HUMAN - COMPUTER INTERACTION BASED ON IMU SENSORS

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Abstract - In this paper we introduce how to establish, collect and process data from IMU sensors. The sensor we use here is MPU 6050. Data received from the sensor is transmitted to the microcontroller through I2C protocol where data will be filtered through a smooth filter. Data from MPU6050 is 6 axis data consisting of acceleration meter and gyroscope which after being filtered and reducing noise at high frequency will be transmitted to computer through UART protocol. On the computer, we build programs in C# to receive data from the microcontroller and process data to send dummy command to control application on computer. From characteristics of data about axis, we can build a state stable algorithm, determine movement trajectory to control the state of the computer mouse [2], [3], which facilitates interaction between people and computers.

Key words - IMU sensor; smooth filter; computer-mouse for the disabled; digital motion processor-DMP; UART;

1. Introduction

Today, the development of electronic devices is going fast, which requires more information exchange and the interaction between humans and machines is not limited to mechanical motion (button,…). Electronic devices can recognize actions, gestures of humans, then process, encrypt and transmit them to computer in the form of digital data or dummy command. Some devices can be used as acceleration sensors, ultrasonic transceivers, infrared sensors… In this paper, we use acceleration sensors MPU to get the data to perform communication in computer.

Acceleration sensors have been widely used in recent years. Some devices such as: smart phones, aircraft controls, gaming equipment… are using acceleration sensors. Using accelerometer with 1 axis, we can make the system self-balance; with 3 axes (acceleration) we can control the mouse; with 6 axes (acceleration + gyroscope) we can determine angle 3 axes to control planes, play games or motion tracking. Using acceleration sensors we can detect motion and hand gestures (left move, right move, left rotate, right rotate…). Using parameter of 6 axes to detect hand states, we can use those data to control the application (mouse, plane…).

Inertial measurement unit (IMU):

Inertial measurement unit (IMU) is integrated devices which consists of two types of sensor: accelerometer sensor and gyro sensor, placed on three perpendicular axes to track the position and orientation. IMU combines the advantages of two systems described in above applications as low latency, high frequency, self-contained, small, and lightweight.

Theory acceleration sensor and gyro sensor:

Acceleration sensor:

An accelerometer is a simple object, attached to a spring with constant elasticity coefficient k. Displacement of objects with mass m blocks from the center to the location to be measured is x. Using Hooke's law and Newton's law we can determine the acceleration as follows:

Hooke's Law $F = kx$ (1)

Newton's law: $F = ma$ (2)

From (1) and (2) we have inferred acceleration:

$$a = \frac{kx}{m} \quad (3)$$

From formulas(3), it is easy to see that the calculation is simple acceleration, but the actual springs in linear ranges around a point called the original position and it will generate errors in the read values acceleration when there is a relatively large impact force on the spring. Thus, the construction of enhanced sensor accuracy is required, with the aim to make the object always keep the position at its original location. This is done by closed-loop system with the power and range shifts in the magnetic field. Acceleration can be determined by the amount of power generated electromagnetic force to keep the object lying in bed. This method is usually constructed using micro-electromechanical systems (MEMS) [4], [7].

Gyro sensor:

The term of Gyroscope immediately appeared from the mid-nineteenth century, and in recent decades it has been widely used and is replaced globally with the gyro. The original theories of gyroscopes are used to explain the motion of an object such as the Earth turns. And gradually gyro has been developed and widely applied in many fields, especially in the inertial navigation system INS. The gyro was the first practical application to assist in determining the direction of ships, submarines and aircraft by determining the rollϕ, pitchθ, yaw ψ from the frame of reference of a particular principle .Traditional gyro system is called Gimball quarterly. However, the gyro system is too bulky and heavy to be extended to used for other purposes such as monitoring humans and robots. Everything changed when the micro-electromechanical systems (MEMS) was born, allowing the implementation of small, light and cheaper gyro called Coriolis vibrating gyroscopes (CVG). The gyro has many advantages such as frequency response of thousands of Hz, the low noise "sliding phase" (jitter).

2. The device structure and operation principle

2.1. Introduction to device

2.1.1. About MPU6050

MPU6050 is the world's first integrated 6 axis motion sensor. It combines one 3 axis accelerometer and one 3 axis gyroscope, and it has its own digital motion processor (DMP) which can process the motion data with its inside algorithm. The chip itself has an internal of 16 bit analog to digital converter (ADC), so the output data are 16 bit

digital values. There are 117 registers in total inside the chip and all of the registers are 8 bit, so it needs two registers to hold the value for one axis' data. The detection range of the accelerometer is +2g, 4g, 8g, 16g and that of the gyroscope is +250, +500, +1000, 2000º/s, the range can be chosen by setting the corresponding registers[1], [8].

2.1.2. Introduction to MSP430

The TI's MSP430 is a very clean 16-bit byte-addressed processor with a 64K unified address space, and memory-mapped peripherals. The MSP430 excels where low power consumption is important. Many applications such as water meters are currently achieving more than 10 - year operation from a single button cell battery. It programs very well in C, making assembly language programming unnecessary. There is no memory bank switching to make the compiler's life difficult; it uses a normal RAM for its stack; it has a clean 16 bit instruction set. In fact, it is somewhat like an ordinary desktop RISC processor, but requires very little power [9].

2.1.3. Introduction to I2C protocol

I²C is a multi-master protocol that uses 2 signal lines. The two I²C signals are called 'serial data' (SDA) and 'serial clock' (SCL). Virtually any number of slaves and any number of masters can be connected onto these 2 signal lines and communicate between each other.

The data rate has to be chosen between 100 kbps, 400 kbps and 3.4 Mbps, respectively called standard mode, fast mode and high speed mode.

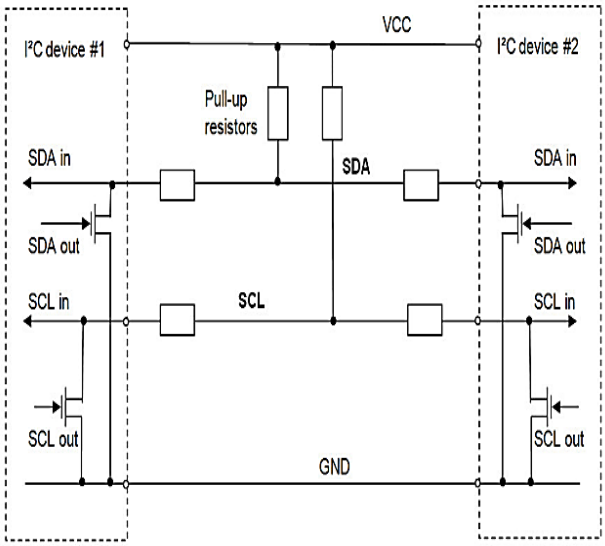

Figure 1. *I2C bus with 2 devices connected*

2.2. The device structure

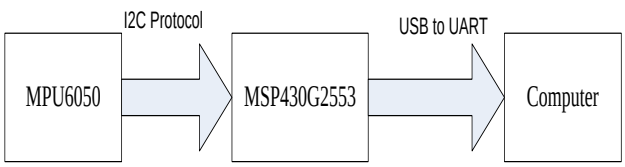

Figure 2. *Overall block diagram*

MPU6050 is communicated with MSP430G2553 through the I2C data. MSP430G2553 is connected with computer through UART protocol. Figure 3 shows the connection between MCU, MPU6050 and PC.

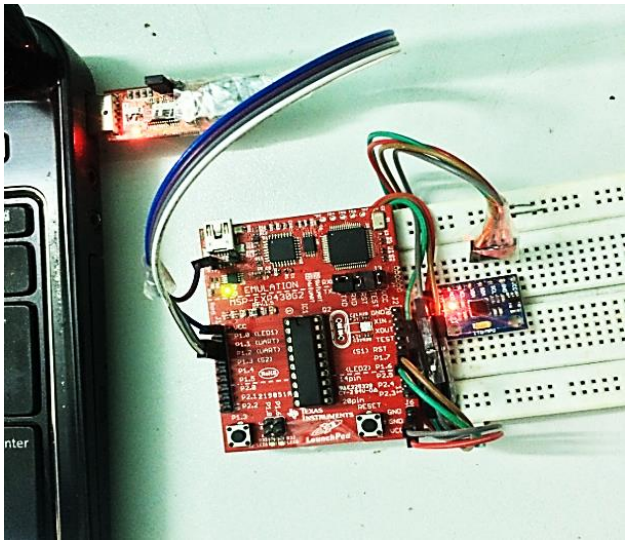

Figure 3. *System implementation*

2.3. MCU Algorithm

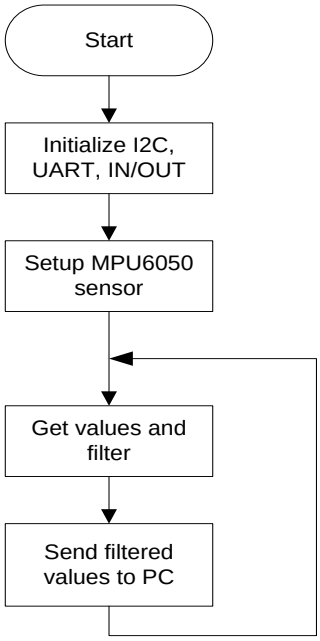

Figure 4. *Processing steps in MSP430*

Figure 4 shows that the task of this overall block is to get data values from MPU6050, then process data through filters and finally send the filtered data to computer using UART protocol.

- **Initialize I2C, UART, IN/ OUT:** prepares for connection between MPU6050 and computer.
- **Setup MPU6050 sensor:** Working like other difference modules. This sensor module needs a setup step. The main task of this function is to select the range and frequency operation of acceleration and gyroscope.
- **Get and filter values:** We get digital signal from MPU6050. The accelerometer can detect acceleration in accuracy, but the results can suffer

from the vibration error. Especially when human hand is moving the accelerometer, the data would be unstable, so the smooth filter is applied to the accelerometer data. It is filtered by the equation x.

- **Send filtered values to PC:** Filtered values are sent to computer through UART and will be processed in PC application.

2.4. The smooth filter

In this project, we use the moving average filter smooth.

A moving average filter smoothes data by replacing each data point with the average of the neighboring data points defined within the span. This process is equivalent to low-pass filtering with the response of the smoothing [5], [6] given by the equation:

$$x[k] = \frac{\sum_{i=0}^{N} x[k-i]}{N+1} \quad (4)$$

Where,

x[k]: the kth smoothed value.

From (4) with N = 4 so we get:

$$x[k] = \frac{x[k]+x[k-1]+x[k-2]+x[k-3]+x[k-4]}{5} \quad (5)$$

The smooth filter is applied to both accelerometer and gyroscope data.

3. Application program and result

3.1. Application program

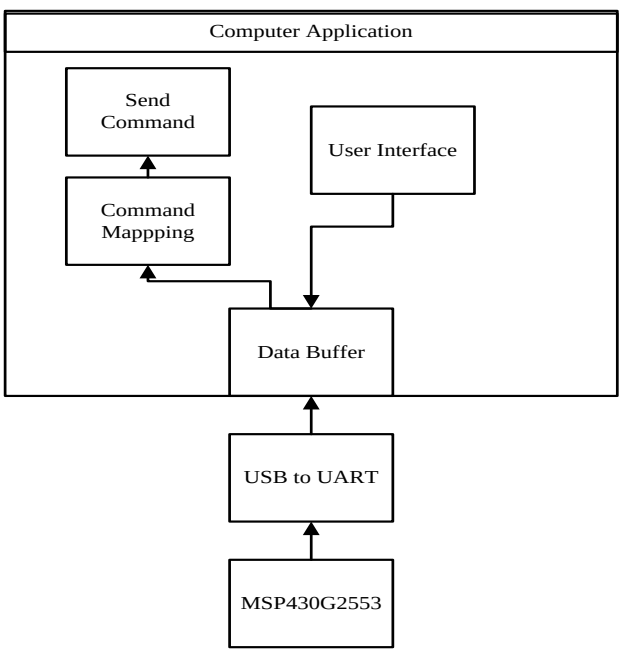

Figure 5. *Computer application program*

Figure 5 shows the diagram of this application. Computer would receive data from USB port, then process it and send command to control application.

- **USB to UART:** board is converted from USB to TTL to transmit data through UART (Universal Asynchronous Receiver/Transmitter) protocol.
- **Data buffer:** data received from USB is sent to data buffer.
- **User Interface:** the program interface and algorithm are designed by using C# on Window Form.
- **Command Mapping:** translates data from MSP430.
- **Send Command:** sends command to control application. Application can be mouse move event, right click, left click…

MSP430G2553 sends data to computer through USB to UART; computer using software C# to receive data from USB port. User interface would be controlled to connect port. Data from buffer would be read and processed. Here dummy command to control applications will be mapped onto corresponding data from MSP430.

3.2. Data processing on computer

Software C# is used to receive data and process it [10].

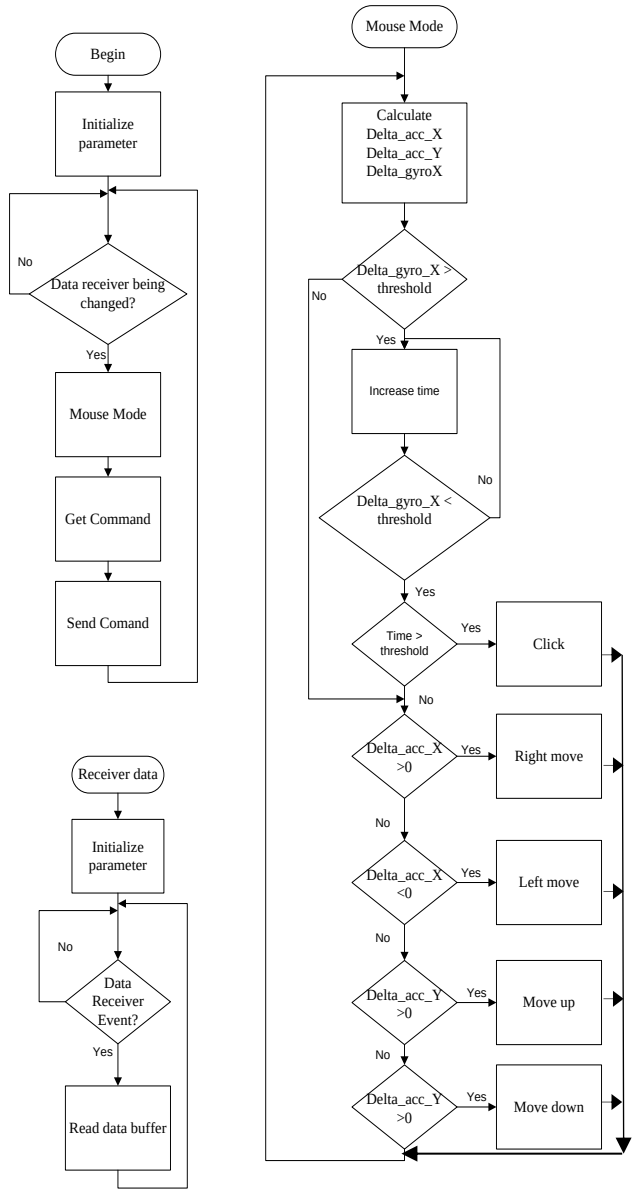

Figure 6. *Receiving and processing algorithm*

3.3. Result

Figure 7 shows waveform of accelerometer data when MPU6050 rotates right following X axis with accelerometer angle of 90^0. When MPU6050 is rotated, accelerometer data will change. We can determine a threshold value which changes.

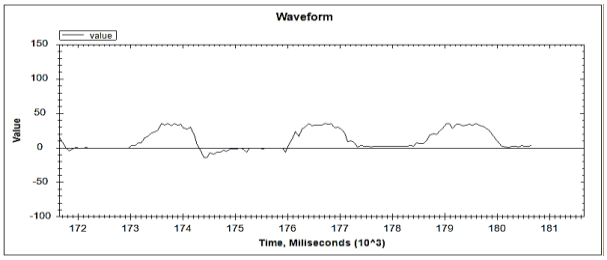

Figure 7. *Waveform of accelerometer data*

Figure 8 shows waveform of accelerometer data when MPU6050 rotates left following X axis with accelerometer angle of 90°. We can see that accelerometer value is less than zero. Both Figure 1 and Figure 2 accelerometer value are stable and it will change when MPU6050 rotates its original state.

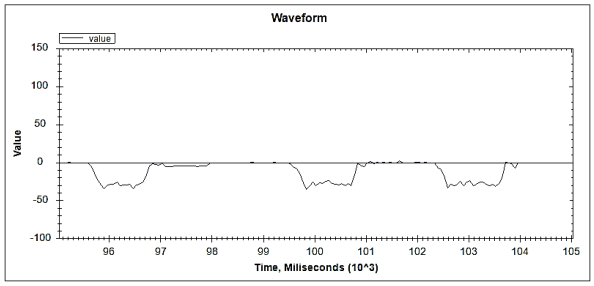

Figure 8. *Waveform of accelerometer data*

Figure 9 shows waveform of gyroscope data when MPU6050 rotates right or left following X axis. Gyroscope value will change when MPU6050 rotates right or left. Gyroscope value will return to its original value when MPU6050 is in stable state.

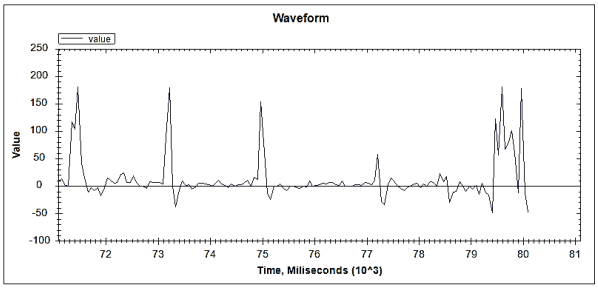

Figure 9. *Waveform of gyroscope data*

From their characteristics, accelerometer and gyroscope are used to detect, recognize hand motions. Then we use it to control application. For example, when user rotates hand right, value accelerometer will change, and respectively command right move cursor.

4. Conclusion and perspective

This paper shows that acceleration sensors can detect action, movement of objects (hand, plane…). From data receiver, we can control the computer with a simple operation without interacting it directly. The result of filtered data is stable and accurate. It can be applied to control planes, game devices, track movements of objects. In the next research, we will use Kalman filter and wireless connection to connect hardware and computer. This method is more stable and reliable, more convenient and flexible for users.

REFERENCES

[1] Liqiang Du, "Design and implementaion of home use porttable smart electronics", Michigan Technological University.

[2] E. Foxlin: Chapter 7. Motion Tracking Requirements and Technologies. 2002.

[3] G. Welch, E. Foxlin: Motion Tracking: No Silver Bullet, but a Respactable Arsenal. *IEEE Computer Graphics and Applications*, November/December, 2002.

[4] Norhafizan Ahmad, Raja Ariffin Raja Ghazilla, and Nazirah M. Khairi, "Reviews on Various Inertial Measurement Unit", *in International Journal of Signal Processing Systems Vol. 1*, No. 2 December 2013.

[5] Savitzky, A., Golay, M.J.E. "Smoothing and differentiation of data by simplified least squares procedures", *Analytical Chemistry*, 36(2), p.1627, (1964).

[6] José Luis Guiñón, Emma Ortega, José García-Antón, Valentín Pérez-Herranz," Moving Average and Savitzki-Golay Smoothing Filters Using Mathcad", *International Conference on Engineering Education – ICEE 2007*.

[7] Diego E. Serrano, "Design and Analysics of MEMS accelerometers", *IEEE Sensors 2013*.

[8] InvenSense Inc, "MPU6000 and MPU6050 Product specification Revision 3.1", [online]: http://www.elecrow.com/download/PS-MPU-6000A.pdf

[9] John H.Davies, "MSP430 Microcontroller Basics", 2008.

[10] John Sharp, "Microsoft Visual C# 2013 step by step", 2013.

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