Design 6 DOF Manipulator with the Help of Kinematic Arrangements & Controlled Via Hand Gestures for Hazardous Handling

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Abstract:- *Manipulator plays an important role in industry it makes our live easier and better, it accompany people in everyday life and takeover their daily routine. This paper presents the design and implementation of manipulator which aimed to be used for handling hazardous materials. Manipulator is designed on the basis of kinematic arrangements and it can be controlled through teleoperators(master/slave). Here the manipulator (slave) movements are controlled by Hand Gesture (master) using MPU6050 and flex sensor from a distant location using a bluetooth wireless modules.*

Keywords: Manipulator, MPU6050, Flex Sensor, Wireless Modules, Arduino

1. INTRODUCTION

Human robot interaction is an active area in robotic research. Research in robotics results in the development of two fields: Robotic manipulation and the input feeding system. In present days robots became a helping hand for human being as robot can perform many tasks that are difficult to complete for human being in very less time with comparable accuracy such as medical surgeries, industrial applications such as mass production and pick and place heavy parts, in agricultural field, in different hazardous conditions, in land mine detection, in vacuum chambers, etc. as per instruction of human being. Robot manipulators are composed of links connected by joints to form a kinematic chain. Joints are typically rotary (revolute) or linear (prismatic) as shown in Fig.1.1. A revolute joint is like a hinge and allows relative rotation between two links. A prismatic joint allows a linear relative motion between two links. Revolute joints denoted by R and prismatic joints by P. Most industrial manipulators at the present time have six or fewer degrees-of-freedom. These manipulators are usually classified kinematically on the basis of the first three joints of the arm. The majority of these manipulators fall into one of five geometric types: articulated (RRR), spherical (RRP), SCARA (RRP), cylindrical (RPP), or Cartesian (PPP). This paper focused on an articulated manipulator which is helpful to pick and place hazardous object or chemicals (which has harmful radiation) from a distance to avoid hazardous accident. This manipulator is controlled through Teleoperators. Here manipulator is treated as a slave and its input is controlled by hand gesture glove (Master), using MEMs technology (MPU 6050) and flex sensor. The slave device is consisting of mechanical structure of a robotic arm and their movements such as pitch, roll and yaw are controlled by hand glove movements. Master and slave communication is accomplished using the wireless bluetooth modules, the range of communication between master and slave device is about 100 meters as both are spatially separated.
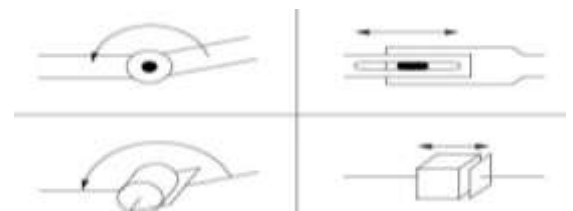

Fig. 1.1 Prismatic and Revolute joints[17].

2. LITERATURE REVIEW

To control a manipulator with the help of gesture is becoming a famous technique in many applications. Variety of techniques has been adopted around the world few of them are "Gesture Controlled Mobile Robotic Arm Using Accelerometer"[2]. In this paper Vivek Bhojak has used RF modules for wireless communication and accelerometer to control the pitch and roll movement, he also used push button to open and close the end effector (gripper)."Design and Implementation of a Wireless Gesture Controlled Robotic Arm with Vision"[4]. In this paper Love Aggarwal has used two accelerometers one accelerometer is attached on the human hand, capturing its behavior (gestures and postures) and thus the robotic arm moves accordingly and the other accelerometer is mounted on any of the leg of the user / operator, which is used to control the platform (which is being used here to increase the workspace). "Control of Robot Arm Based on Hand Gesture using Leap Motion Sensor Technology"[12]. In this paper P.D.S.H. Gunawardane proposed the technique of controlling a 3 DOF manipulator (slave) through the bilateral system using Leap Motion Controller (LMC) which is act as a master device, The idea of using leap motion is quite good because it provides a good precision however there are some limitations that it is not able to perform well on all light conditions and it has a specific hardware and special programs are required to obtain and process its data and it also requires an app and very limited numbers of apps are available in airspace . Proposed technique doesn't have any such limitations it elaborates the control technique of pitch and roll axis motion via accelerometer and yaw axis motion through

gyroscope, To achieve optimum control of end effector (gripper) with the maximum accuracy flex sensor is used in place of push button and also to establish the wireless communication channel between master and slave device, Bluetooth is used in replacement of RF modules thus its consumes much less power than RF modules.

3. DESIGNING KINEMATIC STRUCTURE

Dimension and work space configuration as per requirement is the first step to design a robot. Second step is to determine the specification of an individual actuator. To reduce the gross weight of the manipulator structure, aluminium sheet is being used. The other properties of aluminum sheets are to provide more strength, to retain and grip the all parts firmly with each other. A developed manipulator in this research is an articulated manipulator with 6 DOF along with revolute joints, including shoulder, elbow, wrist, and base. Here Servo motor is used in order to control the motion of manipulator, Main benefits of using servo motor over stepper and gear motor that it provides high torque and accurate rotation in a limited angle[14]. Servo motor operates by using the received signals through the microcontroller, it can also be programmed to meet the requirements [11].

All parts are cut and drilled properly according to the design template and all part are assembled. Figure 1.3 shows the final look of the robotic arm

Fig. 1.2. Complete structure of Manipulator

4. PHYSICAL MODEL OF THE KINEMATICS

A manipulator design relies on physical modeling of the kinematics, electronic controller for proper motion controlling, and software designs. The manipulator used here has a six axis. Three axis are major that related to the base, shoulder and elbow respectively are required to move the manipulator to the appropriate position, and three axis are smaller which are related to the roll, gripper spin and gripper pitch. This design has six revolute joints.

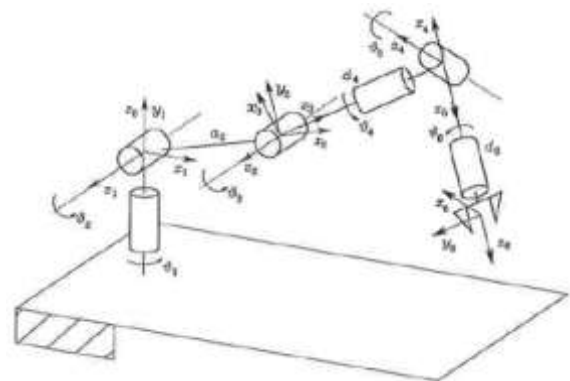Figure 1.4 shows the kinematic structure of the manipulator.

Fig. 1.3. Kinematic Structure of Manipulator courtesy to [16]

Table 1. D-H Parameters 6 DOF Robotic Arm

Frame	α_{i-1}	a_{i-1}	d_i	θ_i
0-1	0	0	0	θ_1
1-2	90	0	0	θ_2
2-3	0	L_3	0	θ_3
3-4	0	L_4	0	θ_4
4-5	-90	0	0	θ_5
5-6	90	0	0	θ_6

The forward kinematic equations of the manipulator shown in Figure 1.3. are as follows:

Symbol Terminologies:

α: Rotation about the z-axis.

d: Distance on the z-axis.

a: Joint offset.

θ: Joint twist.

Only 'θ' and 'd' are joint variables.

First we create the joint coordinate frames by the D-H convention. The link parameters are shown in the Table 1.

It is straightforward to compute the transformation matrices which is represented by 'T' as:

General Equation Matrix

$$T = \begin{bmatrix} Cos\theta_i & -Cosa_i Sin\theta_i & Sina_i Cos\theta_i & a_i Cos\theta_i \\ Sin\theta_i & -Cosa_i Cos\theta_i & -Sina_i Cos\theta_i & a_i Sin\theta_i \\ 0 & 0 & Cosa_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Therefore, the resulting matrix multiplication calculates the final transformation matrix, which gives the position and orientation of the robot's end effector with its base.

Joint transformation is defined as follows:

Base Joint:

$${}^{0}_{1}T = \begin{bmatrix} C\theta_1 & -S\theta_1 & 0 & 0 \\ S\theta_1 & C\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Shoulder Joint:

$${}^{1}_{2}T = \begin{bmatrix} C\theta_2 & -S\theta_2 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ S\theta_2 & C\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Elbow Joint:

$${}^{2}_{3}T = \begin{bmatrix} C\theta_3 & -S\theta_3 & 0 & L_3 \\ S\theta_3 & C\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Wrist Joint (rotation):

$${}^{3}_{4}T = \begin{bmatrix} C\theta_4 & -S\theta_4 & 0 & L_4 \\ S\theta_4 & C\theta_4 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Wrist Joint (roll):

$${}^{4}_{5}T = \begin{bmatrix} C\theta_5 & -S\theta_5 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ -S\theta_5 & -C\theta_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Gripper Joint:

$${}^{5}_{6}T = \begin{bmatrix} C\theta_5 & -S\theta_6 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ S\theta_6 & C\theta_6 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

It can be started with the base of the robot which is joint 1 and then it transform to the joint 2, then to the joint 3 until to the end effector of the robot.

Total transformation between the base of the robotic arm and the hand is

$${}^{1}_{6}T = {}^{1}_{2}T \times {}^{2}_{3}T \times {}^{3}_{4}T \times {}^{4}_{5}T \times {}^{5}_{6}T$$

By multiplying these transformation matrices we get final equation of transformation:

$${}^{1}_{6}T = \begin{bmatrix} R_{11} & R_{12} & R_{13} & R_{14} \\ R_{21} & R_{22} & R_{23} & R_{24} \\ R_{31} & R_{32} & R_{33} & R_{34} \\ R_{41} & R_{42} & R_{43} & R_{44} \end{bmatrix}$$

Where by multiplying, we get

$$R_{11} = -C_{12356} + C_{1256}S_{34} - C_{124}S_{34} - C_{123}S_{46}$$
$$+ C_{1356}S_{24} - C_{134}S_{26} + C_1 S_{2346} + C_{1456}S_{23} - C_6 S_{15} \rightarrow (1)$$

$$R_{12} = C_{135}S_{462} - C_{145}S_{362} + C_{16}S_{342} - C_{1346}S_2$$
$$- C_{1326}S_4 + C_{13245}S_6 - C_{12}S_{3456} - C_{1246}S_3 + S_{156} \rightarrow (2)$$

$$R_{13} = C_{134}S_{52} - C_{12}S_{2345} - C_{13}S_{245} + C_{14}S_{235} - C_5 S_1 \rightarrow (3)$$

$$\boldsymbol{R_{14} = C_{123}L_4 + C_{12}L_3 - C_1 S_{23}L_4} \rightarrow (4)$$

$$R_{21} = -C_{2356}S_1 + C_{256}S_{134} - C_{24}S_{136} - C_{23}S_{146}$$
$$+ C_{356}S_{124} - C_{34}S_{126} + S_{12346} + C_{456}S_{123} + C_{16}S_5 \rightarrow (5)$$

$$R_{22} = C_{35}S_{1246} - C_{45}S_{1362} + C_6 S_{1234} - C_{346}S_{12}$$
$$- C_{236}S_{14} + C_{2345}S_{16} - C_2 S_{13456} - C_{246}S_{13} - C_1 S_{56} \rightarrow (6)$$

$$R_{23} = C_{34}S_{152} - C_2 S_{1345} - C_3 S_{1245} + C_4 S_{1352} + C_{15} \rightarrow (7)$$

$$R_{24} = C_{23}S_1 L_4 + C_2 S_1 L_3 - S_{123}L_4 \rightarrow (8)$$

$$R_{31} = -C_{3456}S_2 + C_{56}S_{234} - C_3 S_{246}$$
$$- C_{2356}S_4 + C_{234}S_6 - C_2 S_{346} - C_{256}S_{234} \rightarrow (9)$$

$$R_{32} = -C_{36}S_{24} + C_{345}S_{26} - S_{23456} - C_{46}S_{23}$$
$$+ C_{235}S_{46} + C_{452}S_6 - C_{62}S_{34} + C_{3461} \rightarrow (10)$$

$$R_{33} = C_{234}S_5 - C_2 S_{2345} + C_{32}S_{45} + C_{42}S_{35} \rightarrow (11)$$

$$R_{34} = C_3 S_2 L_4 + S_2 L_3 + C_2 S_3 L_4 \rightarrow (12)$$

$$R_{41} = R_{42} = R_{43} = 0 \rightarrow (13)$$

$$R_{44} = 1 \rightarrow (14)$$

Where

$$C_{123456} = Cos\theta_1 Cos\theta_2 Cos\theta_3 Cos\theta_4 Cos\theta_5 Cos\theta_6$$

and so forth

$$S_{123456} = Sin\theta_1 Sin\theta_2 Sin\theta_3 Sin\theta_4 Sin\theta_5 Sin\theta_6$$

5.   IMPLEMENTATION

Fig. 1.5 shows the methodological approach of the proposed research work. It starts with designing of the robotic arm structure and computing for the torque of each motor in the arm. The microcontroller is chosen based on its data rate and how many I/O devices it can handle. The bluetooth module is chosen based on its maximum distance and its availability in the market.
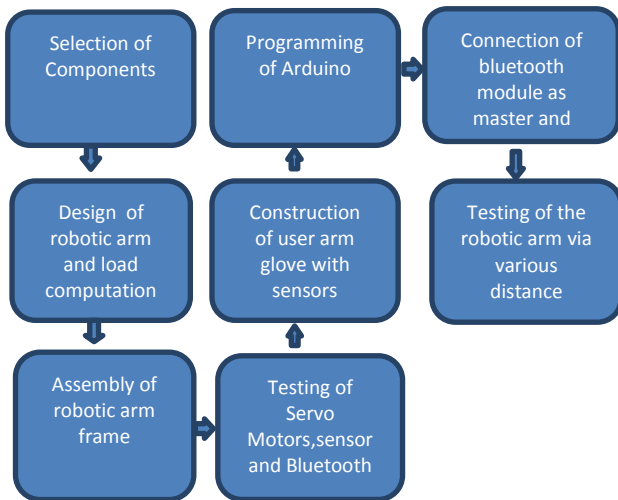

Fig. 1.4. Flow chart of the Methodology

The fabrication of the arm frame is done via Aluminium material. The robot arm is constructed by placing the servo motors to robotic arm joints and followed by the construction of user glove controller. Various input sensors are placed to glove controller and is set to specific position for corresponding human joints. The last integration of the system is the connection of bluetooth modules to the user and robot arm controller specifically Arduino modules. Lastly, software is developed for the mapping of input readings from sensors to corresponding servo movements. There are some robotic arm movements that a human cannot perform. Because of that, the glove controller and robotic arm is configured to corresponding translation of input movement to specific robot arm movement.

6.   SOFTWARE DEVELOPEMENT

The first process is acquisition of sensor readings from the glove controller. The first primary input device is the flex sensor. This sensor is connected in a voltage divider circuit. The output voltage reading is obtained by measuring the voltage from the second resistors that is connected in series to the flex sensor. This analog voltage is connected to the analog input port of the Arduino. The analog input ports on the Arduino have an analog to digital converter with 10 bits of resolution. An input ranging from 0V to 5V will be translated to integer values ranging from 0 to 1023. The short flex sensor will then have an integer value of 40 when bent and 90 when straightened. The long flex sensor will have an integer value of 150 when bent and 250 when straightened. The second primary input device is the MPU6050s which are inertial movement sensors that combine a 3-axis accelerometer and a 3-axis gyroscope.
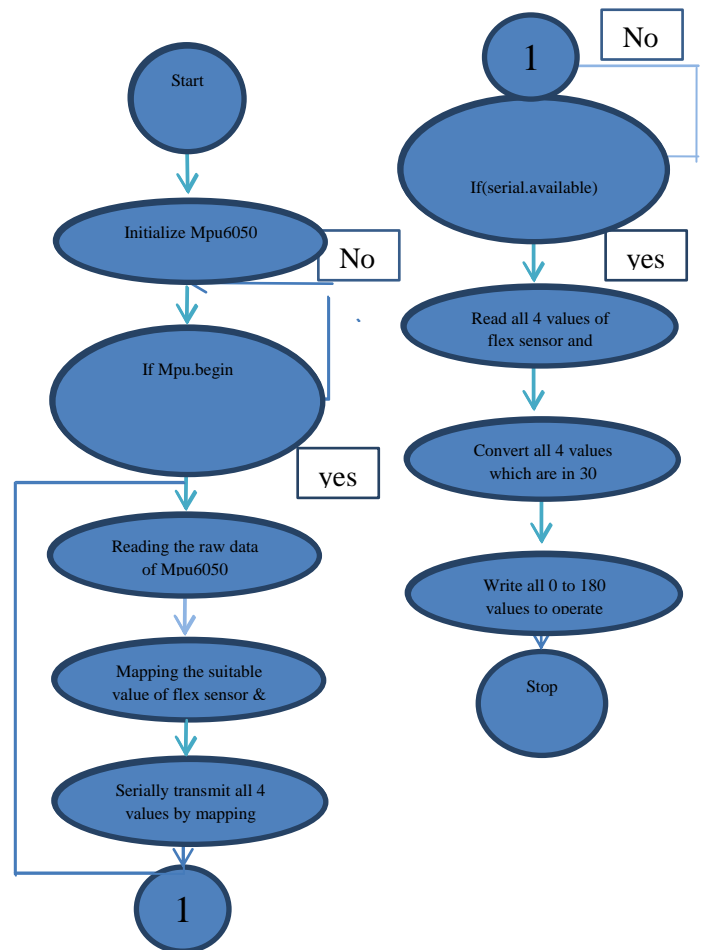

Fig. 1.5.Flow chart

7.   RESULTS AND DISCUSSION

Fig. 1.7. shows the various extended positions of robotic arm such as straight, upwards, downward and upward

left that will move as per the instructions of master glove controller till the front end of the workspace.

Fig. 1.6. Arm in various positions.

The Arduino microcontroller boards are used because of its number of inputs and outputs and ease of use in prototyping. The bluetooth module are used to provide wireless connection with low power consumption in short range applications. The MPU6050 sensors are used to provide the accelerometer and gyroscope data for the controller. The robotic arm is made from aluminum material to minimize the weight. The testing process for the robotic arm is divided in several parts that evaluate the individual movement of the robotic arm during operation. The final step in the testing process is the combination of all movements and evaluation of all factors that determine whether using tele-operation scheme the robotic arm can handle and transfer object at desired location. Fig.1.8. shows an example operation of transferring a glass of water from one position to a different position using the glove controller and robotic arm setup. The 2ft by 2ft workspace of the robotic arm setup, shown in Fig. 1.9.

Fig. 1.7 Overall Operation of Glove Controller and Robotic Arm Setup

Fig. 1.8 Workspace Area

The manipulator is designed in such a way that it focuses the criteria of obstacle avoidance for height movement, in this respect the manipulator is able to transfer the object from point A to B with obstacle for height movement that determined the ability of the arm to pick up objects at different elevations in the workspace. The next test is the transferring of object from point A to B with obstacle for lateral movement that determined the ability of the arm to avoid obstacle and reach short to long ranges. The next test is the pouring of chemicals to determine the ability of the arm to transfer liquids from one place to another. The last test of the system is the full operation of the arm that deals with all the specified tests above. The entire robotic arm and glove controller system was tested 10 times for manual test and 25 times of transferring tests. It was able to pass all the testing methods with at least 90% of success rate in each test. The maximum weight it can lift is 100 grams.

8. CONCLUSION

For the research to have a clear vision for its goal, it is stated from the start that there is a need in programming a machine that can operate from a distance. In the real world humans are more susceptible in accidents that happens in manufacturing factories that lacks superior machines. Humans mostly makes mistake when performing any task and when that happens it usually ends unpleasantly because it may result into injury and worst, taking a life. In order to make better machines it is considerable to develop a control that can effectively operate a machine. In this research, the machine is a robotic arm and to control it, sensors are used that are attached to the gloves. For a robotic arm to be controlled in a more efficient way, gestures can be used to give commands to the machine. The robotic arm imitates the gesture movement to perform a certain task. Movements are recognized by the sensors attached to the gloves. Sensors like the flex sensors are attached to the index finger and to the elbow because these parts of the arm only move in a single axis. The accelerometer and gyroscope sensors are attached to the wrist and to the side of the upper arm of the user to replicate its x, y, and z movement by the robotic wrist and the robotic arm. To operate at a distance an Bluetooth module can establish

connection from the robotic arm to the glove controller. This way the user of the robotic arm is much safer in transferring hazardous chemicals and other materials that are harmful to human health because of the fact that the arm can be operated from a distance. As long as the user has a clear view from the arm, it must be possible to operate it effectively. The risk for dealing dangerous materials is going to be decreased as long as the control of the arm is maintained to be accurate. In this research project, a wireless controlled robotic arm was constructed for handling hazardous chemicals. Six degrees of freedom (shoulder yaw, shoulder pitch, elbow pitch, wrist pitch, wrist roll and end effector grip) was integrated using servo motors. Two Arduino boards were utilized to recognize the user arm movements and to control the robotic arm. A complete wireless connection between the user controller and robotic arm module was established. A user glove was constructed that is equipped with multiple sensors that served as the robotic arm controller. A robotic arm with six degrees of freedom was controlled through various sensors. The servo mapping was able to generate the correct mapped servo values coming from the sensor readings and output it to robotic arms joints. This mapping process was able to translate the orientation of shoulder pitch, shoulder yaw, elbow, wrist pitch, wrist yaw, and gripper of the user. The range test was able to establish a good connection that varies within a range of -10dBm. The conversion of the robot arm controller was accurate since it was able meet the maximum distance error of 2cm for every transferring operation. It was able to avoid any obstacle present in the workspace, and was able to perform the pouring of chemical accurately. Overall, the robotic arm was able to perform the user movement and obtained a success rate of at least 90% in each test.

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