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The Low-Cost Interactive Tennis Training Platform

Hung-Kuang Chen
National Chin-Yi
University of Technology
Department of
Electronic Engineering
hankchentw@gmail.com

Po-Jung Wu
National Chin-Yi
University of Technology
Department of
Electronic Engineering
wupojung@gmail.com

Yong-Cheng Chen
National Chin-Yi
University of Technology
Department of
Electronic Engineering
vulewarextic@gmail.com

Abstract

Within this paper, we implemented a low-cost interactive tennis training system for tennis beginner. This system includes gyroscope module, accelerometer module, RF module, RS232 module and microcontroller. We designed and implemented two circuits, one is to install in the racket for collecting user's information; another is to receive data and pass it to the computer. In additional, we implemented several algorithms for pre-processing data and analyzing data. We'd got the user's grip posture with our algorithms and showed result in 3D with OpenGL.

Because we used MEMS(Micro Electro Mechanical Systems) components and PIC18F2550, the cost for this system will be cut down. We believe that is a low-cost, reliable, real-time, interesting, and interactive system for training the beginner.

Keyword：MEMS、Gyroscope、Accelerometer、Interactive、GAME。

1. Introduction

With the technology changes by flying, the TV game we play at home are matured with it. Nowadays, most manufactures have already see the interactive as a sale point for home use TV games. The most classic example is the Nintendo Wii[1], in order for Wii to catch gamers' postures to enter the game uses, it add in an accelerometer and gyroscope in the remote. However, the home use TV game focuses more on the entertainment, therefore, it has an un-real result. For instance, if waving the remote from upper right to lower right, Wii will only figure as toward right only. In our point of view, it should be more accurate to the users postures, therefore, it should invent an interactive object to catch users' posture, and use it on the tennis game to generate the reality feels.

2. Related work

Previous research [3-5] mainly use the device on market to design an interactive object, such as Nintendo Wii, mostly the ADXL330 [2]. These researches is all stimulate the Wii remote to the computer mouse signal. To use these signals to stimulate users actions, it is easy to implement, but always missing the accuracy. Moreover, [6-7] is to use application on game console (gamepad) and it is missing the interactions, and also mainly focus on entertainment.

Regarding to the gyroscope research, it is very broad, therefore, the writer didn't go through details. There is still one valuable to talk about is [8] regards to the usage of sport - to use it on measuring the jogging and running. From this research has already give more usages on the gyroscope. This paper also looking forward to this direction also go into the tennis coaching has [9], these researches were only applications with multi medias, and do not have large amount of interactions on the device. This made the users are not along with the training. This paper used gyroscope and accelerometer to let users to learn faster on interactive operations.

3. System Overview

The Figure 1 displays this paper's system structure, where the Gyroscope uses L3G4200D produced by the ST company, which has 16-bits output , and it can read by ±250, ±500, ±2000 dps. The details as shown in section 3.1. The accelerometer is specialized for its small volume and its energy efficient by using ADXL335and its ±3g. The MCU part was using the PIC18F2550 produced by Microchip Company, it was build-in 10-bits Analogy/ Digital Converter (ADC) to allow the cost of the platform lower down in this paper. In order to user friendly, it used wireless between computer and device. It used nRF24L01 module to its design, it was operated within 2.4 GHz. The main board (receiver) was also using the same PIC18F2550 with nRF24L01 through PL2303HX module to transmit

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the signal to USB port to computer. For the computer, PL2303HX would a serial port. The software installed on the computer was invented by MFC, as shown 3D by OpenGL API.

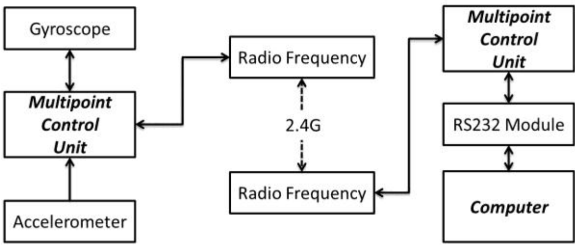

Figure 1. System Overview

3.1 Hardware Architecture

This paper designed and implemented the circuit, one was installed in the tennis racket which we called it Device Board (or Client) included the Gyroscope and Accelerometer for collecting users' information; another was to receive data and transport to the computer which we called it as Main Board (or Server). The below is to discuss the components of the design circuit:

PIC18F2550 is produced by Microchip Company. its most highlighted function is the build-in 10-bits ADC, this research didn't need to use several ADC0804 ICs to lower the cost. On the other hands, this chip provided I2C and SPI protocol is convenient for other components' communication. Within the future, it can upgrade to an USB device. We operated this MCU as 20 MHz in this case to let every components process in high speed to let the experiment more realistic.

The Gyroscope in this paper is L3G4200D, it has 16 - bits digital output with three kinds of measurement ranges (FS) - ±250, ±500, and ±2000 dps to a selection of four kinds of Digital Output Data Rate (ODR) - 100, 200, 400, and 800Hz. This device has build-in high-pass filter (HPF) and low-pass filter (LPF). In order to get a more detail information, we didn't use the filter at all in our research.

To get a better experiment result, this paper used same position (still motion) to get result in different settings as three FS and four ODR outputs. The results(12 differ kinds) were shown in the figure 2, where Yaw-axis is red, Pitch-axis is green, and Roll-axis is blue.

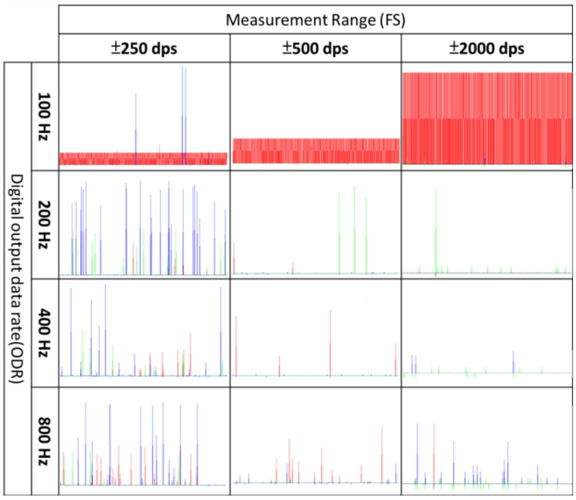

Figure 2. Gyroscope Settings

As shown in Figure 2, the best setting is FS= ±500 dps and ODR=400 Hz. (The experiments below were all set with this standard)

ADXL335 is a small, thin, low power, and complete 3-axis accelerometer with signal conditioned voltage outputs. It is with a minimum full-scale range of ±3 g. The output signals were analogy voltage, we used build-in 10-bits ADC in PIC18F2550 to convert data to digital data, the detail is shown in section 3.3 .

nRF24L01 was a single chip radio transceiver for the worldwide 2.4-2.5 GHz ISM band. It worked with SPI interface. We used PIC18F2550 to communicate between Device Board and Main Board. By using wireless, we defined a protocol for it. Details are shown in session 3.2 .

RS232 is a very easy to use in communication. However, it was even none 9-pins port in recent released computers, therefore , we used PL2303HX to simulation Serial port with USB. But logic voltage was TTL-logic[0,5v], not tradition serial port[+15,-15].

3.2 Communication Protocol

We set the needed data as a length of 14 Byte sequence, as figure 3 where B(begin Char) in the figure3, always '0xa0' , is E(end char), always '0x0a' and so on. This paper use wireless to transport data, in order not to lost the data and receive the wrong data, we added two strategies: Sum Check (as S in figure 3) and Cyclic Redundancy Check (CRC - as C in figure 3):

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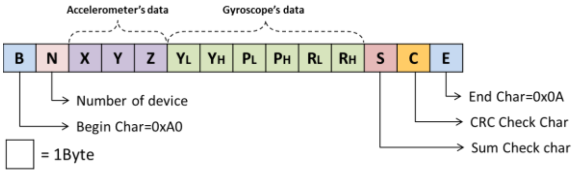

Figure 3. Packet Define

As shown in figure 3, where Sequence_i is each squares of 1 byte in the sequence of 14 byte. We can calculate the Sum check (as S in figure 3) by equation 1,that is a fast and easy way to check data。The rang of $\text{Sequence}_0 : \text{Sequence}_{13} (as\ B = \text{Sequence}_0, X = \text{Sequence}_2, E = \text{Sequence}_{13}\ and\ so\ on)$,this is to assure the original data has error or not.

$$S = (\textstyle\sum_{i=1}^{10} \text{Sequence}_i) \tag{1}$$

On the other hands, we used the CRC method to calculate the data $\text{Sequence}_1 : \text{Sequence}_{11}$ as *bitStr* , we selected *polynomial = 0b10001001* through the calculation to get *shiftReg*, we will follow the next data as Sequence_{12} (as C in figure 3) was. This is to avoid the mistakes from wireless communication or lost.

CRC8 algorithm

```
function crc8(bit array bitStr[1..len], int
polynomial)
{
   shiftReg:= initial value
   // commonly all 0 bits or all 1 bits

   for i from 1 to len
   {
      if most significant bit of shiftReg XOR
bitStr[i] = 1
      {
         shiftReg:= (shiftRegLeft shift 1) XOR
polynomial

      }else
      {
         shiftReg:= (shiftRegLeft shift 1)
      }
    }
    return shiftRegister
}
```

3.3 Data Transform

We transported the data from device to computer as in section 3.2 to get the data we need. When the data be accepted, we must calculate the related data to determine the program, and we focus on Gyroscope and accelerometer:

Accelerometer

$$\text{V}_{\text{analog\_output}} = \frac{1}{2}\text{V}_\text{s} \pm \frac{1}{10}V_s \times g_{current} \tag{2}$$

Let

$$V_{analogy_{zerog_{ref}}} = \frac{1}{2}V_s$$
$$S_{factor} = \frac{1}{10}V_s \tag{3}$$

Then

$$V_{analog\_output} = V_{analog\_zerog\_ref} \pm S_{factor} \times g_{current} \tag{4}$$

Because V_{analog_output} and $V_{analog\_zerog_{ref}}$ in equation 4 are analog signal. In this paper, we transform them with build-in ADC with PIC18F2555 by equation 5.

$$V_{analog} = V_{digital} \times \frac{V_{reference}}{2^{resolution}} \tag{5}$$

Then, we get the current gravity factor by equation 6.

$$g_{current} = \pm\left(V_{digital_{output}} - V_{digital_{zerog_{ref}}}\right) \times \frac{\frac{V_{reference}}{2^{resolution}}}{S_{factor}} \tag{6}$$

In this case，$V_{reference} = 3.3$，$2^{resolution} = 2^8 = 256$，$S_{factor} = 0.33$.

Gyroscope

L3G4200D's output is 16-bits digital signal with 2's complement. That is the original data can not be used. It must be transformed flowering like this:

Step1: get true angular rate

The L3G4200D output can be expressed as shown in equation 7:

$$R_t = \text{SC} * (R_m - R_0) \tag{7}$$

Where, R_t is the true angular rate given in dps, $R_m$is the L3G4200D's output in signed integer LSBs, R_0 is the zero-rate level given in signed integer LSBs(the gyroscope is stationary state, but has output)SC is the scale factor(or call sensitivity) given in dps/LSB . the FS detail shown in table 1.

Step2: calculate the angular displacement

$$\Delta R_d = \Delta R_d + h * R_t \tag{8}$$

Where ΔR_d is the gyroscope's angular displacement on each-axis given in degrees, h is the sampling period given in seconds. If ODR=400Hz, then h=0.0025 s. R_t is the true angular rate given in dps. The data detail shown in table 2.When system power- on or reset, the ΔR_d will be clear by 0.

Table 1. FS typical value

FS	±250 dps	±500 dps	±2000 dps
value	0.00875	0.0175	0.07

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Table 2. ODR typical value

ORD	100 Hz	200 Hz	400 Hz	800 Hz
value	0.01	0.005	0.0025	0.00125

3.4 Pre-proceeding Data

After we got the physical value of gyroscope and accelerometer , we discovered these data have jitters and shifts such as in figure 4, when the gyroscope in still motion, its output should be a straight line by the theory. However, when the actual output as a jitter data, and this is the jitter of gyroscope. We tried to use filter to improve the result because the physical value is off very huge amount with the reality. The below has the explanation of it:

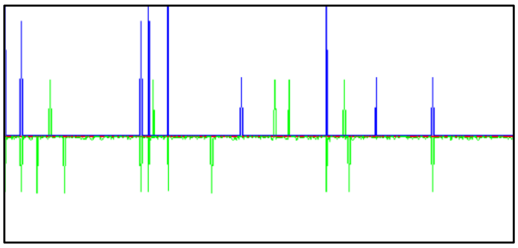

Figure 4. Gyroscope Jitter(still motion)

Fixed-width Average ,FA

We implemented FA by equation 9, it is a simple and fast filter in this case, the data will be segmented which the data will be segmented by the width, and the result is not smooth enough.

$$\frac{\sum_{i=0}^{n} \Delta x_i}{n} \tag{9}$$

Where Δx_i is input data , n is fixed-width, usually set it 5. Although this issue can set a higher n to over come it, it won't have response immediately and may delay. For 9600bps baud rate, with our experiment, the maximum value of n to be accepted is 25.

Simple Moving Average，SMA

We used anchor function called Simple moving average(SMA), this function can be implement by equation 10. For FA, this is the way to get a smooth curve.

$$SMA_{t1} = SMA_{t0} - \frac{P_1}{n} + \frac{P_{n+1}}{n} \tag{10}$$

The most difference between SMA and FA is SMA would have a effect for FA's stable length to a moving(or call shift) . It is when ever one data is added in, it will remove the earliest data to ensure the average is locked into a certain range.

Kalman filter

The Kalman filter (KF) is an algorithm which uses a series of measurements observed over time, containing noise and other inaccuracies, and produces estimates of unknown variables that tend to be more precise than those that would be based on a single measurement alone. It will be implement flowing like this:

Step1: Project the state ahead

$$X_k = X_{k-1} \tag{11}$$

Where, X_k is current measurements, X_{k-1} is previous measurements.

Step2: Project the error covariance ahead

$$P_k = P_{k-1} + Q \tag{12}$$

Where, P is estimate error covariance, and Q is process noise covariance , it is very small, usually the value is 0.000001.

Step3: Compute the Kalman gain K_g

$$K_g = P_k * (P_k + R)^{-1} \tag{13}$$

Where, K_g is Kalman gain, R is measurement noise covariance, usually the value is 0.01.

Step4:Update estimate with measurement Z_k

$$X_k = X_k + K_g * (Z_k - X_k) \tag{14}$$

Step5:Update the error covariance

$$P_k = (1 - K_g) * P_k \tag{15}$$

Flowing ***step1*** to ***step5*** , we can get the smooth data shown in figure 5. Blue line is source, red line is Kalman filter result .

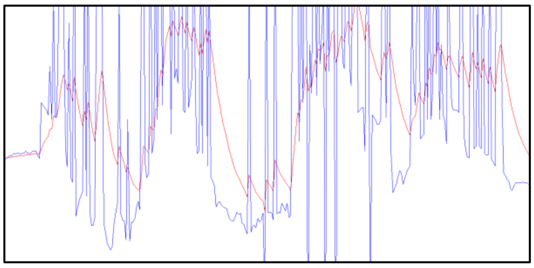

Figure 5. Kalman filter example

3.5 Mapping

According to the 3D object after using filtered data to spin, shift, enlarge, the reflection data will

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follow the tennis racket movement to move. We use accelerometer's data to provide the strength and ways of swinging the tennis racket, the actual experiment steps and ways please check section 4.

4. Experiment

In this paper, we arranged the device withing tennis racket spaces (As B in figure 6), and located the accelerometer at the top of tennis racket (as A in figure 6). This is because the point is the fastest accelerate point when swinging the tennis racket. The gyroscope is located on the face of tennis racket (as G in figure 6) in order to calculate the accurate hitting point for its design. In order to match with different size of tennis racket, we will implement different offsets for each tennis rackets.

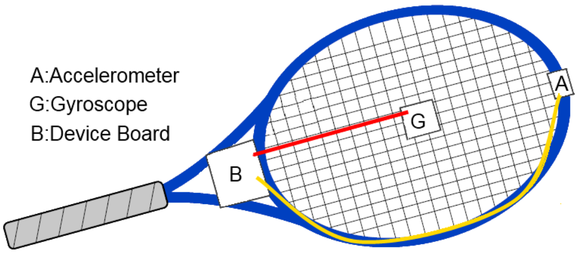

Figure 6. Device Board

This paper of experiment result has two parts, which included the hardware device and the software operation:

Hardware:

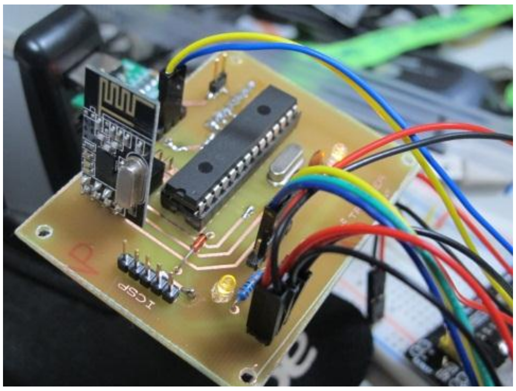

Figure 7. Main Board

Figure 8. Device Board

Software

Figure 9. User Operations

5. Conclusion and Future Expectations

This paper structured an interesting and effective low cost tennis training platform. We used PIC18F2550 as MCU to pair with L3G4200D and ADXL335 to be sensor. As MCU build-in ADC to convent ADXL335's signal , used kalman filte to remove the jitter , in order to get data mapping to reflected tennis racket and let the whole platform operation to show in 3D with openGL. From this, we can let the user learn how to play tennis in a fast and accurate learning process.

As as whole, we have the following **advantages**:

- low cost
- easy to used
- effective

And also the following **disavantages**:

- Cannot provide more settings to the users.
- If the device could change to USB, the platform can be more portable.

We have a few goals to establish in the future:

1) Modify the device to USB device , that will be remove PL2303HX module .the cost will be down .
2) We will try one server to multi devices communication in future. That is one main board, some device boards to let device board locate in different locations to get more accurate experiment number.
3) we will cooperate with tennis coach to a more fully training system to let computer graphics and science to a innovation of helping human learning skills.

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