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Motion Capture System Using Wiimote Motion Sensors

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Abstract—**The purpose of this study is to examine the Wiimote MotionPlus system as a method to capture angular kinematic data of the knee, hip and back of a participant performing a lifting task. Twenty one subjects were recruited and asked to perform a lifting task while having four Wiimotes strapped to the lower leg, upper leg, and back at the hip and below the shoulder blades. The raw signals from the four Wiimotes were filtered and normalized before being combined to obtain the proper change in angular data. The results of the study demonstrate that it is feasible to combine the data from multiple Wiimotes to obtain kinematic data which may be used in ergonomic analysis.**

I. INTRODUCTION

The Nintendo Wii [1] has opened up a world of new possibilities with regards to developing interactive user interfaces based on gesture recognition technology [2]. Researchers are finding inventive ways to apply this technology to scientific and engineering problems, such as developing a stroke rehabilitation assessment and evaluation gaming system [3]. The Wii remote game controller (Wiimote) is an affordable technology with the ability to measure acceleration and track displacement; therefore, it is natural to consider using it as an actual motion capture system.

There are a number of commercially available motion capture systems. The most notable system is Vicon, which offers an infrared (IR) camera system that tracks reflective markers on a subject [4]. The Vicon system has a high degree of accuracy and repeatability [5]. The Measurand system utilizes fiber-optic technology, where the fiber-optic ribbon is able to detect different shapes and motion [6, 7]. Xsens offers a system that uses inertial motion trackers placed on the subject [8]. Each of these and other similar systems have their own benefits and drawbacks, however they are relatively expensive when compared to the Wiimote.

The sensors of the Wiimote can be used in a variety of different ways to capture kinematic data. The Wiimote camera is often used to track illuminated IR targets [9, 10]. The positions of the reflective targets attached to the person are calculated by their tracked location in the camera frame. However, using this method it is difficult to determine the orientation of the target. When attached to the subject, the Wiimote's accelerometers may be used to detect the Wiimote's motion [11]. This method works well for recognizing broad gestures but it is not reliable for measuring accurate movement data due to drift over time caused by sensor noise. Sensing orientation with the accelerometers is not accurate when the Wiimote is in motion because the accelerations due to gravity cannot be completely isolated from other accelerations. The Motion Plus attachment to the Wiimote contains rate gyros that measure angular rate in three degrees of freedom. Rate gyros have been used before in kinematic analysis [12]. Mayagoitia, Nene, and Veltink did a study comparing readings from inexpensive rate gyros with a more expensive vision-based system and found that the rate gyros performed well at all speeds over multiple testing conditions [13].

The purpose of this study is to examine the viability of the Wiimote MotionPlus to capture kinematic data of the leg and back movements of a participant performing a lifting task. By integrating the signals from four Wiimotes it is possible to calculate the change in angle of the knee, hip and back. The significance of this study is in demonstrating the feasibility of using an inexpensive off-the-shelf sensor to capture kinematic data.

II. METHODS

A. Subjects

Twenty one subjects consisting of males and females over a wide range of ages participated in this study. The only significant difference was that males were taller than females. The study protocol was approved by the Georgia Institute of Technology Internal Review Board.

B. Experimental Setup

Wiimotes with Motion Plus were used to gather data about the movements of a participants back, hip and right leg. Wiimotes have three dimensional accelerometers and solid state angular rate sensors and relay the data over Bluetooth at a rate of 100 samples per second. The power button is located at the top and on the front of the Wiimote. Wiimotes were attached upside down, with the front facing away from the body and were strapped on to the side of the right leg and over the spine at the hip and below the shoulder blades (Fig. 2b). Velcro straps were used to keep the sensors in place. The Wiimotes report X, Y, Z acceleration values and the yaw, pitch and roll rates over Bluetooth to a laptop

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Figure 1. Experimental setup.

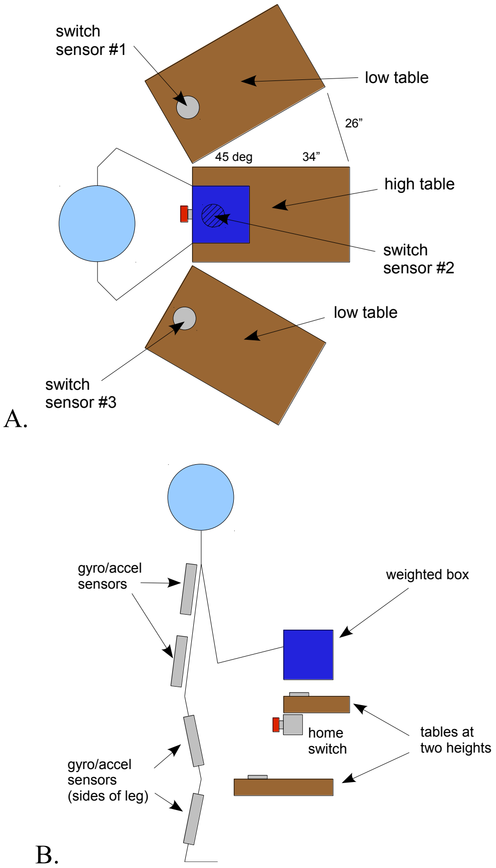

Figure 2. Experimental setup (a) viewed from the top and (b) the side.

computer that recorded the raw information directly while the tasks were performed.

In addition four switches were wired to a digital I/O circuit connected to the laptop (Fig 2a). The on/off values of these switches were recorded during the tasks. Subjects were asked to lift up and set down a box on top of these switches. The switch data were used to measure the task performance. The overall setup of the lifting task is shown in Figure 1.

C. Task Protocol

Subjects were shown a safety training video on how to properly lift items and then asked to don the equipment. The lifting task was performed in a simulated poultry plant environment with the room temperature set to 40°F. The subjects were asked to stand with their feet in the same location throughout the task. The high table (Fig. 2b) was at a height of 37 inches from the ground, while the two lower tables, positioned on either side of the high table, were 17 inches from the ground. The front edges of the tables were 10 inches from the center of mass between the participant's feet and the two side tables were at 45° angle of the center axis.

At the verbal command "go", subjects pressed the home switch, then picked up a box filled with 20lbs of sand from the high table, twisted 45° to the right without lifting their feet, and placed the box onto the lower table, before returning to the upright position and depressing the home switch. The subject then reversed the movement. The task alternated between the left and right directions for ten minutes. Subjects were allowed to do this at their own pace using techniques that they were comfortable with. This resulted in the following switch sequences: 2 to 3, 3 to 2, 2 to 1, and 1 to 2 (Fig. 2a).

D. Data Recording Software and Hardware

The software used to record the data during the experiment consists of a program written in Python integrating data collection from several modules: Four Wiimote Plus devices over Bluetooth, a USB connected switch monitoring Arduino module [14], and a USB connected SparkFun heart rate recorder.

The switch monitoring Arduino module contains an Arduino C program to capture switch closure information. This avoided switch bounces and relayed the switch data along with a timestamp to the data recording laptop over USB.

The software was written in Python and ran on a laptop with Ubuntu 10.04 OS. The CWiid API [15] was used for Wiimote connectivity. The connections to the USB devices use the Python 'serial' module. The program has a simple GUI that guided the researcher through the steps to connect the Wiimotes. Once connected, the software recorded the data from each of the devices along with timestamps for synchronizing them later during analysis.

III. TECHNICAL PROCESS AND RESULTS

In order to have meaningful subject kinematic data to analyze, the raw rate gyro data from the Wiimote needed to be converted to the proper units and then extracted over time sequences based on the raw switch activation data.

A. Converting raw Wiimote data to useable form

The data from the Wiimote gyroscopes were recorded as integer values ranging from 0 to 16,383. The raw data were centered around the zero angular rotation values using the Matplotlib linear detrend function, which subtracts each value by the mean of the entire data set [16]. The data were converted to units of degrees per second using a factor of 13.768 [17].

B. Fast Fourier Transformation

The data were run through a 5th order Butterworth filter. The data were interpolated at a sampling rate of 100 samples per second and a Fast Fourier Transform (FFT) was applied to determine the parameters for the filter. From the empirical evaluation of the FFT results, it was determined that the low-pass filter parameters would be a pass-band of 8 Hz and block-band of 12 Hz (Fig. 3).

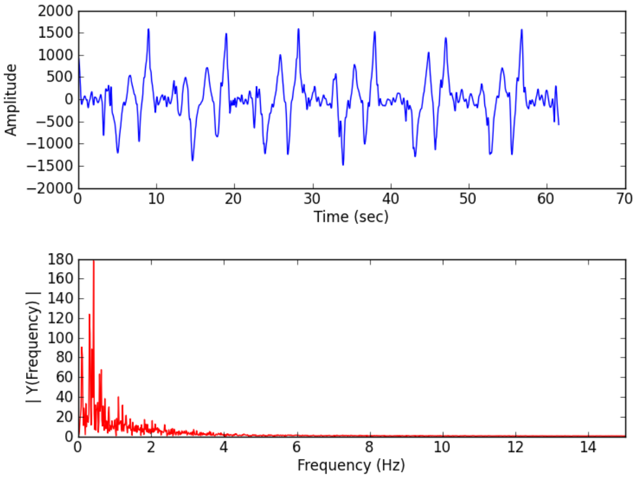

Figure 3. A Fast Fourier Transform was applied to the raw data (top) and the frequency spectrum was plotted (bottom)

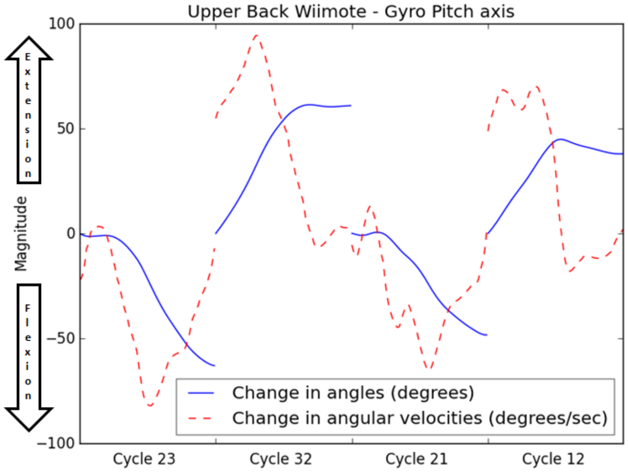

Figure 4. Change in angle (solid line) and change in angular velocity (dashed line) data from a representative subject.

C. Switch Processing and Normalization

The task was split into cycles based on when the boxes were moved. The switches were used to calculate the start and stop times for each of the movements. Data was filtered to remove improperly registered switch presses.

After switch processing and splitting up the data into each individual cycle, the data were normalized. The time axis was normalized by creating 100 intervals equally spaced between the start and end of the cycle and interpolating the values onto those timestamps. This determined a data value for every percentage of the way through the cycle. This was done in order to compare data between cycles.

D. Calculate Kinematic Data

The normalized rotation rates were integrated for each cycle to calculate the change in angle throughout the cycle. This determined the relative angle at each percentage through the cycle. To calculate the change in back, hip and knee flexion and extension angles the gyro axis corresponding to the direction of motion was selected. The pitch axis was used for the upper and lower back, and the yaw axis was used for the upper and lower leg, due to the orientation of the Wiimotes on the participant. The changes in hip, and knee angles were calculated by subtracting one Wiimote angle from another in the selected axis; upper leg from lower back, and upper leg from lower leg, respectively. The change in back angle was taken as the upper back Wiimote's change in angle.

Figure 4 shows the raw values of change in rotation rates plotted against the final change in angles obtained after processing the data. Figure 5 shows the average back, hip and knee angles for all the different cycles performed by an individual. The average and an envelope of one standard deviation are shown. The positive angles in the plots correspond to extension and the negative to flexion.

IV. DISCUSSION

Wiimotes are cost effective, self-contained instruments useful for measuring kinematic motion. There are several issues to contend with when dealing with the Wiimote MotionPlus modules as motion capture devices. These include the sensor drift, attachment of the Wiimotes to the participant and the lack of commonly available data recording and analysis software.

Wiimotes do not include a magnetic compass module to easily obtain an absolute angular motion reference. Rate gyros experience drift over time due to signal noise from the rate gyro modules making it difficult to measure the absolute limb angles. In this experiment this did not pose a problem because the analysis was performed using the change in angle over relatively short movement cycles.

As with other motion capture systems, the anthropomorphic variations of participants make rigid attachment of motion sensors difficult and result in a possible source of tracking error. Based on observation, the pitch axis of the Wiimotes was less accurate due to the looseness of the mounting system. The rigidity of the Wiimote attachment system used in this experiment could be improved upon by attaching Velcro straps directly to both ends of the Wiimote rather than a single Velcro strap with the Wiimote inserted in a neoprene pocket. This would require modification to the mounting system to maintain functionality of the buttons.

Wiimotes are designed and sold as gaming system peripherals; therefore, there is no official software to capture the motion data for kinematic analysis. There are a number of third party software libraries and example programs to capture data [15], but none are specifically written to do what is needed for an experiment similar to this one. The software developed here served to combine the signals from four different Wiimotes, and combine the information to determine the knee, hip and back change in angle of a participant.

The results of the physiological effects of this study will be published elsewhere [18]. The participants performed the lifting task pre- and post-intervention, with the intervention consisting of a 5 week regimen of traditional strength training or Wii Motion gaming, as well as a control group.

Future work could include further development of the software to analyze and filter the raw data of the Wiimote into meaningful kinematic data that could be of use to biomechanists and physiologists. This could also include

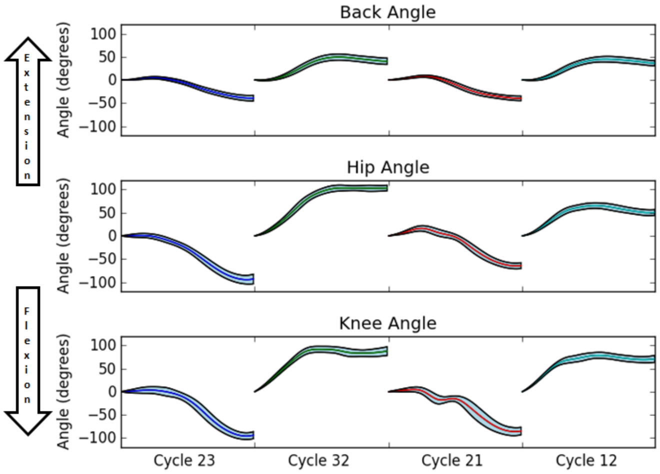

Figure 5. Average change in angles with 1 standard deviation envelope from a representative subject.

software development to record the signals from the Wiimotes over Bluetooth and store it on a smartphone. This mobile application could be enhanced to not only gather this information, but also perform basic analysis and display performance indicators. The purpose would be to develop a cost effective and portable solution for gathering kinematic data of the nature described in this paper in manufacturing plants such as poultry processing, or in harsh environments such as farms where little or no electricity is available to set up complex equipment to gather data about human movement performance.

V. CONCLUSION

Although further work is needed to make the analysis software more complete, and Wiimote attachment method more rigid, Wiimotes function well for capturing useful kinematic data making this a viable solution to use in everyday applications.

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