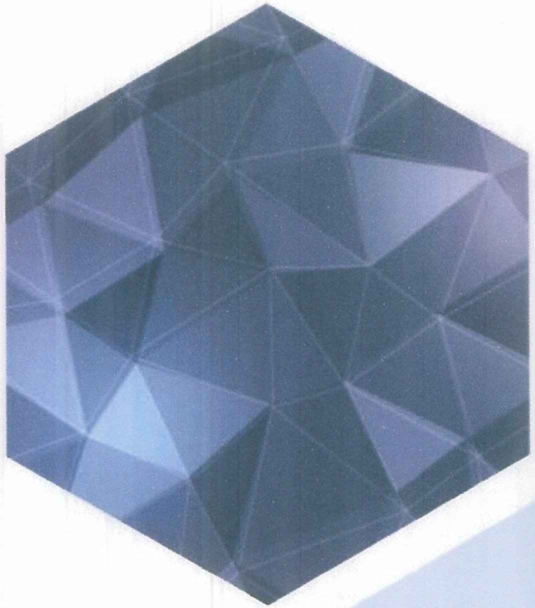

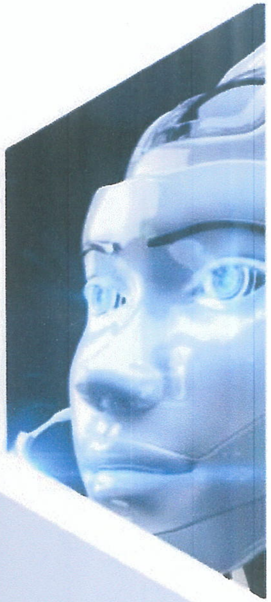

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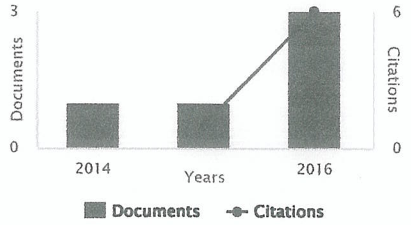

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