Gyro-Accelerometer based control of a robotic Arm using AVR Microcontroller

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***Abstract*—Most of the robotic arm is controlled by using accelerometer sensor with an artificial intelligent algorithm. This paper is proposed a gesture recognition based 6DOF robotic arm controller using gyro-meter with accelerometer to improve the stability and to detect the rotational gesture of human arm. The arm also has the capability to grab object. To find out the angular position of an object, it is easiest way to fuse 3axis accelerometer and 3axis gyro-meter sensor. A low cost MEMs chip (integrated 3-axis accelerometer and 3-axis gyro-meter) used to detect human arm gesture as well as its angular position. Here gyro gives gesture orientation data to determine dynamic gesture behavior. An artificial algorithm used to evaluate all gesture data which helps to train the robotic arm. The most popular Kalman filter used to find out the exact position of human arm more accurately. The communication between human hand and robotic arm interaction has been established wirelessly over *IEEE* standard Zigbee protocol interface. The result is that the arm's movement is synchronous with human arm gesture i.e. like a shadow mode. The artificial arm response time is very fast with human arm gesture. The control strategy is easier than other systems like joystick control and this system applicable for industrial purposes. This robotic arm has been developed in Arduino IDE platform and it is also applicable in different platform like embedded, intelligent peripheral and so on. In conclusion, some tests has been performed with this robotic arm and the results are discussed.**

Keywords—gesture; accelerometer; gyrometer; servo; arduino uno; interface; MEMs; arm; DOF; DMP; automation; sensor etc.

I. Introduction

Control a robotic arm is still hassle and time consuming in many industrial section. Many universities and researchers works in this field to make its simple and smarter (or skilled). The unique phase is human-robot interaction. This interaction mode varies in different purposes. Potential application range from the pure athletic application of Real Steel (Hollywood robotic boxing movie) [9] or the sci-fi television channels Robot Combat League to augmenting traditional robotic surgery (Da Vinci system) etc.

In this field many research works for recognizing human gestures, recurring to vision based system [1],[2], motion capturing sensors [3] or using finger gesture recognition systems based on active tracking mechanisms [4]. Also many user interface available such as icon-based programming, color touch screens, 3D joystick, 3D or 6D mouse [8] or wireless artificial neural network system [5],[6],[7]. Motion capturing system is very popular because of simple way to control a robotic arm with accurately and efficiently. Accelerometer and gyro-meter sensor chip makes this operation very accurate and efficient. MEMs gyros make motion analysis of a human movement directly programmable into an embedded robotic control system very easily.

However, in this paper is proposed gesture recognition based shadow mode robotic arm. This arm has 6DOF (degrees of freedom). MEMs 3-axis accelerometer and 3-axis gyro-meter used to detect users current position i.e. gesture and posture as well as angular position. An artificial algorithm used to recognize data from sensors, then processed signal sends to control unit over zig-bee protocol. Finally, results and performance of proposed design presented and discussed.

A. Why Gesture based robotic arm is needed

At present day human race is becoming complex and difficult. In this situation most of cases human completed their task by using robotics system. Robotic controlling system varies in different cases. Gesture based control is unique phase and most popular way. It's performs task with users gesture. That's why this process is very easy, time saving and efficient. Gesture based negative shadow mode arm may helpful for hand missing autistic person. Not only for autistic person but also helpful for industrial automations which saves controlling complexity and time. Gesture based arm also helpful on rescue operations. The most unique feature is its synchronous movement with human hand gesture.

B. Related Works

We know that gesture based human-robot interaction is most popular in present decade. So this system is not new today but there control strategy is different. Some researchers control this system using artificial neural network and back propagation algorithm system [5]. Most of the cases used 3-axis accelerometer. Others used 3 or more accelerometer and gyro-meter sensors.

978-1-4799-6062-0/14/$31.00©2014 IEEE

II. Proposed Design

A. System Overview

The whole system divided into two sections. One is data transmitting section and another is data receiving section. These two systems are interfaced with xbee protocol. Here we used hand made artificial robotic arm which contains 180degree rotation angle. We also use MPU-6050 IMU board. The MPU-6050 devices combine a 3-axis gyroscope and a 3-axis accelerometer on the same silicon die together with an onboard Digital Motion Processor (DMP) capable of processing complex 9-axis Motion Fusion algorithms. The parts feature a user-programmable gyro full-scale range of ±250, ±500, ±1000, and ±2000°/sec (dps) and a user-programmable accelerometer full-scale range of $\pm 2g$, $\pm 4g$, $\pm 8g$, and $\pm 16g$[10]. It's detects hand gesture and send data to main board for processing. With the help of complex geometry we calculate the proper angle of movement of hand gesture in main board. Then these data sends to receiving section by xbee module. Transmitted data received by receiving xbee module and processed by receiving sections main board. Then servo moves with main board instruction which is received from transmitter section. The main board for processing unit used Arduino Uno (contains ATmega microcontroller) [11],[12].

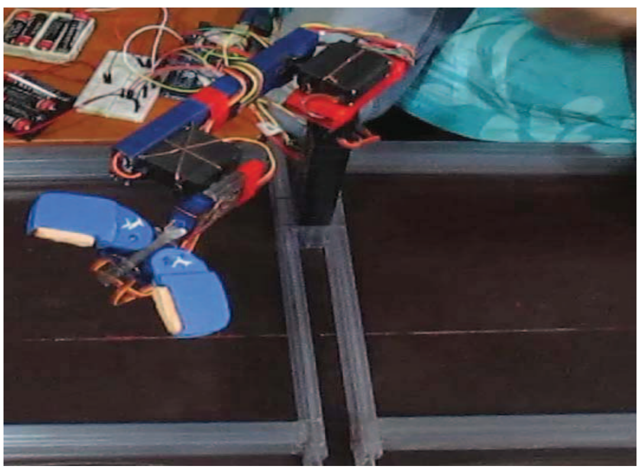

Fig. 1. Robotic arm controlled by human hand gesture.

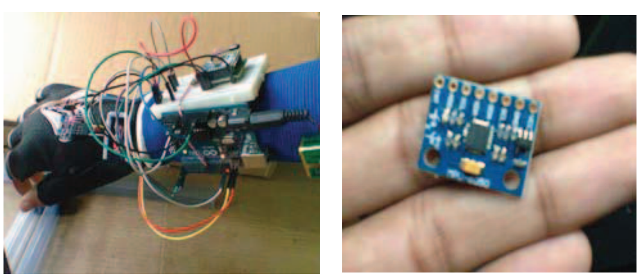

Fig. 2. Wireless data transmitting section with Xbee module. Right figure shows MPU5060 IMU board. Total system is able to transmit hand gesture data wirelessly.

B. Block Diagram

At first sensor read data from hand gesture then it sends to main board for calculation. Then it sends over xbee module to receiving end. Receiver module's receive data and then transfer it to main board. The main board utilizes these data for movement of servo motor. This whole system can express as follows:

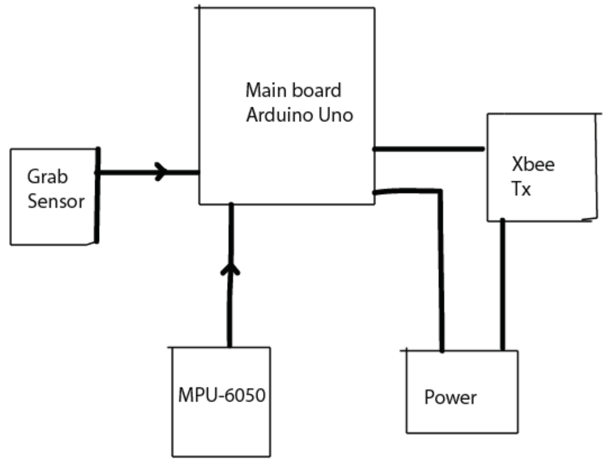

Fig. 3. Block Diagram of hand gesture transmitting section.

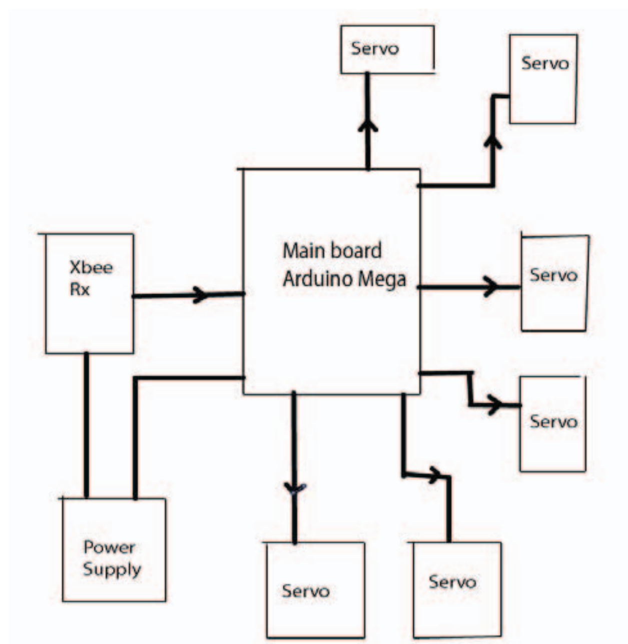

Fig. 4. Block Diagram of hand gesture data receiving section. This system also control the robotic arm.

C. Methodology

The sensor board i.e. MPU-6050 placed horizontally on top of a hand glove. It is also remarkable that sensor placed on metacarpal portion. When hand moved in different angle than sensor detect its acceleration as a raw value. At a time sensor detects gyros raw value. These values fed by main board.

Now its time to process raw data converts its meaningful angle. For processing purpose arduino-uno board used which has Atmega328P microcontroller and 16MHz crystal oscillator. Different library function and geometrical calculation used to find out exact angle of gesture and behavior. By combining accelerometer data and gyro data we calculate proper angle along a specific axis. Normal calculation angle is little bit deviate with world frame and time. To solve this problem we use most popular Kalman filter. This filter re-calculate angle each time to get real time exact angle and compare with world frame. Basically this calculated angle range is 0-360 degree. Our motor movement range is 0-180 degrees, that's why to maintain synchronous movement 0-360 degrees scaled down as 0-180 degree by movement mapping in algorithm section.

Now it's a challenge sending calculated data wirelessly. In this system we use IEEE standard series2 xbee module. We selects AT mode and high baud rate for better performance. We prefer AT mode because we transfer data in serially to avoid more complexity also.

At receiving section transmitted data received by another xbee module. Then data sends to main board. Main board contains mapping instruction which help to move servos with proper angle which sends from transmitter section. In this way we get a synchronous movement with hand gesture.

III. OPERATION STRATEGY

A. Arm Movement Control

For synchronous movement of a robotic arm we need to consider an ideal frame containing (X, Y, Z) axis. In our experiment we considered world frame as ideal and then calculate our sensor displacement along with (X, Y, Z) axis. Then we mapped it with servo angle.

The arm consists of six servo motor. Each motor can move 0-180 degree. Motors are specified for definite axis rotation. That means x-axis data used to control a motor which set for x-axis rotation. As a result arm move along x-axis. In this way another two motors for Y and Z axis movement. Their control strategy is in same way. But our designed arm has two motors and they combine along X-axis movement. Two motors combined for grab purpose. To perform grab operation a liner sensor used. These values are also sends over xbee protocol serially.

A tricky method used for grab control. We mapped sensor value with servo movement angle. These two servos relative movement are opposite. Suppose if one servo rotates from 0-180 degree then another servo rotates from 180-0 degree at a time for same sensor value. Hence its grab an object easily. We used highest baud rate of xbee module. That's why movement of arm is synchronous with human arm gesture.

B. Calculation

It is important term to find out displacement angle of human hand. The sensor provides us some raw value. Then we can transform it with geometrical calculation.

Let, acceleration component denote as x_a , y_a and z_a

And gyro component denote as x_g , y_g and z_g

If R vector on the XYZ axes. Please notice the following relation:

$$R^2 \approx R_x^2 + R_y^2 + R_z^2$$

Since the tilt of the X-axis actually shows rotation around the Y-axis, and the angling of the Y-axis shows (negative) rotation around the X-axis.

The rotation around the X-axis (φ)

$$\varphi \approx \tan^{-1}\left(\frac{y_a}{\sqrt{x_a^2 + z_a^2}}\right)$$

The rotation around the Y-axis (ρ)

$$\rho \approx \tan^{-1}\left(\frac{x_a}{\sqrt{y_a^2 + z_a^2}}\right)$$

If the Z-axis is aligned along the gravitational acceleration vector, then it is impossible to compute rotation around the Z-axis from the accelerometer. That's why need gyro values to find out Z rotational angle.

$$GyroX_{rate} = gyroX / 131.0$$
$$GyroY_{rate} = -(gyroY / 131.0)$$

Where 131 is constant.

The rotational angle along with Z-axis can be define as

$$gyro\_angle\_z = (gyroZ_{rate} \times dt) + lastZ_{angle}$$

$$kalAngleX = (accX_{angle}, gyroX_{rate})$$

$$kalAngleY = (accY_{angle}, gyroY_{rate})$$

All above equations are generalized form and shows the calculation methodology. To perform actual Kalman calculation library function needed.

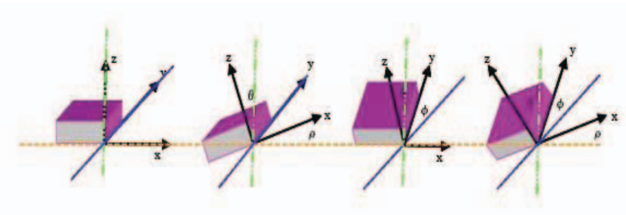

Fig. 5. Geometry of angle calculation using accelerometer and gyrometer.

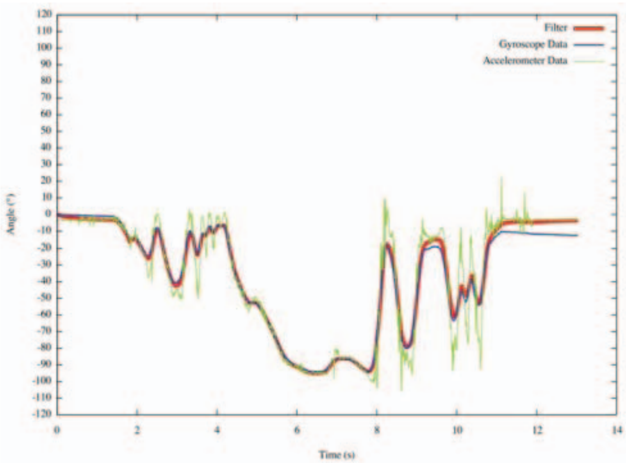

Fig. 6. Accelerometer data, Gyroscope data and Filtered data.

C. Mode of Operation

Robotic arm moves along X, Y, Z axis. When it moves along X rotation axis that means acceleration detects along Y axis. In the other hand when it moves along Y rotational axis that means acceleration detects along X axis. Z rotational axis determined with combining accelero and gyro values. When sensor rotates along x-axis then acceleration raw value of x component varies from –X to +X, in this case Y and Z component zero. When sensor rotates along Y-axis then acceleration raw value of Y component varies form –Y to +Y, in this case X and Z component zero. Z rotations get from combination of raw acceleration and gyro value. So we can conclude robot operation mode as follows- if accelerometer held horizontally then an acceleration reported along Z axis; $z_a \approx g$, $X_a \approx 0, Y_a \approx 0$. When rotate along Y axis; $X_a \approx -g, Y_a \approx 0, Z_a \approx 0$. When rotate along X axis; $X_a \approx g, Y_a \approx 0, Z_a \approx 0$. But we cannot determine easily Z rotational axis. That's why gyro-meter used to find out gyro rate and then we can calculate Z rotational angle.

We know that every moving or static body normally placed on ground wall and act as a gravitational force. To understand this term let consider a fig.7 shown below

Here we see that each axis has two component + and - . If we take our model and put it on Earth the ball will fall on the Z- wall and will apply a force of 1g on the bottom wall.

If the sensor move along Y rotational axis then friction force generate from –X to +X axis; in this case arm move along with Y rotational axis, because the control strategy mapped in this way. When sensor move along with X rotational axis then friction force varies form –Y to +Y axis; in this case robot move along X rotational axis.

It is remarkable that we cannot get Z rotational axis with the help of accelerometer. To calculate this we need rate of change degree that means gyro rate. By combining accelerometer and gyro rate we can calculate Z rotational angle. This process is also stable and accurate than other strategy.

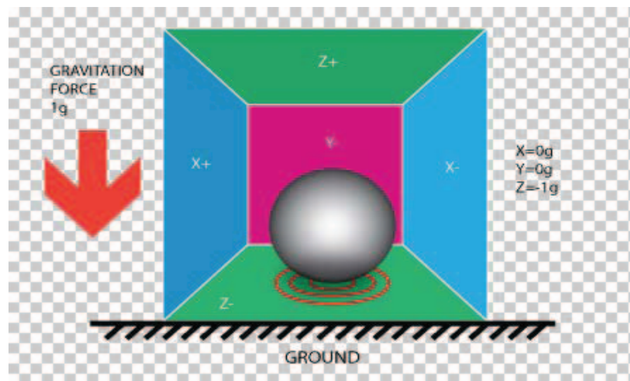

Fig. 7. Accelerometer and Gyrometer internal control strategy.

IV. Proposed Algorithm

The total algorithm system is divided into two main parts. One is transmitting operation and another is receiving operation. The internal data acquisition and processing algorithm can be given as follows

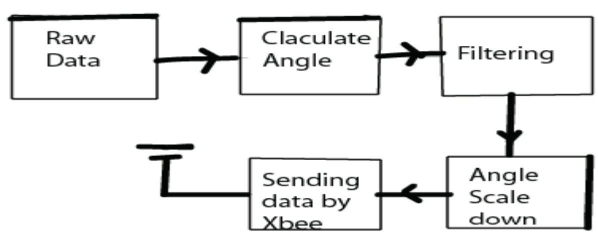

Fig. 8. Algorithm of internal calculation of transmitter section.

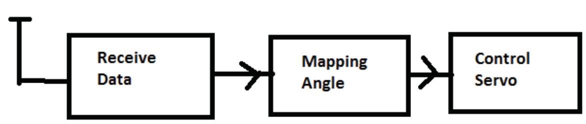

Fig. 9. Algorithm of internal processing of receiving section.

V. Designed Hardware And Result

A proper hardware and software for the operation of this robotic arm has been designed and given below.

A. Total Hardware Structure

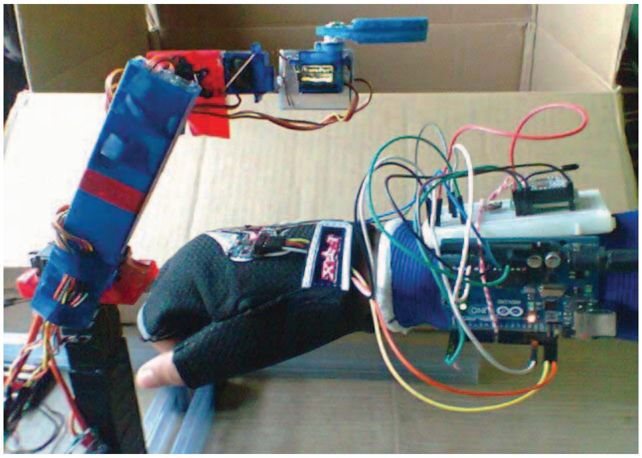

Fig. 10. Total hardware of transmitter and receiver section of proposed design.

B. Result

In this system an important issue is its time response and stability. In our experiment we used accelerometer and gyro-meter to stable the movement of arm. Its movement is synchronous with human hand gesture. Its response is also first as we use powerful Zigbee protocol for transferring and receiving data. The synchronization data given below.

TABLE I. Gesture Recognition Data

Observation No.	Along X-axis (deg.)		Along Y-axis (deg.)		Along Z-axis (deg.)	
	Sensor	***Arm***	***Sensor***	***Arm***	***Sensor***	***Arm***
Human1	45	42	50	52	90	91
Human2	30	33	40	41	75	72
Human3	150	155	98	100	175	172

X-axis recognition rate: 96.33%

Y-axis recognition rate: 98.33%

Z-axis recognition rate: 97.67%

Recognition rate for human1: 98.00%

Recognition rate for human2: 97.67%

Recognition rate for human3: 96.67%

Over all recognition rate: 97.45%

VI. Conclusion and Future work

Our experimental design is prototype. Here we try to improve its stability and first response. The control strategy is synchronous with sensor movement that means with human arm gesture. In different research paper proposed many design in which neural network used to find out Z-axis rotational angle. But in this system we used just a 3-axis gyro-meter which helps to find out Z-axis rotational angle and makes the control system easier. Gyro system makes this system more stable and synchronous response.

By applying this prototype methodology we can control industrial robotic arm easily. Using wireless camera module and powerful protocol then its may be controllable from far distance away also without face to face presence of human user.

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