A Comparison of Mobile Patient Monitoring Systems

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Abstract. A survey of Mobile Patient Monitoring Systems is presented in this paper. Mobile patient monitoring systems have shown progress in terms of basic core functionalities needed for monitoring and detection of biosignals. However, their deployment is restricted to a small segment of health care delivery. The objective of this survey is to identify causes behind low deployment. We have selected twelve mobile patient monitoring systems and compared them against a set of functional and non-functional requirements.

1 Introduction

Mobile Patient Monitoring (MPM), a sub-area underneath M-Health, refers to continuous or frequent measurement and analysis of biosignals of patients by employing mobile computing and wireless communication technologies [1]. Mobile patient monitoring is one of the techniques to reduce health care delivery costs associated with traditional patient monitoring systems. Mobile patient monitoring systems primarily acquire biosignals and transmit them to the remote location where a doctor can monitor vital signs to detect any abnormality. Through the use of advanced features in current generation mobile networks, MPM systems now aim to provide more personalized care through wearable, portable and implantable systems. Thus MPM is emerging as an efficient method for chronic diseases management.

Despite the numerous benefits offered by MPM systems, a very low uptake has been observed globally [2] for these systems. In this paper, we have surveyed various MPM systems to identify the reasons behind low acceptance of these systems by end users. A set of functional and non-functional properties are identified to compare different MPM systems. Our paper identifies a set of non-functional requirements that are emerging as desirable features for next generation MPMs.

Rest of the paper is organized as follows: Section 2 presents an overview of mobile patient monitoring systems. Different types of requirements for MPMs and comparison of various MPMs against these requirements is described in Section 3. Section 4 discusses some of the MPMs and their specific features. Results of the comparison are summarized in Section 5.

G. Huang et al. (Eds.): HIS 2013, LNCS 7798, pp. 198–209, 2013.

2 Mobile Patient Monitoring Systems

Existing mobile patient monitoring systems vary in terms of types and numbers of features supported by them. This section presents an overview of twelve existing MPMs. These MPMs are selected on the basis of diversity of features implemented in them, techniques used for detection, communication, interpretation and analysis of biosignals.

1. *Intelligent Mobile Health Monitoring System (IMHMS)*[3] The main objectives of IMHMS system is to intelligently predict patients health status and to provide them feedback through mobile devices. The IMHMS system uses Wearable Wireless Body Area Network to collect data from patients. The system stores the results of patient's examination and treatment in a central database. One of the main features of this system is use of data mining techniques to extract relevant information from biosignals. IMHMS also provides a flexible, simple and user-friendly interface. The system needs improvement with respect to providing secured transmission of biosignals.
2. *MobiHealthcare System (MHCS)*[4]
   The MHCS is mainly designed for cardiac, hypertensive or sub-healthy patients. The system provides specifically designed sensors to collect physiological signals. It collectively processes spatially and temporally collected medical data. The system is deployed on a server with big data storage where data mining and visualization is done. Although the system is capable of detecting abnormalities in biosignals and cardiac phenomenon, it can be extended to calculate the risk factors for cardiovascular and chronic diseases with more powerful data mining solutions.
3. *Multi-Touch ECG Diagnostic Decision Support System (MTDDS)*[5]
   The system is specially designed for cardiac patients. The system is capable of providing remote mobile communication to speed up diagnostic decision making using multimodal analysis engine. The prototype is capable to display ECG in three dimensional multi-layers on a multi-touch mobile device. The system prototype makes assessment faster and provides better medication management; however the system needs more contents and features for decision support system.
4. *Wireless Intelligent Sensor System (WISS)*[6]
   The WISS is intended for real time personal stress monitoring. The system provides affordable health monitoring services by utilizing plug-and-play sensor units complying with the common industry standard. It predicts critical performance aspects and stress resistance of soldiers under extreme conditions. The distributed wireless intelligent sensor system provides low-level real-time signal processing results in only transmission of compressed results. The system is convenient for prolonged stress monitoring, stressful training and normal activity. The system makes use of custom designed short-range communication devices to reduce power consumption and to increase the security. The system can be extended to evaluate the psycho-physiological state of individual persons.

5. *The MobiHealth System (MHS)* [7] The main objective of MHS is to provide a highly customizable vital sign monitoring system based on next generation public wireless networks. The MobiHealth System is based on generic service functional architecture platform provisioned for ubiquitous healthcare services. The system can support not only sensors, but a broad range of body worn devices and actuators. The measured vital signs are transmitted live over public wireless networks to healthcare providers. The major merit of MHS is its trial results, conducted successfully in many countries. Trials revealed low bandwidth and higher data loses as the major shortcomings of the existing network infrastructure.
6. *Mobile Cardiac Wellness Application (MCWA)*[8] The MCWA is a mobile patient-centric, self-monitoring, symptom recognition and self-intervention system that supports chronic cardiac disease management. The systems consists of back-end data repository, data mining, knowledge discovery, knowledge evolution and knowledge processing system, providing clinical data collection, procedural collection, intervention planning, medical situational assessment and health status feedback for users. It utilizes patient information and evidence based nursing knowledge to offer real-time guidance. The systems architecture has been presented from three different viewpoints as; an informational view (utilize multiple sources of information to construct patient specific health assessments and wellness), an operational perspective (data collection, patient assessments, patient evaluation, intervention planning and execution) and an architectural design view.
7. *Personalized Heart monitoring (PHM)*[9] The PHM system is aimed to combine ubiquitous computing with the mobile health technology. The system uses wireless sensors and smartphones to monitor the wellbeing of high risk cardiac patients. Smartphone examine real-time ECG data and determine whether the person needs external help or not. The system also consists of a fall detector and a Global Positioning System (GPS). Depending on the situation the smart phone can automatically alert pre-assigned caregivers or call the ambulance. The major shortcoming of the system is smartphones small battery life, usually drains in eight hours when continuously connected to the ECG device.
8. *Tele-Health Care System (THC)*[10] The main purpose of THC system design is to continuously monitor the heart attack patients. The THC system provides continuous mobility to both the patient and doctor. It detects the changes in Heart rate as well as blood pressure of the patient in prior and gives a self - alert ring to the patient and also sending an alert Short Messaging Service (SMS) to the doctor and thus gains immediate medical attention, results in reduced critical level of patient. The THC system implemented Alert services successfully but no steps have been taken to prevent false alarming.
9. *Ubiquitous Mobile Health Monitoring System for Elderly (UMHMSE)* [11] The system prototype is mainly designed for the elderly patients. The UMHMSE system provides the remote monitoring of human vital signs, mobility and location for collecting, gathering and analyzing data from a

number of biosensors. The system uses logistic regression technique to mine data and predict health risk from the knowledge of patients mobility, location and biosignal sensor data. The system suffers from smartphones small battery life and false alarms.

10. *Phone-Based E-Health System (PBEHS)*[12] PBEHS is specifically designed to remotely monitor Obstructive Sleep Apnea Syndrome (OSAS) patients. The system introduces a separate micro-control unit for data processing which significantly improves the smartphone battery life. The system offers a detailed analysis of energy consumption and presents a number of solutions to reduce system power consumption. The power consumption results are improved by 11 hours as compared to old prototype and still has possibility for further improvement using adaptive sampling, feature selection, compression, encoding and load balancing.
11. *CardioSentinal (CS)*[13] The main goal of the CS system is to provide an on-demand 24-hour heart care and monitoring services for elderly and outpatients. It provides monitoring services through biosensors, small-range wireless communication, pervasive computing, cellular networks and modern data centers. The system implements machine learning classification algorithms in order to identify ECG deflection patterns and to support decision making. The biosignal measurements collected by the system lacks in precision (upto 96% in some cases) as compared to the professional measurements in hospital. The system needs improvement with respect to robustness, communication reliability, accuracy, energy consumption and security.
12. *Advanced Health and Disaster Aid Network (AID-N)* [14] The system is purposely designed for the technological advancement of emergency response community services at Mass Casualty Incidents. AID-N system provides Electronic triage tags with built-in pulse oximeter and GPS to estimate the patient triage level and provide emergency services to the victims based on the triage level. The AID-N system uses service oriented architecture (SOA) that has shared data models of disaster scenarios to support the exchange of data between heterogeneous systems. The system itself has been tested successfully but the practical usability requires changes in emergency response protocols.

These systems use different terminologies to describe various components of MPMs. In the rest of the paper, we will use component names from the generic architecture of Patient Monitoring System proposed by Pawar P. A. in [1]. Figure 1 shows the generic architecture of MPMs, broadly divided into two components named: Body Area Network (BAN) and a Back-End System (BESys).

The BAN is defined as a network of communicating devices worn on or around the body which is used to acquire health related data to provide mobile health services to the patient. The BAN consists of a Mobile base Unit (MBU) and a set of BAN devices such as sensors, actuators or other wearable devices used for medical purpose. The sensors may directly transmit the biosignals data to the MBU or do it via the Sensor Front-End (SFE). The BESys comprises of the back-end server which can be of two types: back-end server to which the MBU

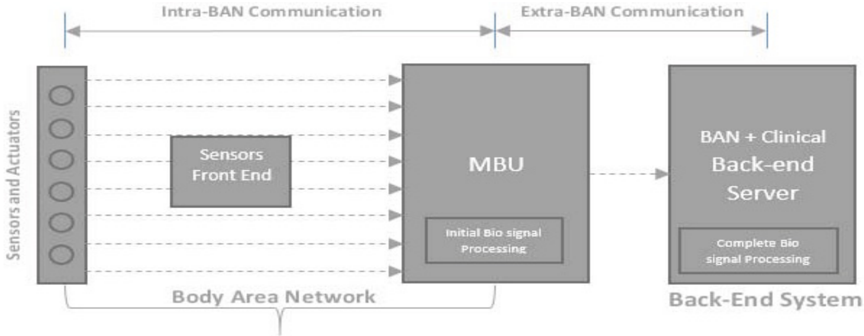

Fig. 1. Mobile Patient Monitoring System Generic Architecture

Table 1. Mobile Patient Monitoring Systems component describing Terminologies

System	**Body Area Network(BAN)**	**Mobile Base Unit(MBU)**	**Back-end Server(BESys)**
IMHMS	Wearable Body Sensor Network (WBSN)	Patients Personal Home Server (PPHS)	Intelligent Medical Server (IMS)
MHCS	Body Sensors	Mobile Device	Data and Data Mining Server
MTDDS	Sensors	Multi-Touch Smartphone	Web server
WISS	Wireless BAN of Intelligent Sensors (personal server (PS) and multiple WISE clients)	primary MBU functions are provided by BAN	Central Workstation
MCWA	Wearable Sensor Suite Mobile	Smart Phone	Server
PHM	Body Area Network	Mobile Base Unit	Back-end System
MHS	Body Area Network (BAN)	Mobile Base Unit (MBU)	back-end system
THC	Wrist Pressure Sensor	PIC Micro-controller	GSM MODEM (Mobile)
UMHMSE	Wireless Wearable Body Area Network (WWBAN)	Intelligent Central Node (ICN)	Intelligent Central Server (ICS)
PBEHS	Sensor Nodes And Micro-Control Unit (MCU)	Bluetooth Module Centralized Controller	Back-end Server
CS	BodyNets	Smartphone Gateway Nodes	Remote Data Centers
AID-N	Embedded Medical Systems for Triage and Biomedical Sensors	BESys is available at the scene in place of MBU	Ad Hoc Mesh Network

transmits biosignals data and clinical back-end server which may host custom health-care applications. Table 1 shows correspondences between components from the generic architecture and the components of the MPMs used for comparison.Though, the twelve surveyed system used different terminologies. The component interactions among them are similar to that of architecture specified above.

3 Comparison Framework

The requirements for MPMs capture the information necessary to build a MPM system from designer's and implementer's point of view. These are the set of precisely stated properties or constraints that a system must satisfy. The requirements of MPMs can be classified into two categories *functional* and *non-functional* requirements as given below:

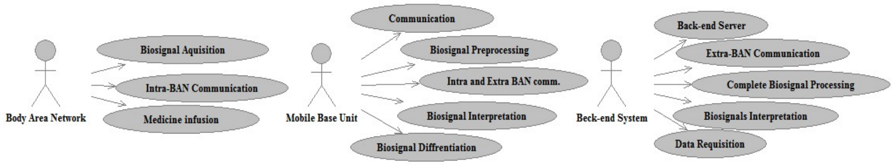

Fig. 2. Representing Functional Requirements as Use cases

3.1 Functional Requirements

Functional requirements typically capture the core functionalities provided by a software system. There functionalities are performed either by a component of software system or an external agent. These functional requirements are represented through use case diagram as shown in Figure 2.

i *Biosignal Processing(FR1)* The system should process biosignals and should be able to take decisions accordingly. Biosignals are initially processed by MBU on the basis of thresholds generated by the BESys and delivered to Back-End Server for further processing.

ii *Biosignals Delivery(FR2)* First, Biosignals acquired by the BAN should be delivered to the MBU in real time. The communication between BAN and MBU is called intra-BAN communication. Second, Data should be delivered to back-end server instantly by MBU. The communication between the MBU and BE-sys is called extra-BAN communication.

iii *Raise Emergency Alarm(FR3)* MBU and Back-end Server should collectively generate an emergency alarm in critical conditions, since the biosignals are processed by both the components.

iv *Biosignals Interpretation(FR4)* The system should be able to diagnose the critical condition signs from biosignal. Biosignals must be correctly interpreted by MBU and Back-end Server.

v *Biosignal Differentiation(FR5)* MBU should automatically discover the correlations between variations in physiological signals and lifestyle such as current activity, food intake and exercise.

vi *Data Requisition(FR6)* To diagnose the patients current health status doctor or clinician needs the current biosignals as well as the past records from the database. The Back-End Server should be able to provide relevant data on request.

vii *Communication(FR7)* The system should provide a communication interface between the patient and doctor. Graphical user interface provided on the MBU should felicitate user with an interface where he/she can interact with the doctor.

viii *Medicine Infusion(FR8)* Sensors should be able to infuse the medicine into the patient body whenever triggered by the doctor or clinician. The requirement should be fulfilled by the BAN.

3.2 Non-Functional Requirements

i *Genericity (NFR1)* The System should be modified according to the patient monitoring needs. It should not be specific to certain disease, group or community of people.
ii *Security (NFR2)* Connection between the Mobile Base Unit and server should be secure and authenticated.
iii *Unique Patient Identification (NFR3)* Patient should be provided with a patientID by which he/she can be globally uniquely identified.
iv *Interoperability (NFR4)* The application should support various specified devices.
v *Privacy (NFR5)* System should maintain the patient privacy by restricting the access to the patient records.
vi *Intelligence (NFR6)* System should be capable of taking decisions on the basis of past and current records.
vii *Availability (NFR7)* System Should be available 24 X 7 for the continuous monitoring.
viii *Response Time (NFR8)* System should be fast enough so that on time emergency services can be provided to the patient.
ix *Easy Wear-ability (NFR9)* Body Area Network should be small in size, easy to wear and convenient for the patient.
x *Graphical interface (NFR10)* 1. The system should provide a graphical interface to display biosignals on MBU and Back-end Server 2. It should provide a graphical interface where doctor and patient can interact with the system.
xi *Accuracy (NFR11)* The data delivered to server should be accurate.
xii *Data loses (NFR12)* The system should be able to overcome data loses introduced due to various noise sources on the communication media.
xiii *Standards (NFR13)* System should follow various Standards provided for data sharing to achieve interoperability between the systems.

The aim of this comparison is to identify similarities and difference among MPMs described in Section 2. We have compared these systems against the functional and non-functional requirements stated in Section 3 The symbol ($\surd$) in Table 2 indicates the fulfillment of the requirement whereas the symbol X specifies the unimplemented or unidentified requirement. Table 2 shows enormous variabilities in the requirement implementation of the MPMs. It can be noticed from the Table 2 that the requirements FR8, NFR5, NFR12 and NFR13 are often missed out most of the MPMs during implementation.

4 Related Work

Our paper has compared twelve mobile patient monitoring systems against various functional and non functional requirements. In this section, we review some of the efforts proposed earlier and which are not covered in the comparison but has significant impact on MPMs with respect to MPMs architecture, BAN, MBU and BESys design.

Table 2. MPMs Comparison on Functional and Non-Functional Requirements

MPM System	FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8	NFR1	NFR2	NFR3	NFR4	NFR5	NFR6	NFR7	NFR8	NFR9	NFR10	NFR11	NFR12	NFR13
IMHMS	√	X	√	√	√	√	√	X	√	√	√	√	X	√	X	√	√	√	X	X	X
MHCS	X	√	X	√	X	√	√	X	X	X	X	X	X	√	√	√	√	√	X	X	X
MTDDS	X	√	X	√	X	√	√	X	X	X	X	√	X	X	X	√	√	√	X	X	X
WISS	X	X	X	√	√	√	√	X	X	X	X	X	X	X	X	√	√	√	√	X	X
MCWA	√	√	X	√	√	√	√	X	X	X	X	X	X	√	X	√	√	√	X	X	X
PHM	√	√	√	√	√	√	√	X	X	X	X	X	X	√	X	√	√	√	√	X	X
MHS	X	√	X	√	X	√	√	X	√	X	X	X	X	X	X	√	√	√	X	X	X
THC	√	√	√	√	X	√	√	X	X	X	X	X	X	√	X	√	√	√	X	X	X
UMHMSE	√	√	√	√	X	√	√	X	X	X	X	X	X	√	X	√	√	√	X	X	X
PBEHS	X	√	X	√	X	√	√	X	X	X	X	X	X	√	X	√	√	√	X	X	X
CS	√	√	√	√	√	√	√	X	X	X	X	X	X	√	X	√	√	√	X	X	X
AID-N	√	√	√	√	X	√	√	X	X	X	√	X	X	√	X	√	√	√	X	X	X

Most of the MPMs are designed for a specific group or community of people that are suffering from cardiovascular disease [8], Depressive Illness [15], dementia [16], hypertension [4], diabetes [17] or stress and some systems are dedicated to the older age group patients [11] and Mass Casualty Incidents [14]. Only a few architectures are presented for generic mobile patient monitoring systems [18] [19].

The Body Area Networks with some unconventional sensors sets like artificial endocrine pancreas [20], reflectance pulse oximeter [21], small range Bluetooth and an annular photo-detector to reduce power consumption have been offered. A mobile or PDA implementation for real time signal detection algorithm of patient ECG capturing and monitoring have been proposed in Mobile Health Monitoring Application Program [22].

In [23], Fei Hu et al. have identified networked embedded system design, network congestion reduction, and network loss compensation as three major performance issues for the MBU. To contend with such problems, the Personal Electrocardiogram Monitoring System described in [24] continuously monitors ECG and the system saves the ECG along with temperature into a smart phone. The system sends a multi media message to the base station with the current ECG image when it finds an irregular pattern in the ECG, whereas, the Mobile e-Health monitoring [25] shows a multi-tier agent based approach for MPM where the agent acts as a communication media between a patient and a doctor. System allows a patient to select whether the data is to be analyzed locally or on a centralized server. When data is analyzed locally it can prevent false alarms through interrogating a patient about his/her health status. These agents are normally deployed in mobile base units. The Remote Patient Monitoring System in [26] has realized secure and safe remote patient monitoring system that sends the monitoring data periodically to the clinical database. The clinical system automatically contacts the physician about any abnormality in the monitoring signals.

Technology has shifted its concern from individual systems to the distributed, cloud and grid systems where the computing power of the system has no limits but this shift has raised some new issues like interoperability, information sharing and data interpretation amongst different systems. The health information system [27] has emphasized on the need of the interoperability between the medical information systems that tries to provide interoperability between the heterogeneous medical information servers through service-oriented architecture [28] [29], web services and HL7 standards [30] [31].

As the patient monitoring systems are drifting towards maturity, researchers have tried to introduce intelligence into the system for the autonomous decision support. Intelligent patient monitoring system [32] where system can assist the physician in interpreting the medical data, decision making and automating the patient monitoring process through artificial intelligence and a data management system [33] which can effectively encapsulate, extract and interpret real world context aware information ensuring that physicians get the correct data every time. The data server reacts differently depending on the medical data and real time readings of the patients in different condition. To support these type of systems some techniques like data mining for predicting current health status [34] of a patient, applying clustering algorithm to both real time and historic data have been proposed. One more approach for simple data mining is presented as object oriented database system [35] for server and client.

The centralized server approach for data storage will open the doors to a gigantic biosignal data repository which can be used in various ways by research communities. On one hand, the centralized approach has provided various benefits whereas on the other hand, they raised certain issues with patient security and privacy. To deal with such issues the work of Johannes Barnickel et al. proposed to use AES-128 bit encryption algorithm for data storage at central server and password authentication [36] by a sensor server to access the monitoring data. Comprehensive Health Information System [37] has the capability to process patient data according to dynamically evolving set of data mining techniques and to share them among doctors, researchers and e-communities according to patient-defined access policies. Duke University's *Contain Explorer* [38] creates a view of administrative, financial, and clinical information generated during patient care by business intelligence tools from data warehouse.

Some papers presents a totally different aspect of MPMs like patients trajectory monitoring [39] to provide a better understanding of the effect of environmental factors on triggering health attacks in asthma patients hence support individual-based health care. WANDA [40] designed for early detection of Congestive Heart Failure symptoms and also provides feedback for regulating readings.

5 Conclusion

A framework to compare mobile patient monitoring systems with an objective to identify similarities and variabilities among existing MPMs is presented in this paper. It has been observed that most of the MPMs surveyed in this paper monitor biosignals specific to a disease such as patients suffering from cardiac problems. The core functionalities of MPMs include detection of biosignals, communication of biosignals, delivery of biosignals, and interpreting biosignals. Techniques to address the non-functional features such as secure transmission of biosignals, reduction in network congestion, reduction in power consumption, privacy of patient information have been supported by some of the existing MPMs. Other non-functional features such as interoperability between MPMs, autonomous monitoring system, extraction of relevant information from the monitored biosignals are emerging as critical design parameters for MPMs.

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