DEVELOPMENT OF A WEARABLE MOBILITY MONITORING SYSTEM

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ABSTRACT

Monitoring the mobility of people with physical disabilities is an important part of rehabilitation medicine. A Wearable Mobility Monitoring System (WMMS) that can monitor mobility within the home environment and the community for a long period could be a valuable tool for the clinical professional. Current available technologies, such as small accelerometers and the new generation of Blackberry handheld devices, provide a great opportunity to create such a system. This paper presents preliminary research on a proof-of-concept system that evaluates the Blackberry as a WMMS platform. For this pilot study, a simple biomechanical monitoring system was created using a commercial human motion capture system, the Xbus kit from Xsens Technologies. Java software was written for Blackberry 8800 to log and process real-time orientation data sent by the Xbus Master via Bluetooth connection, and also to log GPS coordinates and the GPS data acquisition time. This pilot project provides insight into the data logging expectations for a Bluetooth connection over typical Blackberry devices and real-time programming issues with WMMS applications.

INTRODUCTION

Mobility can be defined as the ability to move independently from one point to another [1]. Mobility is essential for maintaining independence, since mobility is required to perform many activities of daily life; such as, cooking, dressing, shopping, visiting friends, and so on.

Monitoring the mobility of a person with physical disabilities is an important part of rehabilitation medicine. Such monitoring can be used to determine mobility issues outside a hospital environment, evaluate the progress made during and after rehabilitation, and enhance clinical decision-making about the rehabilitation program (i.e., assistive devices and training exercises, etc). Thus, a WMMS that can monitor mobility within the home environment and the community over a long period could be a valuable tool for the clinical professional.

This paper presents preliminary research on a proof-of-concept system that evaluates the Blackberry as a WMMS platform. This pilot study falls within the bigger framework of creating a WMMS that monitors how a person moves in his or her own environment.

BACKGROUND

Current technologies on the market, such as small accelerometers and new generation of wireless communication devices, provide a great opportunity to create a WMMS. With the constant increases in processing power allowing for more complex real-time data processing, smart phones are a good choice as a central node of a Wearable Body Area Network (WBAN). Smart phones have been used to compile information on a person’s location and health status [2, 3]. A less obtrusive and easy to use WMMS can be created with multiple sensors integrated in a mobile phone so that monitoring can happen at only one location on the body [4].

Using mobile/smart phones as the hub of a WBAN takes advantages of the user’s acquaintance with mobile devices [2]. Other advantages are that smart phones and handheld devices are often already integrated with sensors; such as, accelerometers, a camera, and a global positioning system (GPS). In addition, these devices come with a programming development platform usually based on J2ME (Java version for mobile devices), which is known for its portability.

METHODS

System Architecture

The proof-of-concept WMMS system approach consists of a handheld device (Blackberry 8800 handheld, Research In Motion) serving as a hub or central node and a commercial motion capture system (Xbus Kit, Xsens Technologies, Netherland). The WMMS system captured lower limb 3D orientation, as well as GPS data, and GPS data acquisition time.

Figure 1 illustrates the proof-of-concept system architecture. Five motion trackers (MTx) were connected to the Xbus Master in a daisy chain...
configuration. The BlackBerry 8800 used Bluetooth to communicate with the Xbus Master during motion capture, to configure and initialize the Xbus Master and the five MTx sensors. Motion data was in orientation mode, expressed in quaternion units. Another command was sent to the Xbus Master from the BlackBerry to start data capture. Processing the incoming motion data was performed by the BlackBerry to calculate Euler angles for both knees and hips (4 set of Euler angles in total). The processed data, the GPS coordinates and the GPS acquisition time were saved to a file on the smart phone’s SD card. After completing data collection, the file was downloaded to a personal computer via USB to visualize the results.

Biomechanical Parameters Calculations

This biomechanical proof-of-concept system calculated joint angles of both knees and hips. The Cardan/Euler technique was used, which is one of the most widely used methods in biomechanics, to calculate 3D joint angles [5]. For each joint, the relative orientation between the distal sensor coordinate system and the proximal sensor coordinate system was determined by computing the rotation transformation matrix (RTM) of that particular joint.

First, both sensors have a rotation matrix relative to the global coordinate system G (s R):

\[
{s R}_i = \begin{bmatrix}
2q_i^0 + 2q_i^1 - 1 & 2q_i^0 q_i^2 - 2q_i^3 & 2q_i^0 q_i^2 + 2q_i^3 \\
2q_i^0 q_i^2 + 2q_i^3 & 2q_i^0 + 2q_i^1 - 1 & 2q_i^0 q_i^3 - 2q_i^1 q_i^2 \\
2q_i^1 q_i^3 + 2q_i^2 q_i^3 & 2q_i^1 q_i^3 - 2q_i^2 q_i^3 & 2q_i^1 + 2q_i^2 - 1
\end{bmatrix}
\]  

(1)

Where \(q_0, q_1, q_2, q_3\) are the quaternion numbers of one MTx sensor. The subscript S represents the sensor coordinate system and G the global coordinate system. The RTM for one joint (i.e., knee or hip) is then calculated with matrix manipulation:

\[
RTM = s_{proximo}^R \cdot R \cdot s_{distal}^G
\]  

(2)

Where \(s_{proximo}^R\) and \(s_{distal}^G\) represent the coordinate systems of both the proximal and distal sensors respectively. \(s_{proximo}^R\) is the rotation matrix of the distal coordinate system relative to the proximal coordinate system. From the resulting RTM, the Euler angles can be calculated:

\[
s_{proximo}^R \phi = \tan^{-1} \left( \frac{R_{12}}{R_{13}} \right)
\]  

(4)

\[
s_{proximo}^R \theta = -\sin^{-1} (R_{31})
\]  

(5)

\[
s_{proximo}^R \psi = \tan^{-1} \left( \frac{R_{21}}{R_{11}} \right)
\]  

(6)

The Euler angles \(\phi, \theta, \psi\) are also called roll, pitch, and yaw, respectively. Roll is the rotation around the X-axis, pitch the rotation around the Y-axis and yaw the rotation around the Z-axis.

The sensors placement for this application is shown on Figure 2.

Xbus Kit

The Xbus kit consists of an Xbus Master (XM-B-XB3) and 5 MTx motion trackers (MTx-49A53G25) [6-8]. The five MTx and the Xbus Master are interconnected in a daisy-chained configuration. The Xbus Master delivers power to the five motion trackers and retrieves the sampled data. With the output mode set to orientation mode with quaternion units, each MTx data record contains 4 float numbers. Each float number is 4 bytes long and corresponds with the single-precision floating-point value as defined in the IEEE 754 standard. For every data sample, the packet
sent is a total of 87 bytes ((4 bytes * 4 float number * 5 sensors) + 7 bytes for header). The message structure contains the following fields:

<table>
<thead>
<tr>
<th>PREAMBLE</th>
<th>BID</th>
<th>MID</th>
<th>LEN</th>
<th>DATA</th>
<th>CHECKSUM</th>
</tr>
</thead>
</table>

Java Programming

A Java application was developed using the BlackBerry Java Development Environment version 4.5.0.7. The Java application was then uploaded to the BlackBerry platform through the BlackBerry Desktop Manager. The Bluetooth API (application programming interface) from RIM was used to initiate a Bluetooth serial port connection and to write and read data from the port. The Java application used one thread to read incoming data from the Bluetooth port and then parse the data. The checksum was calculated for every sample to verify that there were no errors. If the checksum was correct, data bytes were converted to float numbers and then the biomechanical parameters calculations were completed. The resulting joint angles were then put in a writing queue waiting to be copied to a file. A second thread took data from the writing queue and then copied the data to a file along with the most recent GPS data. The file was stored on the BlackBerry SD card. The procedure used the FileConnection interface from the javax.microedition.io.file package. The GPS data was obtained using the LocationListener interface from the javax.microedition.location package.

Test Procedure

For the static trials, the Xbus Master was set to sample data at 50 Hz and at 25 Hz (5 trials per frequency). The Java application received the data from the Xbus for as long as there was no error sent by the Xbus Master. If the application was still running after 2.5 hours, data collection was stopped manually. For each trial, the time the system ran without error, the battery level of the BlackBerry before and after each trial, data loss, and the error that was stopping the Xbus Master were evaluated. During static trials, the Xbus Master was powered through a power adapter connected to the wall AC outlet.

Following the 50 and 25 Hz static data collection trials, another five static trials were run at 50 Hz but with minimal processing. For these trials, the Java application was modified to only receive motion data; no biomechanical parameters were calculated, no GPS data was received, and no data file was created. This was to verify that the Java application was not causing the Xbus Master to stop early during data collection.

Finally, dynamic trials were performed to simulate real orientation angle measurements. The sensors were attached on a subject’s lower limbs and hip (Figure 2). The Xbus Master was powered by battery. Five trials were run at 50 Hz and 25 Hz, for as long as possible. This set of dynamic trials was compared to the first set of static trials.

RESULTS

Table 1 shows the average time and the standard deviation for the static and dynamic trials, as well as the number of trials that stopped due to error. The error that caused the Xbus Master to stop sending motion data was error code 28 (0x1C), sent by the Xbus Master (timer overflow between the Xbus Master and MTx sensors). This error handling from the Xbus prevents data from being lost.

For both the static and dynamic trials, the application was able to run longer without error at 25 Hz than at 50 Hz. Only one trial at 50 Hz ran without error. The other 50 Hz trials stopped due to error code 28. At 25 Hz, the dynamic trials had only one stop due to error code 28, compared to two stops during the static trials. In addition, the averaged time was smaller during the dynamic rather than the static trials. For the static minimal trials, the average time was slightly better than the normal static trials at 50 Hz. However, the application still stopped due to the Xbus error code 28.

The battery trials indicated an average usage of 12.1 ± 2.6% per hour. At this rate, the BlackBerry would run out of battery power after approximately 6.8 hours.

No data were lost for all trials.

Table 1: Results

<table>
<thead>
<tr>
<th>Description of Trial</th>
<th>Average Time (minutes)</th>
<th>Standard Deviation (minutes)</th>
<th>Number of stop due to Xsens Error 0x1C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static (50Hz)</td>
<td>36.40</td>
<td>37.54</td>
<td>4</td>
</tr>
<tr>
<td>Static (25Hz)</td>
<td>99.60</td>
<td>47.33</td>
<td>2</td>
</tr>
<tr>
<td>Static Minimal (50Hz)</td>
<td>50.10</td>
<td>42.89</td>
<td>5</td>
</tr>
<tr>
<td>Dynamic (50Hz)</td>
<td>30.93</td>
<td>20.25</td>
<td>5</td>
</tr>
<tr>
<td>Dynamic (25Hz)</td>
<td>55.73</td>
<td>31.44</td>
<td>1</td>
</tr>
</tbody>
</table>
DISCUSSION

The error sent by the Xbus Master was always error code 28 (0x1C), implying that a timer overflow occurred during measurement (i.e. the Motion Tracker response was not received by the Xbus Master within the measurement period [6]). Comparison between static and dynamic trials showed minimal change in the number of errors encountered. The smaller average time during dynamic trials was caused by the Xbus Master’s batteries that were not able to last more than roughly 1.5 hours.

Results from the static minimal trials showed that, by removing processing, logging sensor data, and including GPS data, the total sampling time did not improve. The error code was always the same: timer overflow. The results suggest that the problems encountered during measurement were a result of external sensor errors.

Java programming problems with conversion of float numbers to a string resulted in excessively long execution times, causing the Xbus Master to stop sending data. To solve this problem, integer numbers were used instead of float numbers. The conversion of integer to string was less time consuming for the Java application.

CONCLUSION

A proof-of-concept system that calculated biomechanical parameters of the human body was created. The objective was to evaluate the BlackBerry as a Wearable Mobility Monitoring System platform.

The BlackBerry device demonstrated capability and good potential as a WMMS hub. Many of the problems encountered during data collection were due to the motion capture system. Thus, the choice of external sensors for long-term monitoring should be made with care.

This pilot study falls within the bigger framework of the creation of a Wearable Mobility Monitoring System that will monitor how a person moves in his or her own environment.

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REFERENCES