Bomb disposal Robot

Discarding explosive through wireless controlled method

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Abstract— **Bomb disposal robot has been developed by different experts around the world to make an affordable and safe device which will be useful for emergency rescue support. A 6 DOF articulated robotic arm mounted on a moveable base is been developed to help bomb disposal squad to dispose bomb safely from distance. The whole operation of the robot can be performed wirelessly from a computer. DC servo motor is used as actuator of the arm, and the servo is controlled by the PWM signal generated by microcontroller. This report is concerned with the mathematical modeling of a 6 DOF robotic arm along with the methodology of the entire prototype development. Architectural and circuitry development are separately deliberated. Lastly, the performance of the developed robot has been discussed.**

Keywords—disposal, articulated, D-H parameter, kinematic, DOF

I. INTRODUCTION

Human lives is becoming more dependent on robotics and the reason behind this is, robots can perform such daily activities with spectacular speed, precision and skill despite the level of difficulty. Robotics technology has already developed so much that, behavioral pattern of human being can be read by them and act according to fulfill that task while the person is not present there [1]. State of the art programming language is deployed on the robots and many advanced electronic devices are working along to increase efficiency in different activities performed by those robots instead of human [2].

Throughout the development in different field of robotics, life threating task like disposing bomb has taken into consideration of research field. Two main aspects of development such robots like-disarmament of bomb with minor direct interaction of human to the bomb and saving crucial evidence of bomb material to trace technology, identifying the developer. Since different civil wars and recent terrorist attack around the world, it has become very risky to law enforcement department to disarm the bomb by hand. Those expert people who usually do this job, they also try to stay away as possible like other human being. A remote means is always required to observe and dispose the bomb. Therefore, robots are needed in many cases to aid the bomb disposal squads. This is the sole purpose of being involved to this project. A bomb disposal robot can save innumerable lives. It is faster, more maneuverable, better equipped with a dexterity that could rival an explosive ordnance disposal technician operating in person.

II. MODELING AND ARCHITECTURAL DEVELOPMENT

Mathematical modeling of any automated system is essential to realize & control and hence achieve the optimized output. Different parameters like manipulator, joint, end effector, actuator, controller, Degree of freedom (DOF) etc. has to be calculated to have optimal response of robot. Concurrently, the Denavit-Hartenberg parameters known as DH parameters have four parameters followed by specific convention to attach reference frames and spatial kinematic chain. The length of intersections between mutual joint is termed as Joint offset (b). Orthogonal projections and common normal angel to the joint axes symbolized as θ called joint angle. The distance of common normal and axis called link length (a). Joint axes orthogonal projection to plane normal followed by common normal referred as twist angle (α) [7]. In this prototype, revolving joint referred as DH parameter joint variable and rest of the three parameters named link parameter are constant.

The prototype represented here has gone through mathematical modeling of different kinematics, preliminary structure analysis, software simulation of implemented circuit and finally hardware development [3,4,5]. In active part i.e. arm of the robot has five axis- one for the base, next bear/shoulder and last one elbow. All three were ensured to move the arm to the specific point and to feel the gripper action two minor axis incorporated like pitch & spin. Total six rotational joint considered in designs though in implementation it was taken to five because two joints that move the bear/shoulder rotate in unique direction. Fig.1 shows the preliminary design of axis and joints [6].

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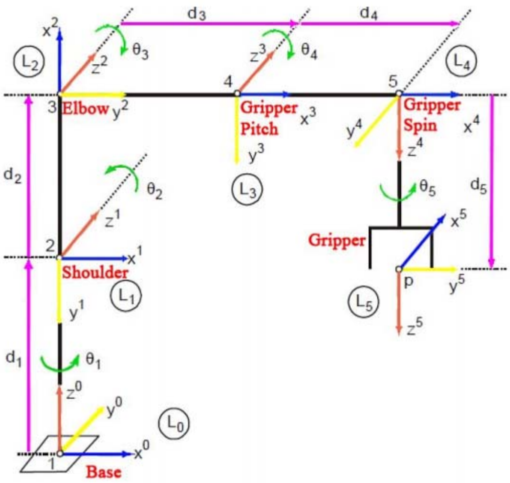

Fig.1. Sample model for link axis & joints for prototype [8].

Let's take a look on the prototype manipulator where links are coupled by either rotational joints or prismatic joints. Here, base is named as link 0 and joint 1 connects base with link 1. Dimensional point of view like in fig. 2 shows i^{th} joint connected from i^{th} link to (i-1). To evaluate the position and specific alignment of link i connection goes to adjacent link i-1. Overall, a system of frame written in Cartesian form like $x_iy_iz_i$ is here to calculate all values. . The arm parameter can be computed after a Cartesian frame $x_iy_iz_i$ is assigned to the robot arm. Two parameters of the link i are the link length a_i and the twist angle α_i. Two joint parameters are the joint angle θ_i and the joint distance d_i as shown in Fig. 2.

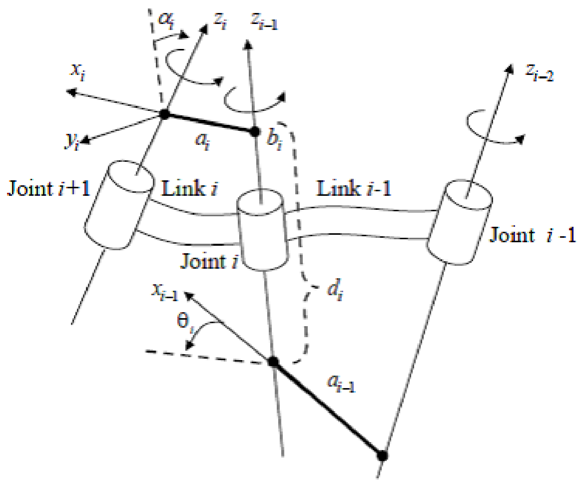

Fig. 2. D-H parameter frame of prototype [9].

To construct frame assignment a transformation matrix which is homogeneous is formed and hence, arm parameter calculated. Now, a frame like $x_{i-1}y_{i-1}z_{i-1}$ to $x_iy_iz_i$ can be found following these steps:

i. Rotation of the frame x_{i-1} y_{i-1} z_{i-1} about the z_{i-1}.

$$Rot(z,\theta_i) = \begin{bmatrix} C\theta i & -S\theta i & 0 & 0 \\ S\theta i & C\theta i & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

ii. Translation of the frame x_{i-1} y_{i-1} z_{i-1} along the z_{i-1} axis by d_i units

$$Trans(z,d_i) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & di \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

iii. Translation of the frame x_{i-1} y_{i-1} z_{i-1}along the x_i axis by a_i units

$$Trans(x,a_i) = \begin{bmatrix} 1 & 0 & 0 & ai \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

iv. Translation of the frame x_{i-1} y_{i-1} z_{i-1}along the x_i axis by α_i units

$$Rot(x,\alpha_i) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & C\alpha i & -S\alpha i & 0 \\ 0 & S\alpha i & C\alpha i & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

The transformation matrix for each joint can be calculated as:

$$H^i_{i-1} = Rot(z,\theta_i)\ Trans(z,d_i)\ Trans(x,a_i)\ Rot(x,\alpha_i)$$

D-H transformation matrix from the frame x_{i-1} y_{i-1} z_{i-1} to the frame $x_iy_iz_i$ can be calculated by using post multiplication rule. The result is as follows:

$$H^i_{i-1} = \begin{bmatrix} C\theta i & -C\alpha iS\theta i & S\alpha iS\theta i & aiC\theta i \\ S\theta i & C\alpha iC\theta i & -S\alpha iC\theta i & ai\theta i \\ 0 & S\alpha i & C\alpha i & di \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

Frame movement & direction compare to base frame evaluated by the matrix:

$$H^n_0 = H^1_0H^2_1H^3_2\ldots..H^n_{n-1} \quad (6)$$

The transformation matrix H^n_0 can be expressed as follows:

$$H^n_0 = \begin{bmatrix} n & s & a & p \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} nx & sx & ax & px \\ ny & sy & ay & py \\ nz & sz & az & pz \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (7)$$

In this matrix, there are two vector's named approach vector and sliding vector signed as "**a**" & "**s**" respectively. Normal to those position a vector "**n**" and position vector "**P**" pointed to base from origin of frame [8].

A. Construction of the Kinematic Structure

The structure of the robot is built with combination of light weight steel plates and aluminum made servo brackets. Steel structure makes the prototype to carry out extra weight and make a balance of joints. At the bottom of the robot, arm is fastening so that if there is heavy weight or something then system can have an equilibrium position to work smoothly. Because, while grabbing a bomb and make necessary movement can make system out of balance. Servo motors was placed to do required shift with possible flexibility. The advantage of the servos is that they can be programmed to return to their initial position. A simple kinematic structure is shown in Fig.3.

B. Hardware development

The hardware is actually divide into two different segment, the transmitter section (see Fig. 4) and the receiver section (see Fig. 5). The transmitting section is adjacent to the computer, connected with pc using a USB cable. And the receiving section is into the robot vehicle. The transmitter panel is constructed with two microcontroller and a RF transmitter. And the receiving section, which is the core of the robot is consist two microcontroller, one de-multiplexer, one H-bridge DC motor driver and a RF receiver.

The USB interfacing of the transmitter board with computer is done by the PIC18F4550 microcontroller, which receives codes through USB buffer sent by the computer GUI application. This microcontroller then sends the code to other microcontroller which is PIC16f877 through I/O pin. The second microcontroller then convert the code to serial data from parallel data using its USART feature and pass the code the receiving end microcontroller through RF transmitter (see Fig. 4). The receiving-end micro controllers run by very low frequency crystal oscillator so that it can generate 50Hz PWM for the servo.

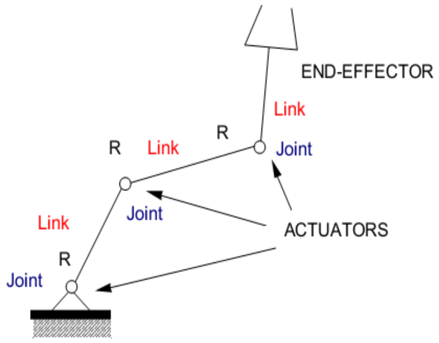

Fig.3. A kinematic structure with three revolute joints

So the transmitting end microcontroller has to run by same low value crystal oscillator so that it can make synchronous communication with the receiver. But for making USB communication with computer a microcontroller must have to run by a much higher than that crystal oscillator. Thus two different microcontrollers of two different frequencies have been used in transmitter board.

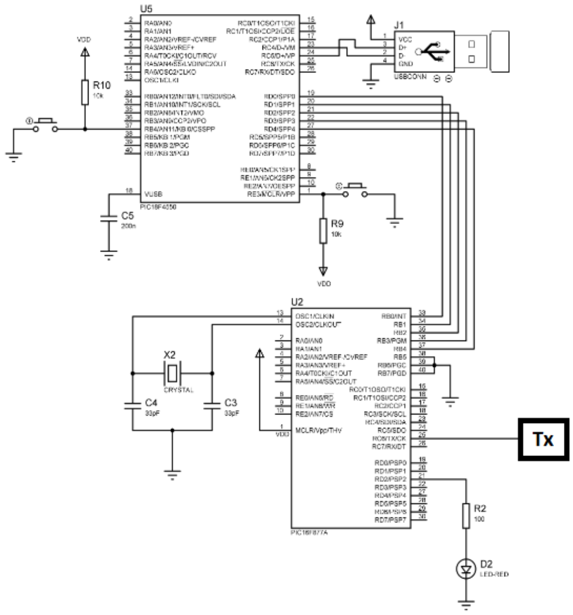

Fig.4. Circuit diagram of transmitting end.

The receiving end micro controller PIC16f877 convert the transmitted code to parallel data from serial data after receiving it through RF receiver. Each valid code has an assigned task to execute, such as driving the servo motor by increasing or decreasing the duty cycle of the PWM, or driving the dc motor.

The DC motors are driven by H-Bridge IC L293D which is controlled by the main microcontroller PIC16f877. And the Servo motors are directly controlled by PWM signal generated by microcontroller. Servo changes its shaft position with the change of the duty cycle of the PWM signal. So, two different codes is been sent from transmitter to receiver for each servo to rotate its shaft in either direction. One code causes the increment of the duty cycle, and other causes the decrement of the duty cycle of the PWM signal. Thus, there are total 12 different valid codes that can be sent from the transmitter to control all 6 servos of the arm. To move the base of the robot to forward, backward, left and right direction, 4 more unique codes is sent. The receiving unit will not react to any signal, unless any of these 16 codes is received.

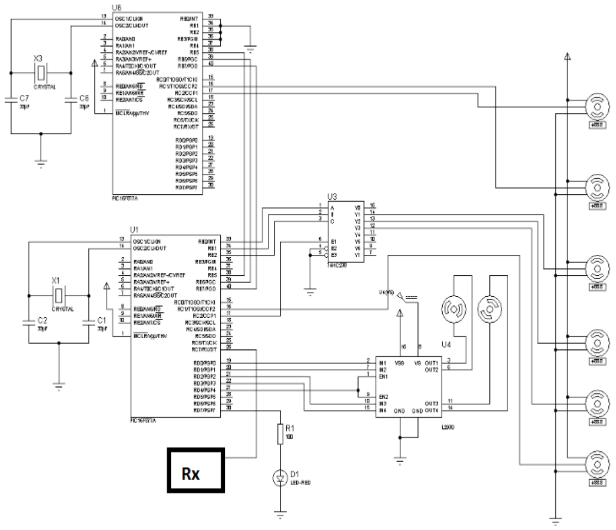

Fig.5. Circuit diagram of receiving end.

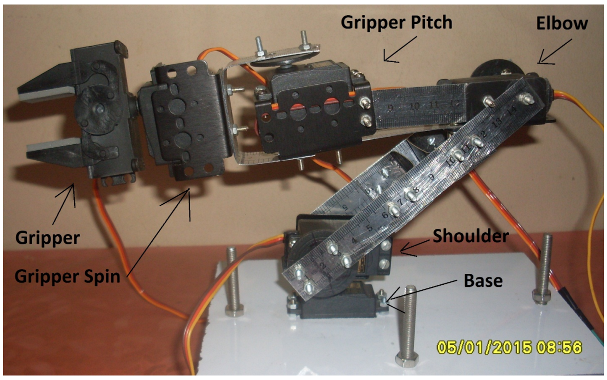

Fig.6. Implemented prototype receiving end.

Developed prototype of bomb disposal robot arm is shown in Fig. 6. The mechanical parts is designed by choosing aluminum because it strong and light material compare to other material. Aluminum is difficult to break due to its quality. On the other hand, Aluminum material also easily to find and the price is cheap. The power, torque and size of the servo motors can affect the dimensions.

III. PERFORMANCE ANALYSIS

To analyze the disposal robot performance, ideal scenario is expected to anyone. That means, a simple bomb has to be placed within certain time limit and robot has to approach that spot, observe the wiring structure and dispose it before explosion. But here some parameter has been defined to analyze performance like-Target reaching: The ability of the end-effector of the arm to reach a specific point is not so precise but still satisfying. The reason behind it is the low resolution of generated PWM signal. As the increment or decrement gap of duty cycle of PWM is not so little, the servo shaft cannot move smoothly from 0 to 180 degree. Load lifting ability: The gripper of the arm can drag something and pull it up. From our calculation in chapter 3, we got that the excess torque available in shoulder is 5.45 kg-cm. Now since the arm is 25cm long, so the arm can lift an object of maximum 218g. Over that range, the servo used in shoulder starts to draw very excessive current which may burn it. Arm Response at Various loads**:** The developed robotic arm has undergone a weight lifting test, where applied force on the end-effector was increasing by varying the weight of the object hold by the gripper. The state of the Arm is shown in Fig. 7.

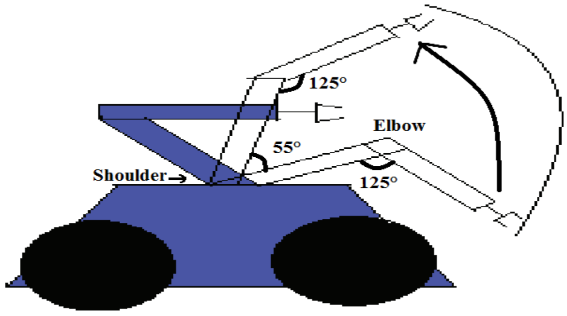

Fig.7. Weight lifting test arrangement.

The angle between shoulder link and elbow link was remaining fixed at 125°, while the shoulder link moved 55° up to complete a trajectory. The recorded value is shown in Table I. Here, worth to mention that the servos were powered by a 6V DC battery during the test. If the applied voltage reduced to 5V DC, then time required to complete that trajectory will be increase.

TABLE I. MEASURED VALUES OF THE WEIGHT LIFTING TEST.

Applied Weight on End-Effector (gram)	**Time elapsed to move up 55° (mili sec.)**	**Total current consumption of the system (A)**
0	850	0.693
25	850	0.709
55	900	0.793
80	1000	0.824
100	1150	0.855
140	1450	1.08
180	1750	1.29
210	2000	1.48
220(Dead Load)	Failed to lift	1.80

IV. LIMITATION OF PROTOTYPE

As a prototype, this disposal robot shows bit of good performance in terms of signal transmission and reception, weight lifting, twisting over wide range of angle etc. Despite of these advantages there are few things need to mention as limitation of prototype-PWM Resolution: The PWM control signal of servo motor which is generated by 8-bit microcontroller PIC16f877 is of very low resolution. The servo motor used in this project rotates from 0 degree to 180 degree with the changing of the duty cycle of the PWM from 10% to 20%. But microcontroller can produce very few value of duty cycle between that ranges. As a result, servo cannot rotate smoothly from 0 to 180 degree. It jumps from one position to other position with keeping gap of at least 8 degrees. If microcontroller of higher bit say 16 or 32 bit can be used then this problem will be compensated. Single channel communication: The transmitter can send only one command to the receiver at a time. So, two different movements of servo cannot be done at the same time. For example, if the shoulder of the starts to enlarge the all other joint will remain halt at that time.

V. CONCLUSION

Disposing a bomb quite a challenging job to military & law enforcement agency worldwide and that why bomb disposal robot demand will increase day by day. This prototype has few limitations in practical point of view, but improvement in design, dexterity, DOF can enhance the chance to implement in real life application.

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