A Smartphone-based Posture Measurement System for Physical Therapy Applications

Synchronization of Multiple Devices via Bluetooth Network

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Abstract: A smartphone-based measurement system was developed for the purpose of measuring time series data for posture in the physical therapy field. We used the iPod touch (Apple Inc.) as hardware and iOS SDK as a software development tool. Posture data (pitch, roll and yaw) were taken directly from Euler angles or by transformation from quaternion data (qw, qx, qy, qz) to the Euler angles, depending on the orientation of the device. This approach allows continuity of data values. Data were stored in the Documents directory of the iOS Appli as a file in CSV format, which can be transferred to a PC via iTunes or sent by email as an attached file if a WiFi environment is available. In order to synchronize two devices, communication via Bluetooth was implemented. The accuracy of the data was checked by comparing with the OPTOTRAK data. Variation of posture while standing still and walking was recorded using this system for 50 elderly subjects.

1 INTRODUCTION

1.1 Background

The rapid aging of society in Japan has increased the importance of approaches that allow elderly people to live a healthy and independent life, in order to reduce medical costs and to lighten the burden of care.

Elderly people suffer various reductions in physical and vital functions, including decreased posture stability that reduces balance and the quality of walking. In turn, these changes reduce ADL (Activities of Daily Living) performance and QOL (Quality of Life). Displacement of the pelvis has been related to falling in elderly people (Ishigaki, et al., 2011), which indicates the importance of posture during walking, as well as while standing still.

Measurement of posture currently requires a laboratory environment or a stationary position sensor device (Ishigaki, et al., 2011). An easy-to-use mobile device for this purpose is required for wider application in community-dwelling elderly people.

1.2 Purpose of the Study

We have previously developed a system for evaluating tremor symptoms in Parkinson’s disease using the accelerometer installed in a game controller (Mamorita, et. al., 2009). The purpose of the present study is to develop a measurement system for posture during walking that is compact, easy to use, and inexpensive for physical therapy applications.

2 METHODS

2.1 Posture Measurement System

As hardware, we chose the iPod touch (Apple Inc.,

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101 g, 58.9 × 111 × 7.2 mm) and the built-in sensors of acceleration, rotation rate (Gyro sensor) and attitude. Software was developed as an “iAppli” using iOS SDK v.4.2 on an Apple Macintosh with Mac OS X (ver 10.6.5).

The system measures 3-axis acceleration, rotation rate and attitude. The coordinates of the system (when the iPhone/iPod touch is laid flat on the desk) are +Z, upward perpendicular; +X, rightward (in portrait view); and +Y, upward (in portrait view). We define three different modes of the device as follows, because the data from the attitude sensor is output to a different variable depending on the placement of the device.

F (Flat): The device is placed flat with the +Z axis pointing upward perpendicular.

H (Horizontal): The device is placed flat with the +X axis pointing upward perpendicular.

V (Vertical): The device is placed flat with the -Y axis pointing upward perpendicular.

The CMMotionManager class and the CMAttitude class of CoreMotion Framework were used to obtain the sensor data. Attitude data are given as the Euler angles (pitch, roll and yaw), quaternion data (qw, qx, qy, qz), and the rotation matrix (m_{ij}, i,j=1,2,3) (Apple Inc., 2010). The method of obtaining data from the sensor was changed as follows, depending on the positioning mode of the device.

F: Px=roll, Py= pitch, Pz= yaw, from the Euler angles.

H: Same as F, but adding 90° to Pz.

V: Euler angles were calculated from qw, qx, qy, and qz using the equations below, and 90° was added to Py to make the reference value equal to zero.

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Px = atan2(2(qw*qx+qy*qz), 1-2*(qx*qx+qy*qy));
Py = asin(2*(qw*qy-qz*qx);
Pz = atan2(2*(qw*qz+qx*qy), 1-2*(qy*qy+qz*qz));
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Data are stored in the “Documents” directory as a CSV file with a file name constructed from the date and time when the data were collected. These files can be transferred to a PC via iTunes or sent by email as an attached file if a WiFi environment is available.

The display during measurement is shown in Figure 1. Using pop-up menus, various functions can be accessed, including setting the measuring time (5, 10, 20(default), 30, 40, 60 sec), reviewing recorded data (up to 20 sec) with pinching in and out and scrolling , display of statistics , display of file names saved in the Documents directory, sending mail, and display of the instruction manual. The functions of connection by Bluetooth, selection of placement of the device (F/H/V), and on/off for saving a file were assigned to the buttons (see Figure 1).

If we want to measure the data from multiple points at a time, inter-device synchronization is required. This function was realized using Bluetooth wireless communication with GameKit framework (Apple Inc, 2010). Two devices are connected as peer-to-peer mode by Bluetooth pairing procedure (Figure 2).

2.2 Subjects and Measurements

The subjects in the study were 50 community-dwelling elderly females from 6 districts of Sagamihara city. The subjects had a mean age of 71.0 ± 4.9 (range: 61-82) years old, height of 152.3 ± 5.3 cm, and body weight of 52.4 ± 7.0 kg. Each subject answered questions on age, sex, height, body weight, history of falling, and amount of daily exercise. Measurements were made for physical functions and activity, including muscle strength for knee extension, bending angle of the upper body, stimulus response time of the body, 10 m walking time at a comfortable speed, and 10 m walking time at maximum speed.

To evaluate the posture of the trunk, the device was attached to the sternum with plastic tape so that the +Y axis of the device was parallel to the perpendicular direction (V position; Figure 3A). To measure rotation of the pelvis, another device was attached with a belt on the sacrum so that the +X axis pointed in the upward perpendicular direction (H position; Figure 3B).

The study was approved by the ethical committee of Kitasato University School of Medicine.

3 RESULTS

3.1 Evaluation of Posture Data

To evaluate the posture measurement, the results were compared with the integral of gyro data. An example is shown in Figure 4, where the blue, red and green lines show the gyro (Gx), posture (Px), and integral (Ix), respectively:

$$Ix(t) = \int Gx(t)\,dt.$$

The absolute difference | Px(t) - Ix(t) | increased with time (about 15.3° at t=20 s). However, if the device was returned to the initial position, Px(t) showed only a small error (about 0.5°) compared to the initial value Px(0).

3.2 Comparison with the OPTOTRAK

To evaluate the accuracy of measured data we used OPTOTRAK (Northern Digital Inc., Waterloo, Canada) and compared the two data. One of the best results is shown in Figure 5, in which the data from OPTOTRAK (blue line) and those from iPod (green one) were plotted. Time axes of two data were adjusted (27 sample points were shifted) so that the correlation between them was maximum (R=0.8886). The RMS (root mean square of differences) value was 2.15 (deg).

3.3 Example Data

In some cases we had observations that the yaw component was subject to a linear drift (Figure 6) especially in rapid movements. This phenomenon did not appear in the other components (pitch and roll) and the cause has not been identified yet.

4 DISCUSSION

A three-axis accelerometer is often used in walking analyses in physical therapy (Hemmi et al., 2009); (Kojima, et al., 2008), but a posture sensor has not been available. Therefore, the device described in this report is likely to be of value for many applications, particularly since it can be used outdoors, rather than being limited to the laboratory.

We used two devices to measure the movement of the subject at two positions of the body. In order to synchronize two devices (i.e. to adjust the time axis of the two data files), onset of the data acquisition was synchronized using Bluetooth wireless communication. This connection, however, was not so accurate nor stable; time to communicate between two devices varied from 1 msec to several 10 msec. Considering that the sampling frequency was 50 Hz, this is not satisfactory. We are trying to do several methods to avoid this problem.

Three or more devices can be synchronized, but the variance of delay will be larger. One can use WiFi to synchronize remote multiple devices if the wireless LAN environment is available, by which a global sensor network could be constructed.

5 CONCLUSIONS

A smartphone-based measurement system was developed for measuring time series data for posture in physical therapy. Data for variation of posture on standing still and during walking were recorded using this system in 50 elderly subjects. The results suggest that the system can serve as a new tool for walking analysis in physical therapy.

ACKNOWLEDGEMENTS

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APENDIX

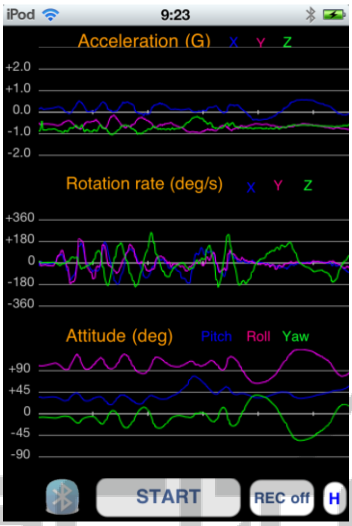

Figure 1: Screen shot of the system. Buttons at the bottom are, from left to right, Bluetooth connection, start/stop of measurement, recording to file ON/OFF and the placement of device (flat, horizontal or vertical).

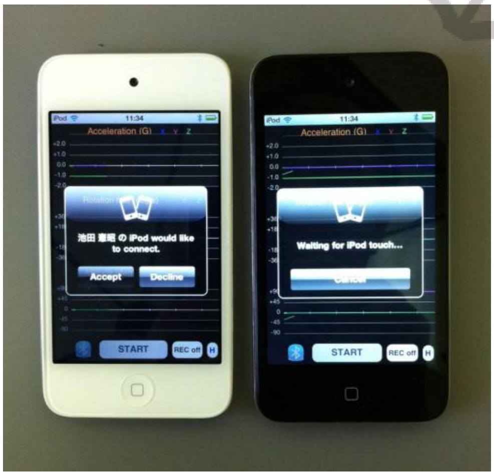

Figure 2: Pairing of two iPods via Bluetooth.

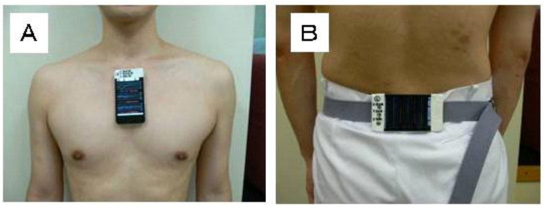

Figure 3: Mounting of the device. A: Vertical setting to measure the posture of the trunk. B: Horizontal setting to measure the rotation of the pelvis.

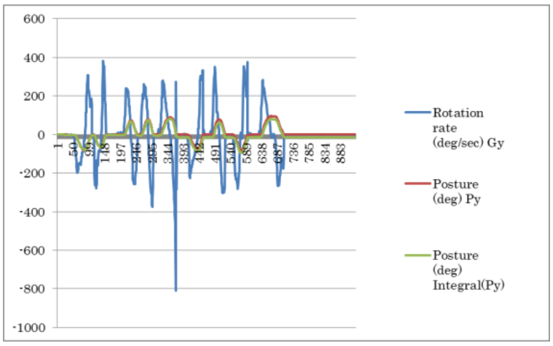

Figure 4: Comparison of posture data (red) and integral values (green) of rotation rate (blue).

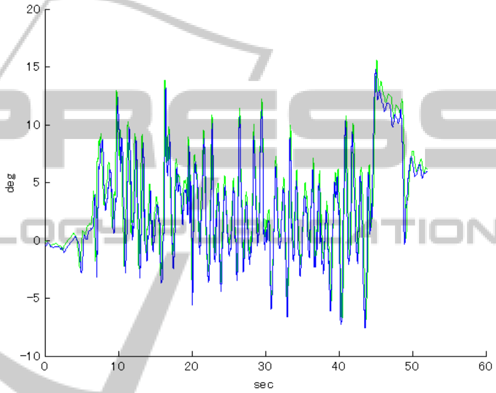

Figure 5: Comparison of iPod data (green) and OPTOTRAK data (blue).

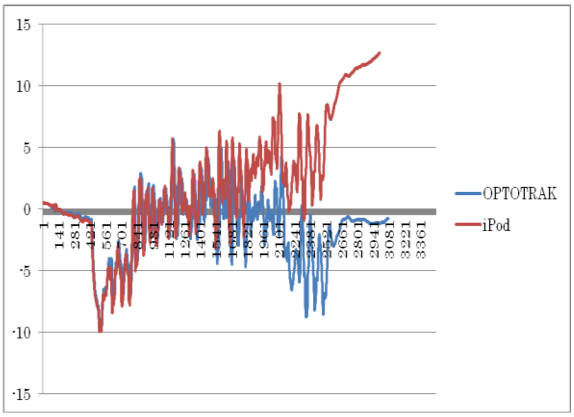

Figure 6: An example of drift. The last half of yaw component of posture data (red) measured by iPod was subject to a drift.