International Journal of Automation, Mechatronics & Robotics– IJAMR
Volume 1 : Issue 3 [ISSN 2374 – 1546]
Publication Date : 30 September, 2014

Development of a Contact Based Human Arm Motion Adaptation System

Varun Nalam,Dr.P.V.Manivannan

***Abstract*—This paper presents the development of a device which can analyze and replicate Human motion on different robotic devices. The system uses contact based sensors which gather data related to position, velocity and acceleration of different joints of human arm and transmit it to a central processor which adapts the data to perform necessary motion on the robot. The system can be used in daily activities and industry for training robots without much knowledge.**

***Keywords*—Motion Adaptation, Control of Robotic Arms, Wearable Control Devices**

1. Introduction

Robotic arms are seen as an increasingly ideal solutions for a variety of tasks in the industry such as welding, painting, assembly, pick and place, product inspection, and testing. Robotic arms possess the ability to accomplish the tasks with high endurance, speed, and precision.It is observed that inspite of the huge advantages associated with application of Robotic Arms in industry, they are not utilized to the maximum potential. The main reason for opposition to Robotic Arms is due to lack of suitable methods for worker robot interaction. The current methods of interaction is through a low level interface in which the robot can be given instruction through commands or teaching using a joystick. The existing methods require high skill and technical knowledge in order to perform simple actions. In this paper ,we discuss our work in developing better control methods for Human Machine Interaction which can be practically implemented.

Human Robot Interaction is a critical task and has been widely researched upon. Some of the previous attempts have tried to address the problem in different methods. The first approach as followed in [1] is parsing natural language commands to a robot control system. The approach uses speech based control of robots. The system would be effective only in noise free environments and would require high amount of signal processing. Considering that most of the industrial plants are not noise free, implementation of such a system in an industry would be a challenge.

Model mediated Teleoperation is another method for controlling robots. In this method, there exists a master model which is structurally similar to that of the slave robot. The slave robot is controlled by motion of the master model. The main advantage of the system is that Haptic feedback can be implemented in the system[2] ,making the control more intuitive. The master has to be structurally similar to the slave which makes the system less adaptable to different robots.

In [3],Van Den Bergh et al introduce a real time Hand Gesture Recognition using Kinect sensor and processing the images. A camera along with a depth sensor is used to recognize different gestures and control the robot based on the gestures. The system is limited by the field of view of the camera and the lighting conditions. Gesture recognition with fundamental principal component analysis has been implemented in [4], but would suffer from similar issues.

The main considerations that were taken into account while designing the system were as follows. The system should be Environmentally independent. It should work effectively in different industrial sites irrespective of location, layout and time. It should be easy to use and adaptable for different users as well as robots. In addition, It should have a very low set up and calibration time. Taking into account all the given considerations, A device that can be worn on the human arm which can record and analyze position, velocity and acceleration of each element of the arm has been found to be the most effective solution. The data so obtained gives the position of the desired end effector based on the position of the palm or the fingertips. Based on the given position of the end effector, the given robot can be set to its needed configuration. Thus the system can be used to control a robotic arm irrespective of the specification of the arm. This paper presents the development of such a system and its implementation on a table top Robotic Arm.

Human Arm: To design a system that can effectively analyze the motion of a human arm,The structure and mechanics of the arm movement are studied. In addition ,The constraints and relationships between joints of the arm have been obtained from the studies as reported in [4].The constraints have been used to to select suitable sensors that can acquire the data necesary to obtain the information required for the robot to execute the task.The relationships between different joints have been utilized to reduce the number of sensors that are to be placed on the human arm.

Varun Nalam
Indian Institute of Technology,Madras,India

Dr.P.V.Manivannan
Indian Institute of Technology,Madras.India

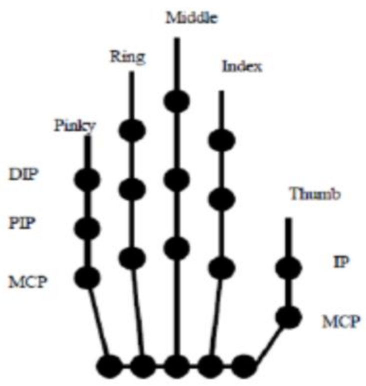

Fig 1. Joint Notations of Wrist[4]

$$0° < \theta_{elbow} < 150° \quad (1)$$

$$0° < \theta_{MCP} < 90° \quad (2)$$

$$0 < \theta_{PIP} < 110° \quad (3)$$

$$\theta_{DIP} = \frac{2}{3}\theta_{PIP} \quad (4)$$

2. System Design

The system proposed in this paper controls a robot based on analyzing the arm motion of the controller and adapting the motion to a robotic arm. The position and orientation of the arm is determined by obtaining the angles of each joint of the arm . The system utilizes two kinds of sensors ,flex sensors and Inertial Measurement Units, to acquire joint angles.. The flex sensor behaves as a resistor whose resistance changes linearly[5] based on the amount of bend. The voltage across the sensor is converted to digital data using an A/D converter. The sensors are placed across the fingers. The IMU provides the orientation of upper arm and palm.

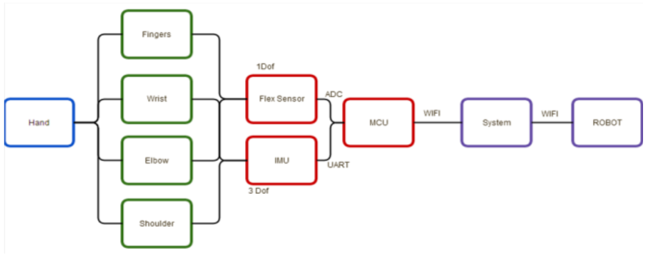

Fig2. Schematic Representation of the system

An embedded system has been designed to acquire and convert the signals from the sensors into data.. An LPC 2148 microcontroller is found to satisfy the requirements for the system and is chosen as the embedded processor. A 10 Bit ADC channel is used to obtain data from the Flex sensors. A linear model for estimating angle is developed by comparing the minimum and maximum values of the ADC channel with the human arm .Noise due to disturbances is reduced by suitable exponential smoothening. The characters from the IMU are converted to vector indices and are scaled suitably. The angles hence obtained is transmitted to the central processor through Wi-Fi at a rate of 60Hz. The kinematics of palm and each of the fingers have been calculated by forward kinematic analysis based on the joint angles by the central processor. The kinematic data can then be used in simulation, virtual reality and controlling robotic arms.

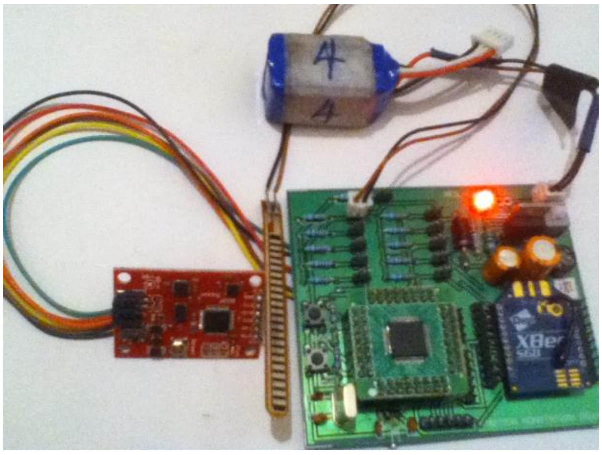

Fig 3. The Embedded controller with IMU and Flex sensor

3. Robotic Arm Specifications:

The robotic arm used is AL5C, which manufactured by Lynx Motion. It is a 5 DoF robot consisting of Servo motors. The shoulder of the robot has two motors to rotate the arm in pitch and yaw motions. The roll motion present in the human arm is absent in the arm. The elbow has one motor enabling flexion and extension of the elbow joint. The wrist has two motors for pitch and roll motions. The robot consists of a sixth motor which is used for opening and closing of the gripper.

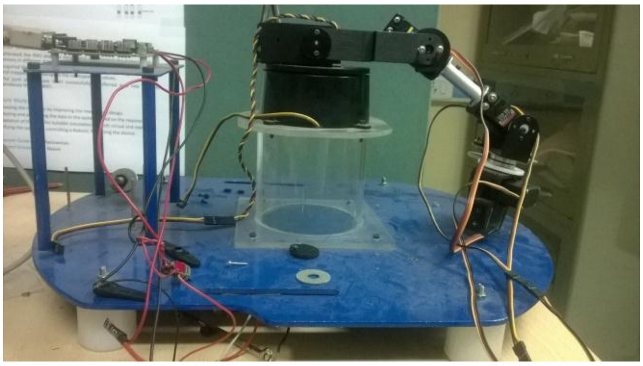

Fig4. The AL5C robotic ARM

The robot is controlled by a SSC 32 servo control board controlled by an ATMEL Atmega 168.The board can control the servo motors at 1µs resolution which is an equivalent of 0.09°.The controller communicates with the central processor through serial communication at a Baud Rate of 9600 Baud/sec. The servos are connected to the controller such that The least significant pin of the controller goes to the base motor and each successive pin is assigned to the immediately adjacent motor. Each of the servos can rotate by an angle of 180°.

Fig5. SSC 32 Controller

The protocol for the commands as defined by the controller is given as

 # (pin number) P(position of motor) S(speed of motor)

where, pin number is the number assigned to the pin to which the particular motor is attached. The position of motor is a number in the range of [500,2500] which maps linearly to [-90°,90°].The speed of the motor is given as a number(X) which specifies the speed to be X*0.09°/second.

4. Kinematic Analysis for Motion Analysis:

The aim of the system is to adapt the motion of a Human Arm to different systems irrespective of the structural differences. In this particular experiment, The motion of a Human arm, which is a 7 DoF system is adapted to a 5 DoF system. In order to achieve the required coordination, forward kinematic analysis of the Human Arm is analyzed to obtain the position and orientation of the palm and followed by the reverse kinematic analysis of the Robot. In order to suit all the practical robots and simplify the calculations, the arm is considered to be a combination of two different systems. The shoulder to wrist is considered one part and the hand is considered to be the other part. The robot is also divided into the arm and the gripper.

The forward kinematic analysis of the arm gives the following relationship between the angles obtained by the sensors and the position of the wrist.

$$\begin{pmatrix} x_{wrist} \\ y_{wrist} \\ z_{wrist} \end{pmatrix} = \begin{pmatrix} \cos(yaw) & \sin(yaw) & 0 & \cos(pitch) & 0 & -\sin(pitch) \\ -\sin(yaw) & \cos(yaw) & 0 * & 0 & 1 & 0 \\ 0 & 0 & 1 & \sin(pitch) & 0 & \cos(pitch) \end{pmatrix} * \begin{pmatrix} x_e^w \\ y_e^w \\ z_e^w \end{pmatrix} + \begin{pmatrix} x_{elbow} \\ y_{elbow} \\ z_{elbow} \end{pmatrix} \quad (5)$$

where

$$\begin{pmatrix} x_e^w \\ y_e^w \\ z_e^w \end{pmatrix} = \begin{pmatrix} L_{forearm} * \cos(\theta_{elbow}) \\ L_{forearm} * \sin(\theta_{elbow}) * \cos(roll) \\ L_{forearm} * \sin(\theta_{elbow}) * \sin(roll) \end{pmatrix} \quad (6)$$

and

$$\begin{pmatrix} x_{elbow} \\ y_{elbow} \\ z_{elbow} \end{pmatrix} = L_{upperarm} \begin{pmatrix} x \\ y \\ z \end{pmatrix} \quad (7)$$

The pitch roll and yaw angles are obtained from the IMU attached to the shoulder and the direction vectors are calculated from the angles.

For the robotic arm, the end effector position is obtained by scaling the position of wrist suitably.

$$\begin{pmatrix} x_{endeff} \\ y_{endeff} \\ z_{endeff} \end{pmatrix} = K \begin{pmatrix} x_{wrist} \\ y_{wrist} \\ z_{wrist} \end{pmatrix} \quad (8)$$

where K is the scaling constant which is ratio of robot arm length to the human arm length.

International Journal of Automation, Mechatronics & Robotics– IJAMR
Volume 1 : Issue 3 [ISSN 2374 – 1546]
Publication Date : 30 September, 2014

The relation ship between end effector position and angles is given by

$$\begin{pmatrix} x_{endeff} \\ y_{endeff} \\ z_{endeff} \end{pmatrix} = \begin{pmatrix} (L_1Cos(\theta_1) + L_2Cos(\theta_2)) * Cos(\theta_0) \\ (L_1Cos(\theta_1) + L_2Cos(\theta_2)) * Sin(\theta_0) \\ L_1Sin(\theta_1) + L_2Sin(\theta_2) \end{pmatrix} \tag{9}$$

such that

$$\min \sum \nabla \theta, \forall (\theta = \theta_0, \theta_1, \theta_2) \tag{10}$$

where L_1,L_2 are the arm lengths.

The position of each servo motor is determined by:

$$P_X = 500 + \frac{2000}{180}(\theta_X + 90) \tag{11}$$

The above relations selects the feasible values for all the servo joint angles and prevents multiple solutions for angles.The speed of each motor can be found as

$$\begin{pmatrix} Vx_{endeff} \\ Vy_{endeff} \\ Vz_{endeff} \end{pmatrix} = K \begin{pmatrix} Vx_{wrist} \\ Vy_{wrist} \\ Vz_{wrist} \end{pmatrix} \tag{12}$$

and

$$\begin{pmatrix} Vx_{endeff} \\ Vy_{endeff} \\ Vz_{endeff} \end{pmatrix} = \begin{pmatrix} (L_1Cos(\theta_1) + L_2Cos(\theta_2)) * Sin(\theta_0)(\frac{d\theta_0}{dt}) + (L_1Sin(\theta_1)(\frac{d\theta_1}{dt}) + L_2Sin(\theta_2)(\frac{d\theta_1}{dt})) * Cos(\theta_0) \\ (-)(L_1Cos(\theta_1) + L_2Cos(\theta_2)) * Cos(\theta_0)(\frac{d\theta_0}{dt}) + (L_1Sin(\theta_1)(\frac{d\theta_1}{dt}) + L_2Sin(\theta_2)(\frac{d\theta_1}{dt})) * Sin(\theta_0) \\ -L_1Cos(\theta_1)(\frac{d\theta_1}{dt}) - L_2Cos(\theta_2)(\frac{d\theta_2}{dt}) \end{pmatrix} \tag{13}$$

Once the rotational velocities of each joint are found,The speed of the motor can be sent to the controller.The robot can thus mimic human arm motion.The same procedure can be followed from the wrist to finger but in most cases, due to presence of very simple designs for grippers,the situation turnss into a one one one mapping.

5. Experimental Validation:

The main function of the device is to track the motion of a human arm to be used for controlling a Robot. In order to assess the effectiveness of the system, the readings obtained from the system are compared with different motion tracker systems. A C# application which stores the data and plots the motion of the end effector is developed for visual representation. A 2-D tracker is considered for comparing the output of the device. The device is worn by the test subject and the tracker is operated with the arm having the device. The data obtained from the device and the tracker are compared.Once the system is validated to give the required outputs,The readings from the sensors are compared to the values of angles as sent in the commands.Since the robot has already been tested and found to be following the commands,the relationship between the angles from the arm and the commands

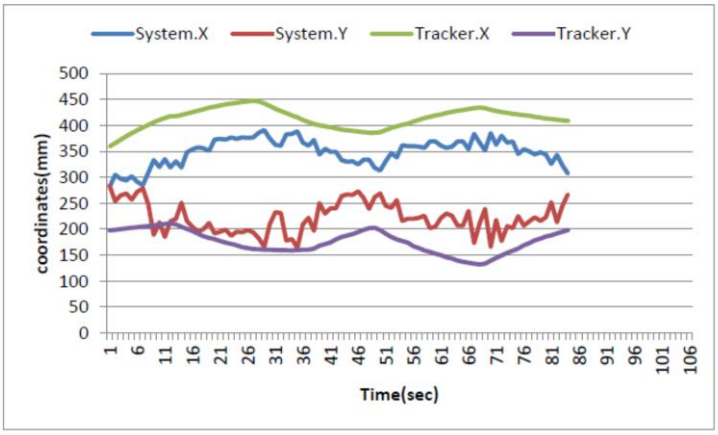

Fig6. Device and Tracker position Vs Time

The error in values of the motion tracker to that as recorded by the system is found to be 7%. The relationship between the Direction vector values found using the sensors and the position command as sent to the bot is shown in Fig.7 and Fig.8.

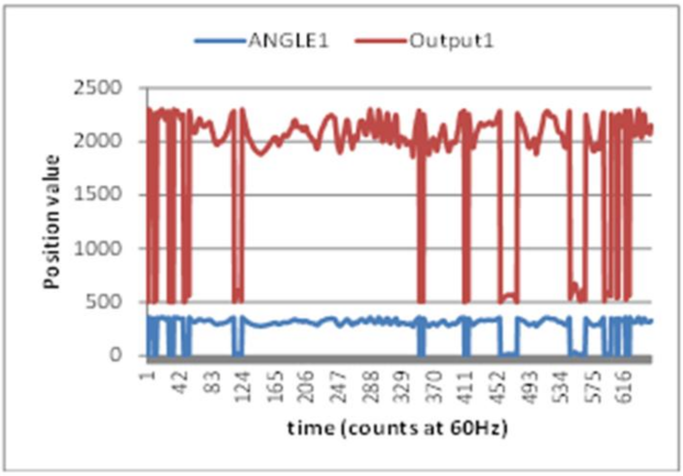

Fig7. Direction vector from IMU and command to servo wrt time

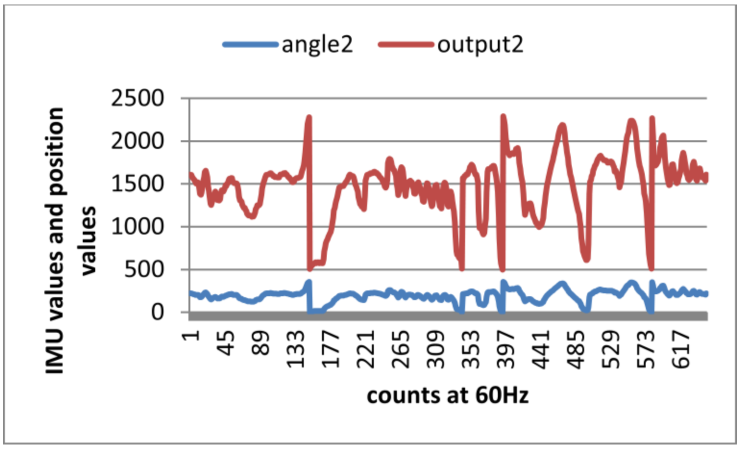

Fig8. Direction vector from IMU and command to servo wrt time

6. Conclusion

In this paper we presented a contact based device for adapting human arm motion to be implemented in controlling and training Robots. The system obtains data from IMU and flex sensors to evaluate joint angles and derives joint positions, velocities and accelerations. The system has been tested against motion tracker systems and is found to give accurate results. A number of contribution have been made. A system that can enable common people to control robots without any training or knowledge has been designed.The system so designed in environmentally independent ,flexible and portable.The system is also intuitive to use making it easier for work men in industries to work more effeciently with new technologies.

References

[1] Learning to Parse Natural Language Commands to a Robot Control System Cynthia Matuszek, Evan Herbst, Luke Zettlemoyer, Dieter Fox

[2] Mitra, P., and Niemeyer, G., 2008, "Model Mediated Telemanipulation", *Int. Journal of Robotics Research.*

[3] Van den Bergh M. *et al*, (2011). "Real-time 3D Hand Gesture Interaction with a Robot for Understanding Directions from Humans". In IEEE International Symposium on Robot and Human Interactive Communication (Ro-Man) (357-362).

[4]Yi-Ru Chen, Cheng-Ming Huang, Li-Chen Fu, "Visual Tracking of Human Head and Arms with a Single Camera," Proc. of 2010 IEEE/RSJ

[5]J. Aleotti, S. Caselli, Functional Principal Component Analysis for Recognition of Arm Gestures and Humanoid Imitation, International Journal of Humanoid Robotics, Volume 10, Issue 04, December 2013.

[6] John Lin, Ying Wu, and Thomas S. Huang, ``Modeling the Constraints of Human Hand Motion," in Proc. of IEEE Human Motion Workshop (HUMO00), 2000, pp. 121-126.

[7] Development of a Contact Based Human Arm Motion Analysis system for Virtual Reality applications -Varun Nalam, Dr.Pv.Manivannan(2014)