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Monitoring Physical Activities Using WBAN

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Abstract— **Recent technological advances in wireless communications, mobile computation, and sensor technologies have enabled the development of low-cost, miniature, lightweight, intelligent wireless sensor devices or "motes". A collection of these devices can be placed strategically on the key positions of the human body and connected by means of a wireless network to form a Wireless Body Area Network (WBAN). WBAN has recently attracted a great deal of attention from researchers both in academia as well as industry. This is primarily due to its unique capabilities and promising applications in areas like healthcare, fitness, sports, military and security. In the healthcare domain, WBAN promises to revolutionize healthcare system through allowing inexpensive, unobtrusive, non-invasive, ambulatory monitoring of human's health-status anytime, anywhere.**

In this paper, we propose a WBAN-based prototype system for remotely monitoring mobile user's physical activities and health-status via the Internet. The system consists of a WBAN and a remote monitoring server (RS). The WBAN comprises a personal server (PS) and a number of custom-made wireless sensor nodes each featuring a motion sensor for monitoring physical activity, and a temperature sensor for monitoring body temperature. The PS is a minicomputer equipped with a GPS receiver for tracking and monitoring user's location, a ZigBee module for communication with the sensor nodes, and a GPRS module for communication with the RMS. The RMS is an internet enabled PC. The sensors measure body motions and temperature and send the measurement data to the PS via a ZigBee network. The PS collects the data, process them and uploads them via GPRS to the RMS where the data can be visualized and displayed for user inspection and/or stored in a file system/database for post analysis.

Currently the system is in a prototype phase and is developed as a proof-of-concept. The proposed system, once perfected, can be used in different application scenarios. For example, for remotely monitoring elderly people, people with disabilities, patients undergoing physical rehabilitations, athletes or soldiers during training/exercises, etc.

Keywords— **Wireless, GSm, GPRS, Zigbee.**

I. INTRODUCTION

This paper is concerned with the design and implementation of a WBAN (Wireless Body Area Network) based prototype system for monitoring mobile user's physical activities and health status via the Internet. In this report, we will also give general information about the relevant areas like wireless body area networks definition, and possibilities), short-range and long-range wireless communication technologies, GPS technology, and GPRS communications.

A. *Background and Motivation*

In the recent years, there have been tremendous advances in wireless communications, sensor technology, mobile computing, and electronic industry. These technological progresses have led to the emergence of a new generation of intelligent wireless sensor devices which are very small in size (some as small as 1 cubic millimeter [4, 5]), light in weight, yet smart and powerful in functionality. Each sensor device is typically capable of sensing, sampling, processing and communicating one or more physical, physiological, or biological signals from the environment where are they are deployed. A number of these tiny wireless sensor devices can be seamlessly integrated into a Wireless Body Area Network (WBAN) to construct a wireless wearable system for monitoring human body parameters such as body motions, body temperature, heartbeat rate, brain activities, respiration, blood oxygen saturation, blood sugar level, etc.

Demands for wireless wearable body monitoring systems are increasing dramatically. The driving forces include increasing number of elderly people and chronically-ill patients who need long-term care and continuous monitoring. According to UN statistics [6], the worldwide population of those over 60 is predicted to reach 2 billion by 2050. Assuming current trends continue, this century will see the first time in human history that the old outnumber the young. Providing care for these will be a major challenge, hence it will be important in the coming years to develop technology which can reduce the workload on the caregivers.

On the other hand, the traditional monitoring systems fall short in many ways. These systems typically use equipments which are very costly, bulky, and unconformable to use due to wiring and cables which restrict user's movement and obstruct their normal activities. Besides, they often require the user to stick to the place where the monitoring equipments are deployed. For 1 example, patients need to stay in hospital for the duration of the monitoring sessions. Thus, too much resource, efforts and costs can get wasted (e.g., dedicated beds, dedicated healthcare staffs, costs to stay in hospital…etc). In addition, monitoring is typically discontinuous and limited to a specific period of time, which only gives a "snapshot" of the health status. Thus, transient anomalies may go undetected! WBAN-based body monitoring systems have the following advantages over the traditional Wire-based monitoring systems:

- •WBAN systems utilize low-cost, tiny, lightweight, wireless sensor devices which do not interfere with (or restrict) user's normal activities.
- •With WBAN, a user can be monitored at anytime, anywhere, and for any duration.
- •WBAN enables concepts like m-health (mobile health) and pervasive/ubiquitous health monitoring [7, 8, and 9].

B. *Goal of the paper*

The primary goal was to design and develop a working WBAN prototype system which could be used for monitoring mobile user's physical activities and health-status via the Internet. Other objectives of the paper were:

• To understand the issues associated with designing and implementing WBAN systems

• To find out what wireless technologies are suitable for building a WBAN system for remote body monitoring.

• To develop a test bed for future researches on WBAN.

C. *Proposed WBAN Prototype System*

The WBAN comprises a number of wireless sensor nodes and a personal server (PS). ZigBee is used to implement the WBAN, and the network has a star topology, where all the sensor nodes (configured as ZigBee end devices) communicate with a central node (attached to the PS) which is configured as ZigBee coordinator. See the following subpapers for further detail about the sensor nodes, the PS and the RMS.

The PS can be mounted, for example, on the hip or waist. The sensor nodes distributed over the user's body. Although three types of sensors (ECG, temperature, and motion sensors) should have been used in the system, however, due to the limited time allowed for the paper, the ECG sensor could not be implemented. Therefore, the current prototype only incorporates temperature and motion sensors. The sensors forward measurement data to the PS through ZigBee radio links. The PS collects the data, processes them, and uploads them through GPRS to the RMS. The PS also collects data from a GPS receiver attached to the PS, and forwards the data through GPRS to the RMS where the data can be processed further and displayed in real-time for user's inspection and/or stored in a database/file system for post-analysis. The WBAN sensor nodes are custom-made devices, designed based around the TI CC2480 and TI MSP430 microcontroller. The PCB is designed using a simple double layered structure, while keeping the maximum size of the board to 23x25mm. Each sensor node incorporates two types of sensors: 1) motion sensor and 2) temperature sensor. Although the current prototype only incorporates accelerometer and temperature sensors, however, other types of sensors (like ECG, EEG, EMG and SpO2) can easily be added to the system. The motion sensor can be used for monitoring body motions and gesture recognition, whilst the temperature sensor can be used to monitor body temperature or the temperature of the ambient surrounding the body.

II. System Components

- The proposed WBAN system consists of the following key elements:
- A number of ZigBee-enabled wireless sensor nodes (SNs) One node configured as ZigBee coordinator device (which we call it "ZNC" short for ZigBee Network Coordinator) and is attached to the PS board.
- A number of sensor nodes configured as ZigBee end-devices, each featuring a motion sensor (tri-axial accelerometer) and a temperature sensor
- Personal Server (PS)
  - The PS is a Linux-based, single-board minicomputer equipped with:
  - A GPS receiver module
  - A built-in GSM/GPRS module
  - A ZigBee device (the ZNC).
- Remote Monitoring Server (RMS)
  - The RMS is based on a Linux-powered internet-enabled PC .

*A. **Sensor Node (SN) - Hardware Platform***

Two types of sensors have been integrated into each sensor node platform:

• Motion sensor (3-axis accelerometer)

• Temperature sensor (NTC Thermistor)

As motion sensor, the MMA7260 accelerometer module from Feescale Semiconductor [64] is used, which is a low-cost capacitive Micro machined Accelerometer featuring signal conditioning, 1-pole low pass filter, temperature compensation and g-Select that allows for the selection among 4 different sensitivities. It also supports Sleep Mode that makes it ideal for battery powered electronics. Other features include:

- MMA7260 Accelerometer Features
- Selectable Sensitivity (1.5g/2g/4g/6g)
- Low Current Consumption: 500 μA
- Sleep Mode: 3 μA
- Low Voltage Operation: 2.2 V – 3.6 V
- 6mm x 6mm x 1.45mm QFN
- High Sensitivity (800 mV/g @ 1.5g)
- Fast Turn-On Time
- Low Cost

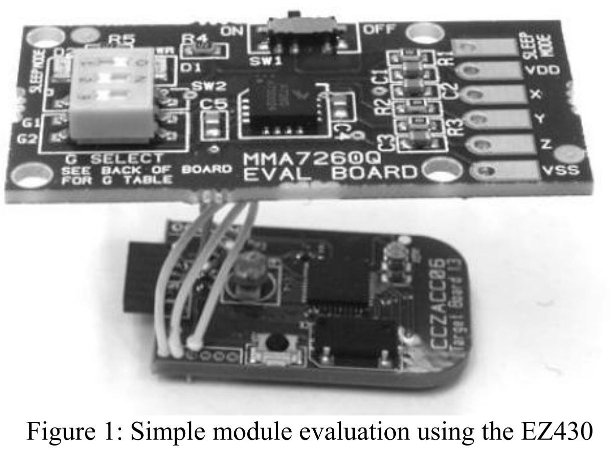

Figure 1: Simple module evaluation using the EZ430 connected to MMA7260 accelerometer module.

For evaluation purposes, MMA7260 evaluation board is used as shown in the figure 1

The temperature sensor is based on the idea of Negative Temperature Coefficient (NTC), which is basically a resistor that changes its resistance depending on the temperature. The NTC Thermistor was implemented using a version of Wheatstone bridge. The implementation detail is reported in [29].

B. ***How GPS Works?***

Signals from navigation satellites include:

- Binary timed code

- Almanac with position of satellite
- Accurate time (from atomic clocks)

With this information a GPS receiver can calculate the time the coded signal takes to get from the satellite to the receiver. Then it uses a technique called “trilateration” which means the receiver collects signals from at least 3 satellites to compute its location as following:

C. *Trilateration*

- Time for signal to travel from satellite to GPS receiver is calculated
- The distance from 3 or more satellites is calculated from that time.
- Receiver calculates its position on earth based on these 3 distances.
- If the distance from three satellites is known, the point of interpaper between the three distances is the receiver’s location.

D. *How GPS receivers calculate Time?*

- Almanac tells receiver exactly where each satellite is located.
- Receiver acquires signals from each visible satellite.
- Coded signal – receiver knows when signal left the satellite.
- Difference in coded signal between time it left satellite and reached the unit is.
- Exact time for signal to reach receiver can be calculated for each satellite in view

E. *How GPS receivers calculate Distance?*

- Timed coded signal travels at speed of light (which is known)
- Offset in timed coded signal from satellite to receiver provides time
- Distance from receiver to satellite is calculated by (time offset X speed of light)
- Distance to a minimum of 3 satellites is needed to determine position.

F. *The NMEA Standard*

NMEA is a standard protocol defined by the U.S.-based National Marine Electronics Association (NMEA) for communication between marine electronic devices such as echo sounder, sonars, navigation instruments, gyrocompass, autopilot, and GPS receivers.

NMEA defined two different standards; one is called NMEA 0183 and the other is NMEA 2000. Most of the GPS receivers support NMEA 0183. The NMEA 0183 standard uses a simple ASCII, serial communications protocol that defines how data is transmitted in a "sentence" from a "talker" to a "listener", for example, from a GPS unit to a computer or mobile phone connected via serial port. NMEA 0183 specified the serial configuration as shown in the table:

The NMEA 0183 standard has also defined the contents of each sentence (message) type so that all listeners can parse messages accurately.

G. **Specification of the NMEA Messages**

- The following describes the NMEA messages:
- Each NMEA message starts with a dollar sign '$'
- The next five characters identify the talker (two characters, e.g. GP for GPS) and the type of message (three characters, e.g. RMC).
- The rest of the fields are comma separated
- The first character that immediately follows the last data field character is an asterisk '*'
- There is a two-digit hexadecimal number representing the checksum which comes immediately after the asterisk. The checksum is the exclusive OR of all characters between the '$' and '*'.
- Each NMEA message or sentence ends with <CR><LF>

H. *Parsing NMEA Stream*

A GPS receiver which uses NMEA 0183 protocol generates data stream consisting of a series of "sentences" delimited by a new line character. Each sentence starts with a single dollar sign ‘$’ followed by five character identifier. The NMEA 0183 standard has defined many different sentences, but only a few of them are usually supported by a typical GPS receiver. The most useful sentences include:

- $GPGGA - Global Positioning System Fix Data
- $GPGLL - Geographic Position, Latitude/Longitude
- $GPGSV - GPS Satellites in View
- $GPRMC - Recommended Minimum Specific GPS/TRANSIT Data
- $GPVTG – Course Over Ground and Ground Speed
- $GPZDA - UTC Date/Time and Local Time Zone Offset.

Out of the above NMEA sentences, $GPRMC is the most widely used, since it contains most of the interesting information, like position fix data (latitude and longitude), time in UTC (Universal Coordinator Time), as well as other derivates like speed. The general format of $GPRMC is given below along with an example.

Format:

$GPRMC,<1>,<2>,<3>,<4>,<5>,<6>,<7>,<8>,<9>,<10>,<11>,<12>*<13><CR>
<LF>

Example:

$GPRMC,104549.04,A,2447.2038,N,12100.4990,E,016.0,221.0,250109,003.3,W,A*22<CR><LF>

Note: The checksum field starts with a ‘*’ and consists of 2 characters representing a hex number. The checksum is the exclusive OR of all characters between ‘$’ and ‘*’.

III. Specification of the GPS Receiver

The GPS receiver we have used in the paper is called “GPS-310FA” which is manufactured by RF Solutions Ltd [61]. The receiver supports NMEA 0183 protocol and produces six types of NMEA sentences, GGA, RMC, GLL, GSV, VTG, and ZDA. See paper 4, paper 4.5.5 for the technical specification of the receiver. And, for extra detail consult GPS-310FA data sheet [61].

A. *Using GPS Time for Time Synchronization*

As mentioned earlier, the GPS navigation satellites or Space Vehicles utilize atomic clocks (cesium and rubidium) which give very accurate time. This accurate time can be used as a global reference time to synchronize local system time (which is typically from crystal oscillator clock that is prone to frequent drifts). For example, we can use the UTC time obtained from a GPS receiver to calibrate the hardware clock on the Personal Server's board or to time-stamp WBAN sensor messages immediately after reception at the PS. In the later case, a precise time to timestamp the messages can be calculated using a simple equation as shown below:

$$T_{stamp} = T_{gps} + (T_{sys2} – T_{sys1})$$

Where: Tstamp is the time which we want to use to time-stamp a sensor message.

- Tgps is the UTC time which is obtained from the GPS receiver
- Tsys1 is the system time when the first NMEA message containing Tgps has been received
- Tsys2 is the system time when a sensor message (to be time stamped) has been received Design and Implementation of the Personal Server And Application Software.

IV. OVERVIEW

In this paper we will discuss the design and implementation of the application software which runs on the Personal Server (PS). We will first describe the required functionalities of the application (i.e., the tasks that the PS application should perform), and then discuss how we have designed and implemented the application so that to meet the requirements. In this paper, we will also provide general information about serial-port programming in Linux, modem communications using AT commands, GPRS communications using AT commands, and Pointto-Point Protocol (PPP).

A. *The Required Functionalities of the Personal Server Application*

Before designing the application, we have to first decide what the application should do, that is to specify the requirements for the application, and then take approaches to find a proper solution which fulfills the requirements. After studying the initial system requirements, it was decided that the application should, in general, be responsible for the following tasks:

Communications with the devices on the PS board

- Data Collection
- Data Processing & Manipulations
- Data Buffering
- Data Compression
- Data Encryption
- Data Communication

The above tasks are briefly described in the following paper.

System Testing and Evaluating To evaluate the performance of the custom-made sensor nodes as well as the performance and reliability of the entire WBAN prototype system, we have performed a number of measurements and tests. In this paper, we will present and discuss some of the initial results which have obtained from the testing and evaluation of the WBAN prototype system. The paper is divided into three papers. The first paper describes the test bed and the methodology used to collect and process WBAN data. The second paper presents and discusses some of the WBAN data which have been collected via GPRS. In the third paper, we will discuss how GPRS poor throughput performance affects the overall performance of our WBAN system and identify the factors affecting the user-level performance of GPRS.

V. RESULTS AND SYSTEM DATA

This paper covers the initial results obtained from the testing and evaluation of the prototype system and presents some of the WBAN sensor data collected via GPRS. Firstly, some of the data collected from the accelerometer and temperature sensors will be presented. Then, we wil discuss how we have handled the GPS data. Finally, we will present a human body model which we call it "Body Avatar" that has been created from the accelerometer sensor data.

A. *Accelerometer Sensor Data*

Figure 2 & 3 show the accelerometer data received from the total of five sensor nodes used. Figure 2 presents the accelerometer data collected from two of the WBAN sensor nodes which have been attached to the right arm.

Figure 3 showstheaccelerometer data from the sensor nodes placed on the torso and the left arm. Each accelerometer sensor has 3 axes, X-Axis, Y-Axis, and Z-Axis. The sensors were configured to send one package of data every 20 seconds, where each package contained 10 samples per second per axis on the accelerometers. Although this is rather low-rate, however, it can significantly reduce the power-consumption.

The sensor firmware are constructed to be able to send up to 200 samples per second, but it was desired to show that this is not necessary in order to get good readings from the accelerometer data.

From figure 2 and 3, it can be seen that nice and consistent data is received with a few exceptions. The sensor at the left shoulder has lost three packages in total, while the sensor on the torso has lost one package. Thus, the system has lost a total of 4 of the 75 data packages sent, which means that the system currently get roughly 95% of the data through. The firmware of the sensors still not entirely perfected, but with some improvements this number should be able to g et higher in addition to some improvement in the design of the sensor boards.

It can also be seen from the figures that there is some delay (time-gaps) between the data package. Each data-package sent had an average delay of 91ms. This delay could be due to the local path losses causing the ZigBee to take longer time to get the data through. Or, it could be due to inadequate design of the firmware controlling the sensor nodes.

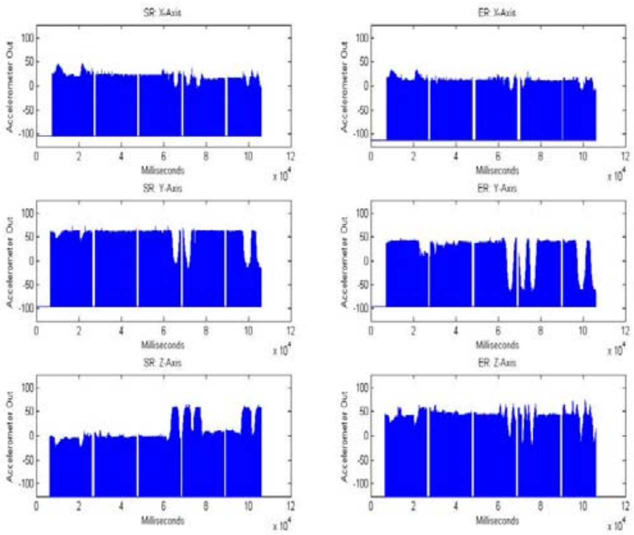

Figure 2: Accelerometer data of the sensor nodes attached to the right arm

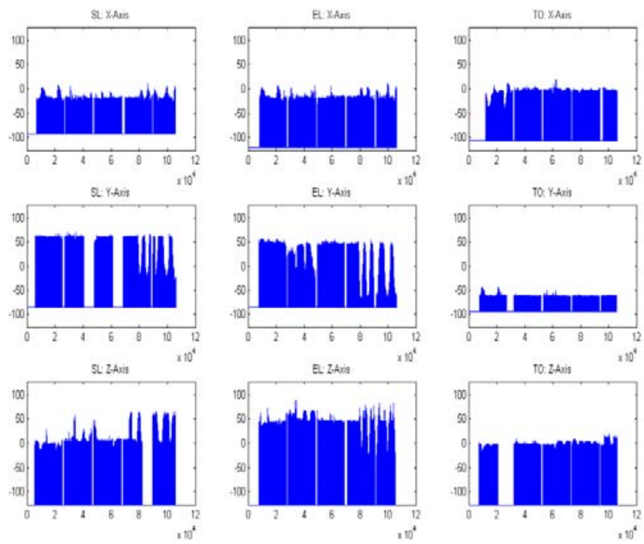

Figure 3: Accelerometer data of the sensor nodes attached to the left arm and torso

B. *Temperature Sensor Data*

To evaluate the sensing capability of the temperature sensors developed during the paper, another test was performed. A hot-air gun (or heater) was used to heat up one of the sensor nodes attached to the left arm. The hot-air was applied and removed systematically to artificially change the temperature of the sensor device. After approximately 110 seconds from the beginning of the test the hot-air was gently applied for about 60 seconds, which caused th sensor to heat up approximately 14 degrees. The hot-air was then removed and the sensor was allowed to cool down naturally. The result of the test is shown in the figure 4.

The temperature sensor was configured to send 1 sample per second, i.e. the sampling frequency was set to 1Hz. This low sample rate reflects the fact that temperature fluctuations are relatively slow, so a higher sample rate is not really needed in normal environmental conditions

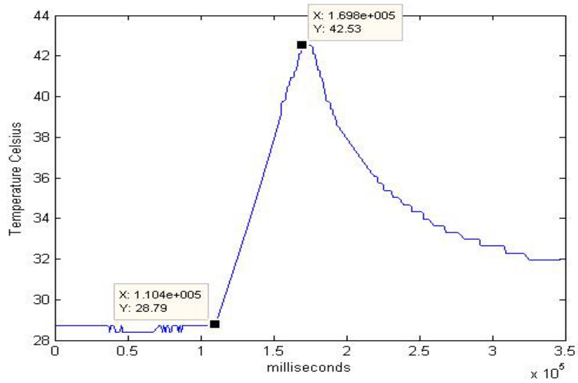

Figure 4: Temperature from worn arm sensor while applying and removing a heat source.

C. *GPS Data*

The GPS receiver is attached to the Hectronic H6039 board which was assigned to be used as Personal Server (PS). As we mentioned earlier, the board was initially designed for automotive applications and assumed a car power supply (with 24V DC output) to be used to power the board. Because of that, only indoor testing could be made, which means that the location information obtained from the GPS receiver is unrealistic— since the receiver is unable to detect enough number of GPS satellites required to calculate its position. Nonetheless, the GPS receiver continuously generated NMEA messages which were useful to test the functionality and reliability of the PS application. For testing purposes, the PS application has collected the NMEA messages (sentences), processed them, and uploads them via GPRS to the remote internet host (i.e., the RMS) in the form of files with the following format:

D. *Body Avatar—Monitoring Physical Activity in Real-Time*

The snapshot images shown in figure 5 demonstrating a simple 3D avatar imitating human body motions (postures). The avatar is created based on the data received from the accelerometer sensors worn on the body. A custom-written MATLAB program is used to process the accelerometer data and calculate the avatar. Detail of the algorithms used to calculate the avatar is reported in [29].

As illustrated in figure 5 D, five sensor nodes are placed on the arms and torso of the user*, two nodes around the elbow joint of each arm, and one node on torso. Since we only had 5 sensor nodes at disposal, only the upper body could be simulated. Modeling the entire body of a human would require more than 10 sensor nodes.

The idea of avatar like the one proposed can be used for different purposes. For example, for gesture/posture recognition, for fall detection in elderly people, for monitoring people with disabilities (e.g., wheelchair users) or patients undergoing physical rehabilitations (e.g. after a car accident).

It can also be used in sport and military applications, for instance, for remotely monitoring athletes or soldiers during physical activities.

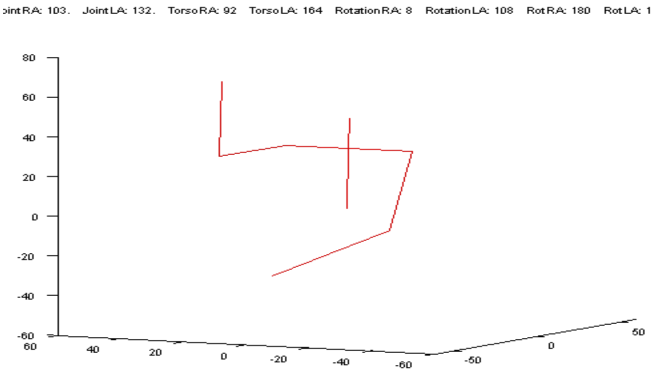

Figure 5: Avatar's Pose (a)

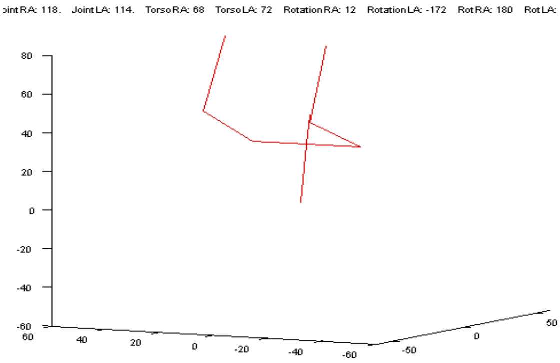

Figure 5: Real Pose (B)

Figure 5: Avatar Pose 2(C)

Figure 5: Real Pose 2(D)

E. *GPRS Performance*

The poor throughput performance of GPRS substantially affects the overall performance of a WBAN system relying on GPRS for extra-BAN data communications. For example, in our WBAN system, the ZigBee module attached to the PS board is capable to collect data from the sensors at around 130kbit/s (effective bit rate) and forwards the data via serial connection at the rate of 115200 bits/s (115.2kbps) to the ARM-based microcontroller on the PS board. The Microcontroller can then send the data via serial connection at the speed of 57600 bits/s (57.6kbps) to the GSM/GPRS modem. However, the modem is only able to send (upload) the data at less than the theoretical maximum speed of 16kbps or 24kbps (when CS-1 or CS-2 is used, which is often the case) or 40kbps in the best case (when CS-4 is used). Thus, the GPRS radio link between the PS and the RMS is the bottleneck link in our WBAN system which affects the overall throughput performance of the system.

VI. CONCLUSIONS

The following outlines some of the conclusions drawn from the paper and the paper work

- Wireless Body Area Network (WBAN) is becoming a major technological trend for ambulatory and prolonged body monitoring.
- A durable, low cost, lightweight and compact WBAN system for remote monitoring is fully possible.
- A working WBAN prototype system has been developed as a proof-of-concept.
- Zig Bee allows low-cost and durable WBAN sy stem to be constructed; however, it sets a limit on real-time performance of the system.
- A C-based, Lightweight, multi-threaded, embedded application software has been developed for the Personal Server, which is capable to collect, process, and communicate the WBAN sensors' data with an internet-enabled remote server securely via GPRS.
- GPRS provides an "always-on" ubiquitous data communication service. However, its
- Poor throughput and latency performance puts limitations for time-sensitive real-time applications. For those applications, 3G UMTS is a better alternative.

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