Pervasive Healthcare System for Real-Time Activity Monitoring using Integrated ADXL345 Tri-axial Accelerometer and Android Smartphone

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Abstract. In this study, we report implementation of a novel Pervasive Healthcare System (PHS) for real-time activity monitoring. The prototype uses integrated ADXL345 tri-axial accelerometer and android Smartphone to provide quality pervasive healthcare services to users at affordable costs. Pervasive healthcare is healthcare to anyone without time and location constraints while increasing both coverage and quality of services. The prototype intelligently monitors body movements of an individual to gain valuable information about the individual’s daily activities which would be analyzed to improve health and quality of life of the individual. We define the PHS architecture, summarize the implementation and show measurement results when tested on life volunteers, it gives high accuracy in activity monitoring of a patient using changes in acceleration patterns and exceeding threshold values.

Keywords: Accelerometer, Body, Healthcare, Monitoring, Network, Pervasive, Sensor, Wireless

I. INTRODUCTION

The increasing population of elderly is one critical demographic processes currently experienced worldwide. The percentage of people over the age of 65 years has increased, making up 10 percent of the world’s population and it is expected to further increase to 22 percent by the year 2050 [1]. This increase has led to prevalence of chronic health conditions among elderly and providing healthcare resources to adequately cater for their healthcare needs is placing extra burden on the current healthcare systems and healthcare providers [2, 3]. Due to the fragile nature of elderly people, they require a comprehensive healthcare system that fulfils their personal needs. This gives rise to an increased focus on developing healthcare systems capable of caring for the elderly and improving their health, well-being and independence. The health issues faced by the elderly are often chronic and complex. One of the most serious health risks they face is falling, which is accepted in medical sector as the leading cause of death for the elderly. Many of them who survive a fall end up suffering from fractures at hips or knees. Even with correctional healthcare services like surgery and rehabilitation 40 percent of them cannot live independently anymore and 20 percent die within a year [4].

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Developing novel healthcare monitoring and reporting applications would assist in detecting almost 80 percent of falls and medical services would be provided immediately to the injured elder. A fall quickly responded to, can prevent long term disabilities.

The increasing use of mobile technologies and advances in Wireless Body Sensor Networks (WBSNs) have revealed the possibility of providing pervasive healthcare monitoring to patients at high risks of falls and other chronic diseases. The body sensors which characterises WBSNs are deployed on the body of patient for real-time data monitoring, acquisitioning, transferring and processing. Using WBSNs for healthcare monitoring will help to improve overall quality of services for patients, reduce stress on healthcare systems and healthcare providers while enhancing their productivity, retention, quality of life and reduce costs of healthcare services. Such systems are termed pervasive, which means healthcare to anyone, anytime and anywhere by removing location and time restrictions while increasing coverage and quality of services [5]. Pervasive healthcare systems offer long-term real-time physiological data measurement and collection. They ensure disease prevention, healthcare maintenance and regular check-up, healthcare monitoring, incidence detection, management, emergency intervention, transportation and treatment [6]. Furthermore, they allow patients to reduce healthcare costs through more efficient use of medical resources and early detection of medical conditions. Technologies that support pervasive healthcare service provisioning can be seamlessly assimilated into patient’s daily routine such that they become invisible, thereby improving autonomy and quality of life of patients [7]. The requirements for pervasive healthcare systems include system portability, usability, reliability, accessibility to variety of services and flexibility. In addition, healthcare systems should be secure and guarantee privacy, allow service personalization, responsive and support automatic decision making.

The prototype Pervasive Healthcare System (PHS) reported in this paper is a real-time activity monitoring tool that is designed to monitor daily physical activities of elderly in real-time using a WBSN integrated sensor (tri-axial accelerometer) and a personal server (android Smartphone). We implement tri-axial accelerometer to continuously monitor physical activities such as standing, walking, running and falling. Physical activity data monitored are transmitted via IEEE 802.11/Wi-Fi to android Smartphone and uploaded to health server. The prototype unobtrusively monitors activities of patients and provides diagnostic healthcare services which can be enjoyed even with limited financial resources. The system is designed to raise an alarm if a fall or an abnormal patient behaviour is detected as it may be indicating a health problem. This will improve the chances of a timely medical intervention and give patient a sense of security, confidence and prolong patient independence. Furthermore, our prototype improves on existing activity monitoring systems which have not been able to address issues of high healthcare costs and low quality of healthcare services provided. Through smart designing methods, PHS processes all events and healthcare services are provided according to the events. The provided services are accessible at the users’ ends (patients and doctors). The current study was aimed at implementing a real-time activity monitoring application that functions in a pervasive healthcare environment.

II. RELATED WORKS

In healthcare, accelerometers have various applications in monitoring movements for prevention, diagnostics, therapy and rehabilitation. Several accelerometer based health monitoring systems have been proposed and developed for healthcare monitoring to help a potential patient or user improve quality of life. An activity monitoring eWatch system designed by [8] was based on a multi-sensor platform worn on different body positions. Their system identified user's activity in real-time using multiple sensors and classifies them during a day. While monitoring user’s activity, they compare multiple time domain feature sets and sampling rates and analyze tradeoff between accuracy of activity monitoring and computational complexity. With the aim of enhancing accuracy in monitoring activity, [9] proposed a methodology to determine occurrence of falls from among other human movements. Their methodology involved collecting source data using wearable and mobile platforms based on three-axis accelerometers to measure subject kinematics. Data collected was processed and classifiers employed were based on neural networks and k-nearest neighbors. Integrating these processes their methodology resulted in movement tracking for four distinct activities over several test subjects.

In a later attempt to develop a system that allows accurate and timely delivery of healthcare, [10] developed a context-aware middleware infrastructure for pervasive healthcare. The middleware offers several key enabling system services that consist of P2P-based context query processing, context reasoning for activity recognition and context-aware service management. It was designed to support development and deployment
of various homecare services for elderly. These services include patient monitoring, location-based emergency response, anomalous daily activity detection, pervasive access to medical data and social networking. An activity monitoring for pervasive healthcare was described by [11]. Their work described an easy-to-configure context-aware mobile application, capable of estimating and evaluating user's activity all day long. [12] presented a study implementing a real-time classification system for different types of human movement associated with data acquired from a single waist-mounted tri-axial accelerometer unit. Their system sort to perform a vast majority of signal processing on wearable unit platform using embedded intelligence to distinguish between periods of activity and rest, recognise postural orientation of the wearer, detect event such as a fall and provide an estimation of metabolic energy expenditure. [13] described a waist mounted tri-axial accelerometry (Triax) system with a remote data collection capability to provide unsupervised monitoring of elderly. Their system provided long term monitoring results for basic activities including lying, standing, walking and running.

This current study improves on these existing real-time activity monitoring systems using a single ADXL345 tri-axial accelerometer. It designs and implements a system that does not only effectively monitor a patients activities in real-time, but through integration of various pervasive health technologies, it also provides patients with various important services to manage their healthcare needs more effectively.

III. SYSTEM ARCHITECTURE

The PHS is designed to monitor physiological data that show activities and fall incidents of elderly. Fig. 1 shows the PHS architecture, which consists of an integrated ADXL345 accelerometer, personal server and health server as principal components.

![Fig. 1. System Architecture of PHS](image)

The accelerometer monitors physical activities and transmits information to personal server. We use an android Smartphone with operating system 2.3v as personal server, hereafter simply referred to as Smartphone. A Wi-Fi radio is attached to the arduino platform to enable data transmission to android Smartphone which sends a detected fall or other activity data through the reporting algorithm to health server. Services are accessed through Graphical User Interface (GUI) of the Smartphone and some services configure the accelerometer to access services on health server. The health server is the main service domain which is implemented by various high-performance servers, large storage capability workstations, powerful communication devices and database. The workstations receive and store patient’s electronic health records.
and provide secure web service links and emergency call center functions. Patients and medical professionals can have access to the health server through web services anywhere, anytime. The process simply involves logging onto the server which gives patients access to their data while it gives medical professionals access to only authorized data.

IV. PHS IMPLEMENTATION

Fig. 2 shows the developed integrated accelerometer hardware which consists of an ADXL345 tri-axial accelerometer implemented on an Arduinofio platform, an attached Wi-Fi radio and Li-Ion battery. The accelerometer satisfies design requirements of minimum weight, reduced form factor, low-power consumption through configuration, seamless integration with PHS, standard based interface protocols and patient-specific customization. The Arduinofio platform has an ultra-low power ATmega328p processor with a clock speed of 8MHz, flash memory of 32Kb, SRAM of 2Kb and programmed in C/C++ based on wiring an open source programming environment. Arduino supports several low power operating modes, consuming 0.2mA in active mode, 0.1μA in power-down mode and 0.75 μA in power saving mode. The WiFly radio is IEEE 802.11/Wi-Fi compliant with configurable power output, maximum data rate of 464Kbps, a pre-loaded firmware to simplify integration and minimizing development time. Its hardware provides PHYsical (PHY) and some Medium Access Control (MAC) layer functions. The ADXL345 tri-axial accelerometer has a high resolution (13-bit) measurement at up to ±16g and is capable of measuring acceleration along X, Y, Z axes. The output data from the ADXL345 is in digital format of 16-bit twos complement and is accessible through either a SPI (3or 4wire) or I2C digital interface.

Data sampling rate of ADXL345 accelerometer is in range of 10-100Hz to achieve high data flow. The accelerometer sampling at a frequency of 50Hz is worn round a user’s waist using a modified mobile-phone carry case. The accelerometer is designed to monitor and transmit patients’ activities on X, Y and Z axes. These activities are translated into the following corresponding motion states of patient, standing (ID_1), walking (ID_2), running (ID_3) and falling (ID_4). The basic accelerometer operations are operated by a workflow algorithm programmed into it. Both tri-axial accelerometer and Smartphone are equipped with Wi-Fi technologies, enabling mutual wireless data communication. Data are transmitted from the tri-axial accelerometer to Smartphone in real-time. The Smartphone is programmed with alarming, comparison and reporting algorithms. The alarming algorithm detects falls by considering the patient’s adaptive posture and cognitive injured body region. The alarming algorithm analyzes the detected parameters and determines injury level to provide relevant data. The comparison algorithm detects whether to transmit data to health server. This saves energy and reduces overhead costs. The basic code of comparison algorithm data flow is given below.

Start
Do
If(KiAcclData1 = = 0)
KiAcclData1 = readValue()
KiAcclData2 = KiAcclData1
Else
KiAcclData1 = readValue()
// Compare with previous
If(KiAcclData1 = KiAcclData2)
SendnewVal

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Monitoring daily activities of a patient in real-time requires a large amount of data. The integrated tri-axial accelerometer is built to collect large amount of data and transmit them continuously. Monitored data are collected, processed, converted to XML and transmitted through Wi-Fi radio over Wi-Fi networking using TCP/HTTP protocols. The accelerometer is initially set in *stand state* and its timer is configured to systematically wake up every 1sec interval to collect measurement samples. This conserves power when a person is in *stand state* (ID₁). The *stand state* is disabled once a measurement value exceeds a certain fixed threshold (T₀), because it signifies a patient is now in an *active state*. The accelerometer enters this new state and continues to collect samples. If accelerometer detects inactivity for a period of 5mins, it returns to the *stand state* and the workflow process starts all over. The workflow process implemented provides automatic activity monitoring, power conservation and alertness.

Fig. 3 shows data transmission process of the prototype PHS. The monitored accelerometer data are transmitted through Wi-Fi radio over Wi-Fi network to the Smartphone. The performance of Wi-Fi is significant to real-time activity monitoring. Using an Access Point (AP) and TDMA schemes, we develop a wireless network that ensures no data loss, systematic data transmission process, reduced network congestion, minimal interference from other existing networks, power conservation and extended battery life of accelerometer. Algorithms embedded in Smartphone are managed by a MoSync/Python application. This application uses MoSync/Python application program interfaces to collect data from accelerometer, process data and send data to health server. Data from Smartphone is uploaded to health server through the upload button on its GUI. This gives patients control over their medical data.

The health server mines the received data, stores patient data and determines health risks using logistic regression. Patients and medical professionals can access health server through internet anywhere, anytime. A patient can receive two types of health data report. The first one displays patient’s health data in simple and understandable terms such that even without much medical knowledge, patients can be aware of their own health status by simply comparing data to reference values. The second one is a long-term medical condition graph. The doctor can monitor a patient’s daily activities and supervise daily living habits. Using internet as a communication platform and being assisted by long-term medical records, online consultation and diagnosis becomes enhanced. The call center informs patients’ emergency contacts by sending short messaging services or phone calls according to an existing priority situation.
V. Results

We carried out measurement tests to monitor acceleration movement patterns for four different physical activities of few volunteers, considered as patients. The first set of measurement tests are from activities involving normal calm movements such as standing (ID$_1$) and walking at a slow pace (ID$_2$). The AcclX, AcclY and AcclZ are used to represent front, side and vertical accelerations respectively. Due to the force of gravity, an output value of $+g$ is always present in the vertical measurement (AcclZ). If a patient is in a vertical position, measurements of ID$_1$ and ID$_2$ mostly show obvious acceleration movements on X and Y axes (front and side axes) while Z axis showed less acceleration movement. Fig. 4 shows acceleration measurement pattern for standing (ID$_1$). Fig. 5 shows the acceleration movement pattern for walking (ID$_2$). The total acceleration ($AcclTot$) for each activity is equal to square root of sum of individual accelerometer output raised to 2 on all axes. That is $AcclTot = \sqrt{AcclX^2 + AcclY^2 + AcclZ^2}$. For the first set of measurement tests ID$_1$ and ID$_2$ measurement ranges of $AcclTot$ is always between [0.9g – 1.3g].

The second measurement tests involved activities with faster paced movements (ID$_3$ and ID$_4$). These tests showed more acceleration movements on Z axis as shown in Fig. 6 and Fig. 7. The tests show that different patient activities generate different movement patterns in acceleration readings. This makes it possible to
group different patient activities by analysing the recorded acceleration data and warn against abnormal activities. Falling has more abrupt movements, therefore its maximum range of acceleration change over z-axis is above 2g. When AccTot is called, we can get abnormal values that are smaller than 0.9g or greater than 1.3g. By carrying out measurement tests, we develop two simple ways to detect abnormal patient activities. These are (a) monitoring the acceleration change over each axis while observing acceleration movement and (b) checking AccTot to see if it is below a low threshold or above a high limit.

VI. CONCLUSIONS

This paper reports implementation of a prototype pervasive healthcare system for real-time activity monitoring using integrated tri-axial accelerometer and android Smartphone. The system proactively monitors physical activities of patients to recommend diagnostic services. This system is one of the first that successfully provides a service oriented pervasive healthcare services by using a single integrated tri-axial accelerometer and android Smartphone. However, future study is required to improve quality of service of body sensors wireless communication, reliability of sensor nodes, security and standardization of interfaces. In addition, further studies on different medical conditions in clinical and ambulatory settings are required to determine specific limitations and possible new applications of this technology.
REFERENCES