A Wireless Wearable Human Jump Analysis System

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Abstract—**In most sports, the vertical jump is one of the most basic actions. Jumping force and explosive power are two specific indicators to reflect the ability of the muscles in one vertical jump. This paper presents a light-weight and easy-to-use wireless system to analyze the process of human vertical jumping up through the use of a Micro Electro Mechanical System (MEMS) accelerometer and a MEMS gyroscope. The system allows the users to be able to measure the jump parameters, including jumping force and explosive power of athletes' lower limbs. Then the noise of the system has been analyzed briefly, and a finite impulse response (FIR) low pass filter is designed to eliminate the noise. The system has been compared with a commercial performance measuring system-Myotest, and a traditional force test platform-HUR. The results show that parameters can be collected precisely by it and there is a possibility to apply this system for other actions.**

Keywords-MEMS; accelerometer; gyroscope; FIR filter; jumping parameters

I. INTRODUCTION

One goal of sports biomechanics is to get athletic body mechanics data precisely. So far, there are not many methods to detect human motion. Some of the most common methods are the video detection, using force platforms, pressure distribution pads, and infrared devices, etc. With the development of technology, MEMS accelerometers and gyroscopes have a small size and light weight, and its output data are accurate and real-time [1]. They can be widely applied to achieve the purpose of monitoring the training effect and improving athletic skills.

In this paper, we propose a light weight modular-based jumping analysis system, which is able to perceive the spatial and temporal parameters from athletes. System hardware components and software are described in system design section. The experiments have been done for system validity evaluation, comparing with a commercial device and a traditional platform.

II. SYSTEM DESIGN DESCRIPTION

This section describes all components of the system. The entire components consist of three major parts. The first part is designed hardware including sensors and a microcontroller. The second part is the software design, using for analysis of the entire process of jump and parameters calculation and results illustration. Thirdly, the fir low pass filter is designed to reduce the noises that exist in the system.

A. Hardware design

To get the acceleration in the jumps we select produced using STMicroelectronics a MEMS triaxial accelerometer LIS3LV02DL produced by STMicroelectronics has been selected. It includes a sensing element and an IC interface, which is able to take the information from the sensing element and to provide the measured acceleration signals to the external world through an I^2C/SPI serial interface. The sensing element is manufactured using a dedicated process developed by ST to produce inertial sensors and actuators in silicon. The LIS3LV02DL has a user selectable full scale of $\pm 2g$, $\pm 6g$ and it is capable of measuring acceleration over a bandwidth of 640 Hz for all axes. It belongs to a family of products suitable for a variety of applications including free-fall detection, motion activated functions in portable terminals and inertial navigation, etc. A jumper's body is bent during the taking off as shown in Fig. 1. In order to measure bending angles, we use a MEMS triaxial gyroscope ITG3200 produced by Invensense. The ITG-3200 features three 16-bit analog-to-digital converters (ADCs) for digitizing the gyro outputs, a user-selectable internal low-pass filter bandwidth, and a Fast-Mode I^2C (400 kHz) interface. Additional features include an embedded temperature sensor and a 2% accurate internal oscillator.

The data from the LIS3LV02DL accelerometer and the ITG3200 gyroscope are synchronized by a S3C2440 processor that the operating frequency can reach 400MHz. The angular rate data from the gyroscope are integrated by the processor to get the bending angles. Then the acceleration values and the bending angles are rearranged again with timestamps before recording on an external a micro Secure Digital (SD) card at the sampling rate of 400Hz. The hardware configuration diagram of the system is shown in Fig. 2.

Once all data from the accelerometer and gyroscope have been collected, the processor packages the data stored in SD card packaged in accordance with the communication protocol, and sends them to a PC computer or a mobile phone via the Bluetooth wireless technology. The sensors, the microcontroller and the Bluetooth equipment are put together in a box with a 3.3 Volt Lithium-Polymer battery.

Figure 1. The bent body.

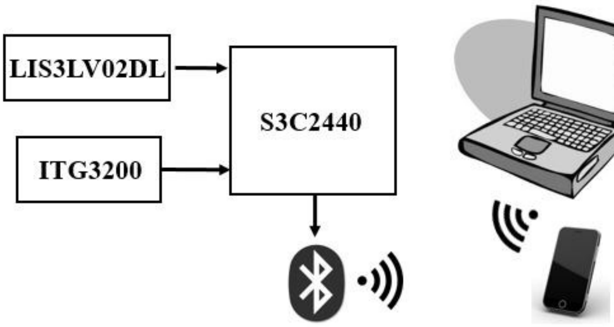

Figure 2. The hardware configuration diagram of the system

B. *Analysis Software Design*

The analysis software has been developed on Microsoft visual studio 2008. Its main functions are to control the S3C2440 processor receiving the packet data from the Bluetooth equipment and extracting acceleration and angle values. Then the jumping parameters can be provides including velocities, heights, the jumping ability and explosive power values. Both average and maximum value of each parameter can be easily calculated. All the data are saved in a log file.

Each and/or every collected data can be directly selected and displayed by the user on the top right graph window as shown in Fig. 3. The corresponding parameters of each jump, including a maximum explosive power value, a maximum jumping force value, a maximum velocity and a maximum height, are illustrated on the right bottom window. The parameters are computed regarding to the following descriptions.

We have known that the direction of a valid acceleration in the vertical jump is upward. The sensor coordinate system is shown in Fig. 4 when the jumper is standing statically. The x-axis direction is in a straight line with the gravity. So the direction of a valid acceleration is in the x-axis. However, the coordinate system of the sensor will change with the bending of the body, as shown in Fig. 5. In this case the Z-axis direction of the sensor is substantially constant. Then according to the angular rate of gyro z-axis output r_z, we can calculate the angle change θ_1.

$$\theta_1 = \int r_z \, dt \tag{1}$$

So the valid acceleration a_1 in this case is calculated as follow

$$a_1 = a_x \cos\theta_1 + a_y \sin\theta_1 \tag{2}$$

Where a_x and a_y are the acceleration values of x-axis output and y-axis output.

When the position of the sensor has a change as shown in Fig. 6, the Y-axis direction of the sensor at this case remains invariant. Similarly, the angle change θ_2 can be calculated according to the angular rate of gyro Y-axis output r_y.

$$\theta_2 = \int r_y \, dt \tag{3}$$

So the valid acceleration a_2 in this case is as follow

$$a_2 = a_x \cos\theta_2 + a_z \sin\theta_2 \tag{4}$$

Where a_z is the acceleration value of x-axis output.

Combining of the above two cases, the valid acceleration in the vertical direction is computed as follow

$$a_{valid} = a_x \cos\theta_1 \cos\theta_2 + a_y \sin\theta_1 + a_z \sin\theta_2 \tag{5}$$

According to Newton's second law, the force is related with the body mass and the acceleration. So the maximum jumping force JF_{MAX} is counted as follows:

$$JF_{MAX} = MAX\{m \cdot A_t\} = m \cdot MAX\{A_t\} \tag{6}$$

Where A_t is the set of all the acceleration values during the jump, m represents a person's weight.

Similarly, power is the product of force and speed. According to Newton's second law, the velocity can be achieved by the definite integral of the accelerations, as shown in Eqs.7.

$$V_t = \int_{t-t_0}^{t} a_t \, dt + V_{t-t_0} \tag{7}$$

Where V_t and a_t represent the speed and the acceleration at time t, V_{t-t_0} represents the speed of time t-t_0, t_0 represents the timestamp.

So the formula for the maximum explosive power is

$$EP_{MAX} = MAX\{F_t \cdot V_t\}$$
$$= m \cdot MAX\left\{a_t \cdot \left(\int_{t-t_0}^{t} a_t \, dt + V_{t-t_0}\right)\right\} \tag{8}$$

Since the person is on the stationary state at take-off, the initial velocity V_0 is equal to 0. The velocity can be expressed as the formula:

$$V_t = \sum_0^t a_t \, t_0 \tag{9}$$

Therefore, the maximum velocity can be calculated by

$$V_{MAX} = MAX\{V_t\} = t_0 \cdot MAX\{\sum_0^t a_t\} \tag{10}$$

Similarly, we can also obtain the height as follow:

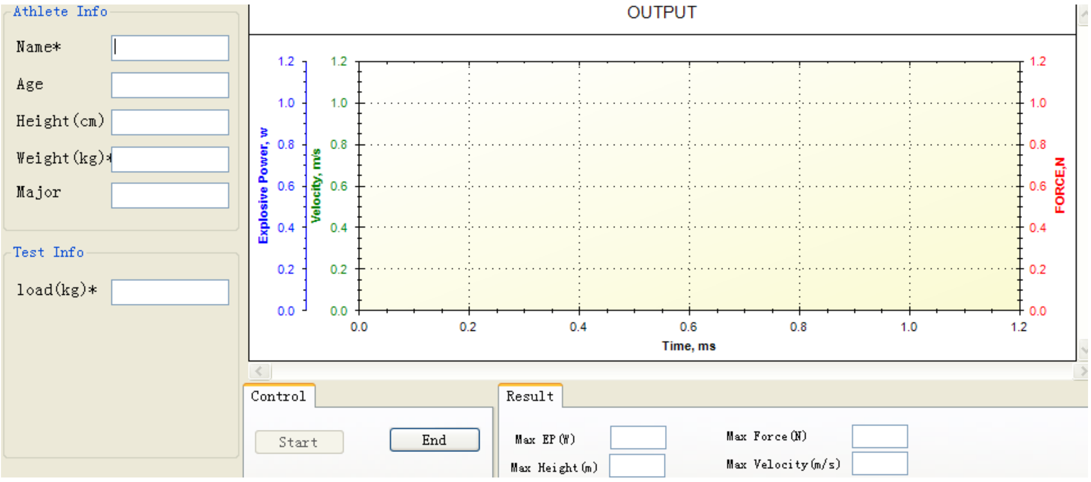

Figure 3. Graphic user interface of the analysis software.

$$H_t = \int_{t-t_0}^{t} V_t\,dt + H_{t-t_0} \tag{11}$$

So the formula for the maximum height is

$$H_{MAX}=MAX\{H_t\}=t_0 \cdot MAX\{\textstyle\sum_0^t V_t\} \tag{12}$$

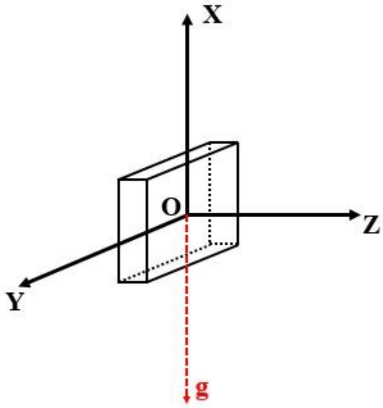

Figure 4. The sensor coordinate system.

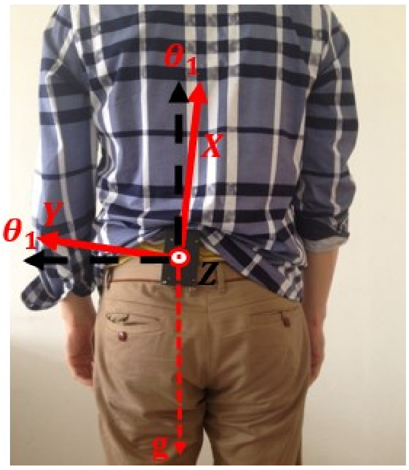

Figure 5. The angle change θ_1.

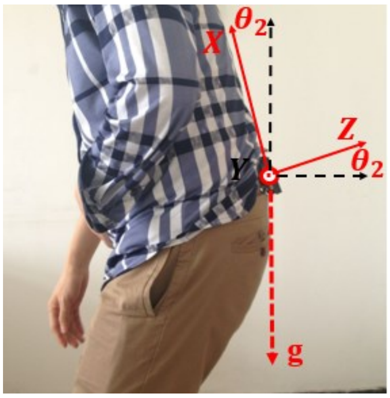

Figure 6. The angle change θ_2.

C. *FIR Filter Design*

A FIR filter is a filter whose impulse response is of finite duration, because it settles to zero in finite time. FIR filter output has not been feedback [2]. This means that any rounding errors are not compounded by summed iterations. The same relative error occurs in each calculation. In addition, the stability is guaranteed and the phase is linear, since the output is a sum of a finite number of finite multiples of the input values [3]. For a FIR filter of order *M*, each value of the output sequence is a weighted sum of the most recent input values

$$y(n)=\sum_{i=0}^{M-1} h(i)x(n-i) \tag{13}$$

Where *y(n)* is the output signal after filtering, *x(n)* is the input signal, *h(i)* is a coefficient of the filter.

A FIR filter is designed by finding the coefficients and filter order that meet certain specifications, which can be in the time-domain and/or the frequency domain. There are many methods to design FIR filter, for example, window design method, frequency sampling method, weighted least squares design and so on. The method that we use for our system is window design method. The principle is that the infinite impulse response is truncated with a finite length window function to get finite impulse response.

Fig .7 shows a spectrum of all output data of our system obtained in one jump. Frequencies of the valid data are between 0 Hz to 30 Hz, so the cutoff frequency of the FIR low-pass filter that is designed to eliminate the noise is 30Hz.

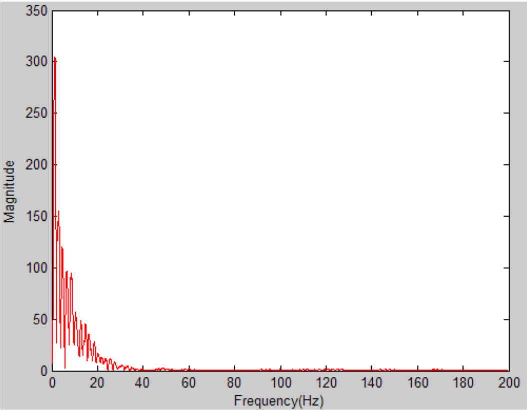

Figure 7. The spectrum of the output data of our system

III. EXPERIMENT

To determine the validity and reliability, many experiments have been investigated. First, we did experiments to verify whether the system could accurately reflect human jumping process. We selected a different weight people to jump for ten times whom were instructed to jump comfortably on the flat floor. Through our analysis software the curve of acceleration values in every jump was viewed.

The second experiment is the comparison among our system, a commercial performance measuring system-Myotest, and a traditional force test platform-HUR. The same subjects involved in this test. Each subject had been attached our system device, as Fig. 1, and the Myotest device was also put on the same position. Then they were instructed to jump in the HUR platform. Therefore, we can retrieve the data from the three devices simultaneously and relatively. After that, the raw data of each system will be processed by their own software to estimate the parameters and compared.

IV. RESULT & DISCUSSION

Fig. 8 shows a variation curve of all acceleration values obtained by our system in the jump. The four stages in jump are separated by the red lines. Stage A represents the process of squatting, when the acceleration values are negative. Stage B represents the body begins to force off. And the jump's body was still in the air in the stage C. Stage D represents the body fell to the ground.

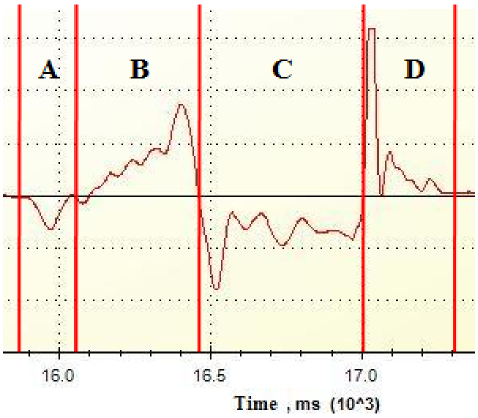

Figure 8. The curve of acceleration values

The jumping force obtained from our system is compared with the Myotest in Fig. 9 and with HUR platform in Fig. 10. The straight lines on the graphs are reference lines where jumping forces of three devices are equal. They can be seen that jumping force data points of both our system and Myotest are relied closely to the reference line. The two data sets obtained from our system and HUR platform are weakly correlated.

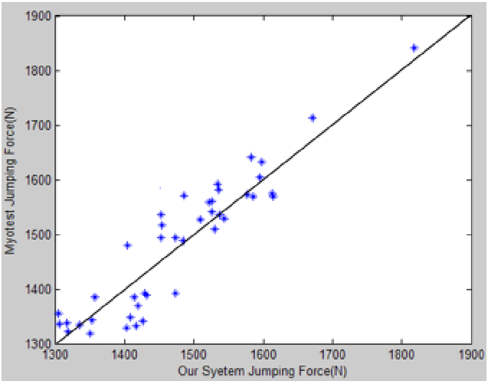

Figure 9. Scatter plot between forces of each subject from our system and Myotest.

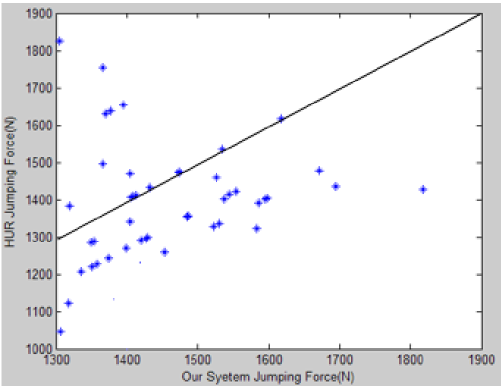

Figure 10. Scatter plot between forces of each subject from our system and HUR.

V. CONCLUSION

Our system is designed and developed for helping a coach to train athletes in order to enhance their leaping ability and explosive power. It also can be used for the people who want to survey their jumping ability in daily exercise. This study has shown that the validity and reliability of our system are proven and can be beneficial for consumer-level usage. Furthermore, our system can also been used in other sports and applications, for example, the barbell bench press and broad jump.

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