22. A Product Line Architecture for Mobile Patient Monitoring System

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1 Introduction

The term mobile health (mHealth) means to adopt Information and Communication Technology (ICT) especially mobile hand held devices to provide health-care and delivery services [1]. The ICT is mainly adopted with an intention to provide cost-effective, efficient and easily accessible health care services. Patient monitoring is one of the health care activities that can effectively adopt mobile devices and allied techniques for chronic disease management and continuous patient monitoring. The Mobile Patient Monitoring (MPM) systems have promise and potential to provide as an effective alternative for traditional patient monitoring techniques.

A number of MPM systems have been developed earlier that offer a varied range of functional and non-functional features. In this chapter, we provide a product-line architecture that essentially captures the similarities and variabilities of these MPM systems. Product Line (PL) architecture is a software design approach especially useful for evolving domains to achieve a higher degree of reuse and customization within the cost and time constraints. The basis of a *PL* is a collection of features, called the scope and a collection of reusable components called the *core assets* [2]. Feature-Oriented Reuse Method (FORM) is an approach for PL architecture development [34] [50] [21] that use feature models to capture both commonalities and variabilities of PL. The output of the feature model analysis can be further used to explore reusable components for product line development.

Keywords: Mobile Patient Monitoring, Product Line Architecture, Feature Oriented Domain Analysis, Domain modeling, context analysis, feature analysis.

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2 Generic Architecture of MPM Systems

The generic architecture for MPM[28] includes system development processes (e.g., planning and designing) and various MPM product variants. From the product perspective, the generic architecture for MPM systems has two components, namely, *Body Area Network* (BAN) and 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. As shown in Figure 1, 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 bio-signal 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 transmits bio-signal data and clinical back-end server which may host custom health-care applications.

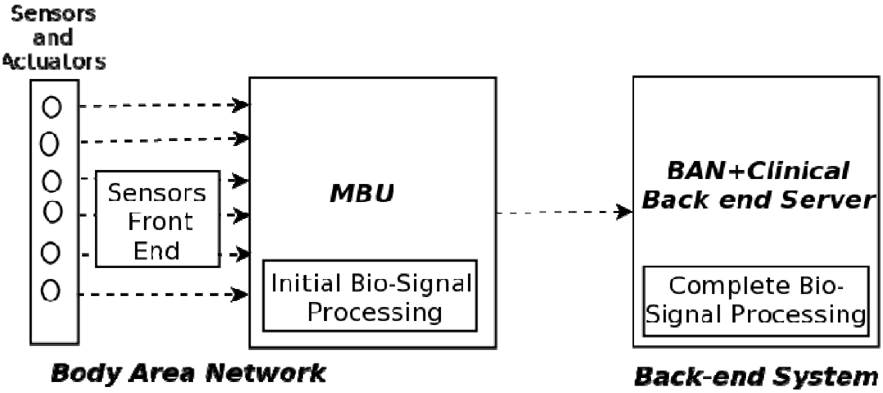

Fig. 1 A Generic Architecture for Mobile Patient Monitoring System [28]

From the process perspective, we can represent the MPM architecture into five steps as: (i) Data acquisition (ii) Data Transmission (iii) Bio-signal Interpretation and Processing (iv) Notification (v) Intervention. BAN acquires the physiological data actively or passively by interacting with the patient. Data can comprise of vital signs, blood glucose levels, responses to specific health conditions and general health questions as well as patient location. Data is then packaged, transferred and delivered to the caregivers and third parties via different modes of communication. Algorithms and/or healthcare workers interpret and review the data and determine if there are any areas for concern. If needed clinicians, family, caregivers, third parties or the patients themselves are notified of a potential problem through either the device itself or an intermediary health-care worker. They can then take an action when intervention is needed. This separation between product and process perspective help system modelers to individually focus on structural and functional elements of MPMS facilitating systematic development of MPMS.

3 Survey of Existing Mobile Patient Monitoring Applications

During last few years, mobile patient monitoring has evolved as the most promising and active application area [3] in the domain of m-Health. As a result a number of mobile patient monitoring systems have been proposed by various researchers. These systems are either designed for a specific community or for people suffering from a specific disease such as cardiovascular disease [4], depressive illness [5], dementia [6], hypertension [7], and diabetes [8.]. Few of these systems are dedicated to the older age group patients [9] and mass casualty victims [26]. The basic functionality provided by these systems include continuous monitoring and delivery of bio-signals [11] [12] and real time signal detection [13]. These systems vary in terms of non-functional features supported by them. For example, few systems provide *interoperability* between the various heterogeneous medical information servers by adopting Service-*Oriented Architecture (SOA*) [14] [15] for application deployment and adopting HL7 standards [16] [17] for data encoding. Some of the additional functionalities realized by these systems included to predict current health status [18] through various data mining techniques, to provide secured access to the monitored data [20] through password authentication, to interpret medical data and to make decisions [22].

Table 1 shows a comparison of MPM systems, in which various systems have been compared against the following functionalities: to process bio-signals (FR1), to deliver bio-signals(FR2), to raise emergency alarm (FR3), to interpret bio-signals (FR4), to perform differentiation of bio-signal (FR5), to acquire data (FR6), to communicate bio-signals (FR7), and medicine infusion (FR8). Table 1 also compares these systems against a set of non-functional parameters such as Genericity (NFR1), Security (NFR2), Unique Patient Identification (NFR3), Interoperability (NFR4), Privacy (NFR5), Intelligence (NFR6), Availability (NFR7), Response Time (NFR8), Easy Wear-ability (NFR9), Graphical interface (NFR10), Accuracy (NFR11), Data loses (NFR12) and adoption of standards (NFR13).

Table 1 Comparison of mobile patient monitoring systems

	FR1	FR2	FR3	FR4	FR5	FR6	FR7	FR8	NFR 1	NFR 2	NFR 3	NFR 4	NFR 5	NFR 6	NFR 7	NFR 8	NFR 9	NFR 10	NFR 11	NFR 12	NFR 13
IMHMS	✓	✗	✓	✓	✓	✓	✓	✗	✓	✓	✓	✓	✗	✓	✗	✓	✓	✓	✗	✗	✗
MHCS	✗	✓	✗	✓	✗	✓	✓	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✓	✗	✗	✗
MTDDS	✗	✓	✗	✓	✗	✓	✓	✗	✗	✗	✗	✓	✗	✗	✗	✓	✓	✓	✗	✗	✗
WISS	✗	✗	✗	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗	✓	✓	✓	✓	✗	✗
MCWA	✓	✓	✗	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	✓	✓	✓	✗	✗	✗
PHM	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	✓	✓	✓	✓	✗	✗
MHS	✗	✓	✗	✓	✗	✓	✓	✗	✓	✗	✗	✗	✗	✗	✗	✓	✓	✓	✗	✗	✗
THC	✓	✓	✓	✓	✗	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	✓	✓	✓	✗	✗	✗
UMHMSE	✓	✓	✓	✓	✗	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	✓	✓	✓	✗	✗	✗
PBEHS	✗	✓	✗	✓	✗	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	✓	✓	✓	✗	✗	✗
CS	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	✓	✓	✓	✗	✗	✗
AID-N	✓	✓	✓	✓	✗	✓	✓	✗	✗	✗	✓	✗	✗	✓	✗	✓	✓	✓	✗	✗	✗

This comparison reveals that numerous MPMS exist but there is an absence of a *reference architecture* against which these existing systems can be compared. One reason behind the absence of reference architecture is that, most of the time MPMS products are *develope*d and they are rarely *engineered* by following systematic development process. A systematic approach to product development typically includes adoption of engineering processes of requirements, analysis and architecture design. While comparing these MPMS, it has also been observed that few approaches exist that perform requirements analysis for MPMS [23] and architecture design for MPMS [24] [25] [26] [6]. However, they overlook the aspect of capturing *variability* and *commonality* among numerous MPMS products. One of the consequences of adopting adhoc approach to MPMS development is that the design information and knowledge about the MPMS is distributed and scattered all over the existing implementations.

4 Feature Oriented Domain Analysis (FODA)

4.1 Background

The FODA is a method of requirements analysis which defines both the products and the processes of domain analysis. In FODA, a feature is a prominent or distinctive user-visible aspect, a quality, or a characteristic which can be identified as mandatory, optional or alternative property for a system. In FODA, domain analysis is defined as a process of collecting, identifying, representing and organizing the relevant information in a domain based on the study of existing systems and their expansion histories, knowledge taken from domain experts, emerging technology, and underlying theory within an application domain [31].

The main objective behind performing FODA is to identify similarities and differences that are present in multiple realizations of a software system. Such an analysis helps to build a set of derivative products efficiently on a common platform. FODA provides a generic description of the requirements of systems and a set of approaches for their implementation [31].

To identify similarities in multiple software systems, the FODA can exploit reuse characteristics of a system platform. For example, in case of MPMS the followings are hardware and software reuse characteristics.

- *Hardware:* The reuse of sensors for monitoring the bio-signals as well as reuse of electronic interfacing control units with hardware modules and for implementing the software.
- *Software*: The reuse of software subsystems for interpretation, evaluation, transmission, and display of sensor data to aid advanced level applications.

The variations exhibited through adoption of multiple technological can be used to identify variabilities among multiple software systems. In case of MPMS, variabilities arise mainly because of different sensor technologies, different numbers of sensors, and different types of measurements, different bio-signal transmission media, and evaluation. Domain Analysis is frequently used to capture these type of variabilities and commonalities of the systems in a domain [30]. The output of FODA would count the following benefits:

- To reduce the development cost and improves the quality due to reuse of well tested components in various systems.
- To lower hardware costs.
- To achieve faster integration and development due to focused application specific development.

The FODA as a method of requirements analysis also develops a common understanding of an application domain in terms of the features, common requirements and scope of the domain.

4.2 A Feature Oriented Domain Analysis for Mobile Patient Monitoring Systems

This section describes the results of performing FODA for the domain of mobile patient monitoring with an intention to capture similarities in terms of functionality, implementation, hardware specification, software specifications, requirements and components. The analysis presented in this section is based on the methodology provided by Kyo. C. Kang et al [31]. The Feature Oriented Domain Analysis is typically carried out in two phases [32] namely, context analysis and feature analysis.

4.2.1 Context Analysis

The purpose of context analysis is to define the boundaries of a domain by using the domain data and constraints. This phase establishes a proper scope inside which the domain analysis is performed. In context analysis, relationships of the candidate domain with peripheral elements are analyzed, and variabilities are evaluated. The output of context analysis is described through structure and context diagrams.

4.2.1.1 Structure Diagram

The structure diagram in FODA decomposes the target domain as higher, lower, and peer-level domains. A structure diagram for mobile patient monitoring system is shown in Figure 2. The diagram covers complete application domain and it consists of subsystems necessary for realizing a full functional mobile patient monitoring system. The layered architecture style is used for structuring the functionalities of MPMS. The various functionalities of MPMS are grouped into three layers.

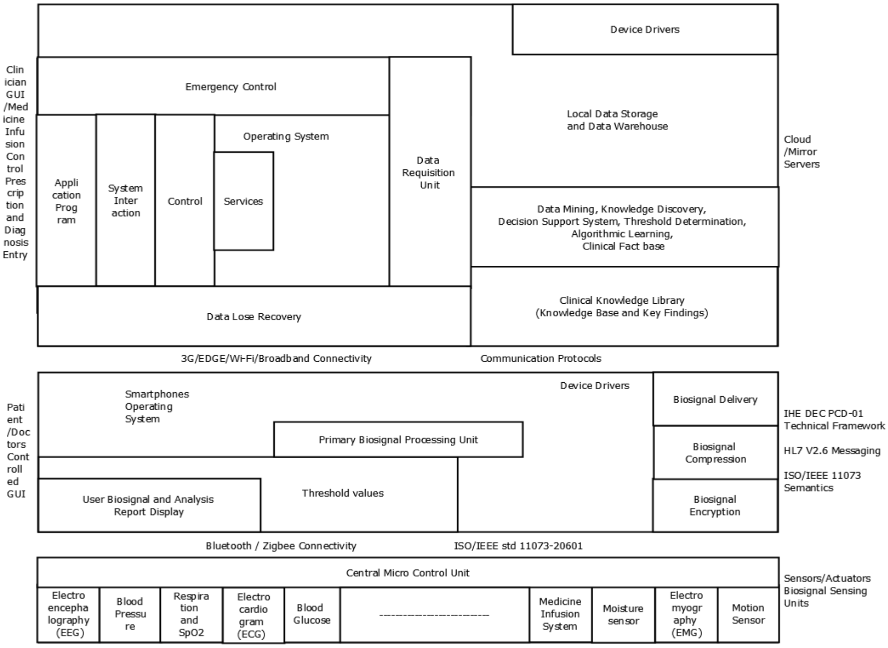

Fig. 2 Structure Diagram

The lowermost layer is the Body Area Network (BAN) which contains the wearable bio-sensing units and central micro-controller unit. The layer falls in the application domain of electronic micro control unit's design where body worn bio-sensors and actuators are developed. In this subsystem, we have included some of the sensing units that are not included in earlier mobile patient monitoring systems previously with an intention to provide additional sensing of physical parameters.

The system also interacts with some of the entities external to it through the defined application interface for the layer. These entities mainly include the standards and semantics defined for medical domain and communication network standards and protocols. Some of the standards defined by IEEE, ISO, HL7, IDE, IHE and DEC are included because these are commonly used in health informatics. The standards are ISO/IEEE std 11073-20601 [35], ISO/IEEE std 11073-104zz [36], IHE DEC PCD Technical Framework [33] and HL7 V2.X [37] and V3 [38] Messaging. These standards mainly deal with optimized exchange protocol for personal health device communication and device specialization for a specific agent. They describe the device capabilities and its implementation details appropriate for sharing of medical information. These standards facilitate optimal patient care and packaging of health-care data in the form of messages.

These standards are primarily intended to be used in clinical environment but it is well suited for wearable sensors [40]. The standards altogether makes the monitoring of data (Electronic Health Record (EHR) and Personal Health Record (PHR)) vendor independent [40] and hence provides a complete interoperability solution for mobile patient monitoring systems.

4.2.1.2 Context Diagram

The Context Diagram in FODA is a data-flow diagram showing data flows between a generalized application within the domain and the other entities and abstractions from system environment with which it communicates [32]. A context diagram showing comprehensive data flows for the mobile patient monitoring system is shown in Figure 3. This diagram captures the major data flows in the form information requisition, information provision, Biosignal transmission and request and response calls. In the diagram, the closed square boxes represent an automated request and response systems and they act as a source and a sink for the information whereas the open messages represent the user interaction. The arrows represent the direction of information flow.

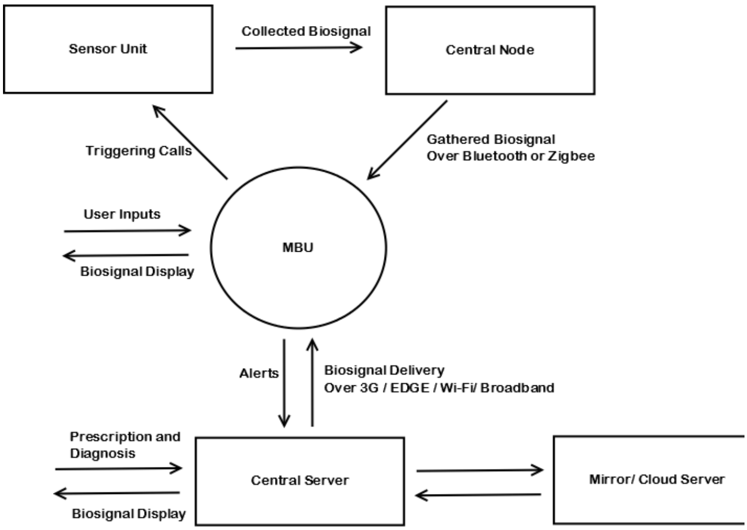

Fig. 3 Context Diagram

The MBU is represented in the middle of the diagram and it acts as a core element of the system which handles the major data flow whereas the central node and central server act as a major source and sink respectively. The data originated from the sensors is gathered by the central node and passed to the MBU where primary bio-signal analysis is done and data is forwarded to central node for further bio-signal processing. Wireless medias like Bluetooth, Zigbee, Wi-Fi, 3G are the most convenient and preferable choice for the data transfer. Smart-phones and mobile networks are the most convenient, powerful [41] [42], wide spread [43] and cost effective [44] choice for the mobile patient monitoring system MBU and data transfer respectively.

4.2.2 Domain Modeling

As defined in Section 4.1.1, the purpose of domain modeling is to define scope for the application to be developed. In our case, the application is mobile patient monitoring system. It provides a better understanding of the systems by systematically describing functions, objects, data, and relationships. The domain modeling phase mainly consists of three phases, namely, feature modeling, entity relationship modeling and operational modeling. The output produced by each phase describes what a system is, what the functions to be performed by an application are and how they perform it. Domain modeling provides activities, features, vocabulary, entities, control flow, data flow and requirements of the system.

4.2.2.1 Feature Analysis

The feature model captures the capabilities of a system from end users point of view. The analysis is mainly focused on the functionalities of the system, performance parameters, and operating environment in which the system application run. We have defined features as the attributes of a system that directly or indirectly affects the end-users by affecting the system performance, quality, security and services. The features shown in Figure 4 are identified on the basis of deliverable functionalities, capabilities, technologies, operating environment and functional and non-functional [29] requirements. These features can be broadly divided into three types as functional, operational and presentation. The functional feature represents the services provided by the applications, operational features represent the actions or tasks performed, and presentation features deals with the user interaction and information representation.

The feature diagram shown in Figure 4 encompasses the features of mobile patient monitoring systems in three levels. The first level of the diagram mainly includes the functional features of MPMS and the components present in the system. The level 2 of the diagram contains the features expected to be delivered by the respective components and some of these features has been further extended in the level 3. The features containing a white circle on the end of a connector represent an optional feature, whereas, the features containing a black circle on the end of a connector is a mandatory feature and the arc on a connector represents an alternative feature.

Bio-signal delivery and bio-signal processing are the only features, which are fundamentally necessary for a mobile patient monitoring system but these features are not sufficient for practically usability. The features we have included in the feature diagram contain many features that are not essential but we have treated them as necessary features to improve the user responses towards the system. Some of these features are discussed below:

- *Genericity*: The System should be modified according to the patient monitoring needs. It should not be specific to certain disease, group or community of people. In mobile patient monitoring systems genericity can be achieved with help of generic architectures [27] [28]. This architecture allows the number of sensors and system functionalities to be modified according to the disease monitoring needs.
- *Intelligence*: System should be capable of taking decisions on the basis of past and current records. It should assist the physician in interpreting the medical data, decision making and automating the patient monitoring process through

artificial intelligence [45] and a data management system [46] which can extract, interpret and effectively encapsulate real world context aware information ensuring that physicians get the correct data every time. The data server should react 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 [18] of a patient, applying clustering algorithm to both real time and historic data have been proposed.

- *Unique patient identification*: Patient should be provided with a patient ID by which he/she can be globally uniquely identified. 2G RFID [47] tags are the most promising choice for the feature; it not only offers unique identity to the patient but also provide solutions for security and patient tracking issues.
- *Availability and Speed:* The system should be available 24*7 and should be able to process gigabytes of data in real time. Cloud servers [9] can ensure the availability and in time processing of data due to its theoretically unlimited processing power.
- *Data delivery*: In Bio-signal delivery, the quality of received Biosignal should be good enough so that the clinical decision making should not be affected. To fulfill the Goodput requirements in consideration with the data loss ratio and round trip time, [48] 3G connections are the most viable option for data transfer. Data compression is also one of the possible solutions for the problem since it reduces the amount of data transferred but introduces significant delay which is intolerable for patient monitoring systems.

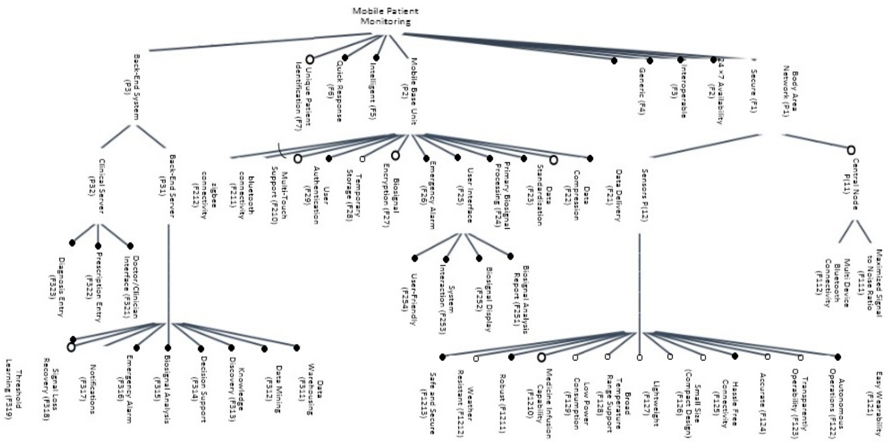

Fig. 4 Feature Diagram

- *Multi-touch support*: For clinical decision making medical images needs to be interpreted in more than one dimension called as multimodal analysis. For multi-modal analysis the device should have multi touch support.
- *Bio-sensors*: biosensors are normally deployed on the patient body to acquire Biosignals. The biosensors deployed in mHealth systems should be easy wearable, accurate, small in size and power efficient.

- *Medicine infusion capability*: The capability is very useful for diabetic, cardiac and asthmatic patients. It can improve the quality of scheduled medicines intake and emergency response time by automatically triggered infusion of medicine into the patient's body. Shinji Ichimori et al. [49] have shown a successful implementation of highly responsive needle-type glucose sensor for diabetic patient. The sensor has been successfully tested independently and can be potentially incorporated into the mobile patient monitoring systems.

4.2.2.2 Entity Relationship Model

The ER model captures and defines the domain knowledge essential for implementing applications in the system domain. The ER model mainly consists of entity classes which are related through *is-a* relationship and *consist-of* relationship. The main aim behind developing ER model is to deliver the system knowledge in terms of entities and relationships for the functional analysis.

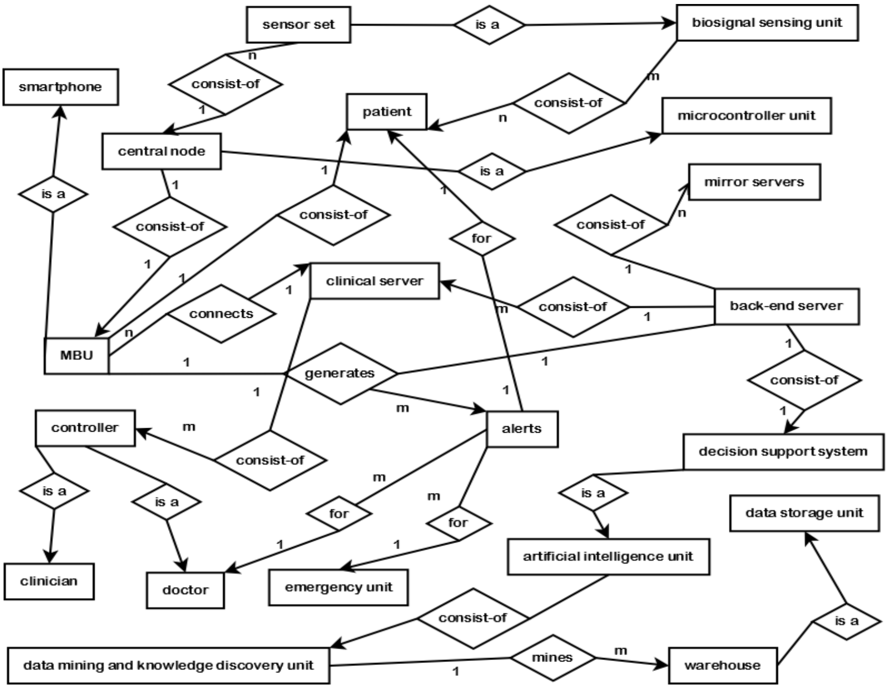

Fig. 5 Entity Relationship Diagram

The entities and relationships shown in Figure 5 are mainly taken from some existing systems whereas few entities like mirror servers and medicine infusion sensors are taken from possible systems. In our ER model, we have replaced some of the *consists-of* relationships with active nouns to describe the connection between two entities.

4.2.2.3 Operational Model

The operational model provides an immediate understanding of the system to the user by describing that how the system works. The model captures functional and behavioral relationships from feature model and entity relationship model. The operational model mainly provides the data and control flow of the system.

The model can be represented by a single operational diagram which identifies the complete system functionalities or with the help of functional model consist of separate state chart and activity diagrams. In operational diagram, a transition causes transfer from one state to the next in response to an event controlled by the conditions and events.

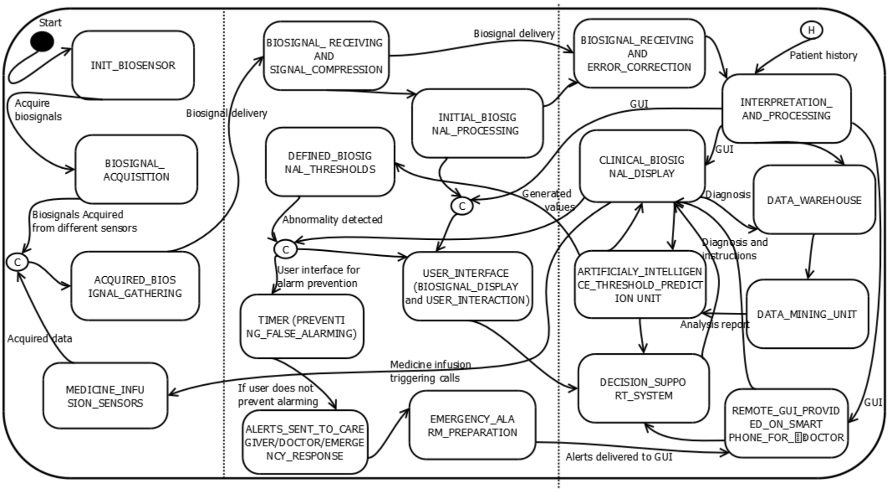

Fig. 6 Operational Diagram

The operational diagram shown in the Figure 6 shows three parallel sub-systems of mobile patient monitoring operating simultaneously and continuously. The first sub-system, BAN offers major functionalities related to the bio-signal acquisition and bio-signal delivery. MBU offers bio-signal processing, emergency alarm and bio-signal delivery. The bio-signal delivery in BAN and MBU is more or less the same except the delivering media. BAN delivers bio-signal to MBU over the Bluetooth or Zigbee link whereas the MBU delivers bio-signals to *BESys* over internet. The major functionalities implemented by the *BESys* consist of bio-signal interpretation, decision support, threshold generation, data mining, data storage, emergency alarm and bio-signal processing. The signal processing in MBU and BESys mainly differs in data processing. In bio-signal processing MBU processes only the current data available for abnormalities whereas on BESys current data is processed with historic data to find any type of abnormalities in the Biosignals. Thresholds generated by *BESys* on the basis of complete data processing are delivered to MBU for primary data processing. The threshold values should normally be defined over a group of patients because it varies with age, sex, weight and many other factors. While generating these values the diagnosis feed by the doctor manually in the system should also be considered. The system also provides the interpreted bio-signal display on various devices to various user mainly differs in the details and functionalities provided to the user. We have introduced some medicine infusion sensors in the MPM system that are successfully implemented in some systems but not integrated with an existing mobile patient monitoring system. These sensors can play an important role in emergency conditions to save patient's life but it also raises certain security issues with patient safety.

5 Deriving the Product Lines from Feature Model

Product Line is an approach to software development that considers development concerns observed in all phases of the production life-cycle of a system. Product lines are developed with an intention to describe experience of system builders in the areas of requirements, data management, algorithm, human-computer interfaces, design processes, testing and validation of a product. Purpose of product lines is to provide systematic guidelines for product development.

In this section, we describe product lines for the mobile patient monitoring system using FODA grammar. Here we are representing product variability observed in MPMS using Extended Modal Transition Systems [51] [52].

PL 1. ↝ *MPM; (* ↝ *P1;* ∧ *F*1; ✓ ∧ F2; ✓ ∧ F3; ✓ ∧ F4; ✓ ∧ ↝ P2; ∧ F5; ✓ ∧ F6; ✓ ∧ F7; ✓ ∧ ↝P3;)

PL 2. ↝ P1; ($\overline{P11}$; ∧ P12;)

PL 3. ↝ P11; (F111; ✓ ∧ $\overline{F112}$; ✓)

PL 4. ↝ *P12; (* F121; ✓ ∧ $\overline{F122}$; ✓ ∧ $\overline{F123}$; ✓ ∧ F124; ✓ ∧ $\overline{F125}$; ✓ ∧ $\overline{F126}$; ✓ ∧ $\overline{F127}$; ✓ ∧ $\overline{F128}$; ✓ ∧ $\overline{F129}$; ✓ ∧ $\overline{F1210}$; ✓ ∧ F1211; ✓ ∧ $\overline{F1212}$; ✓ ∧ F1213; ✓)

PL 5. ↝ P2; (F21; ✓ ∧ $\overline{F22}$; ✓ ∧ F23; ✓ ∧ F24; ✓ ∧ ↝ F25; ✓ ∧ F26; ✓ ∧ $\overline{F27}$; ✓ ∧ $\overline{F28}$; ✓ ∧ F29; ✓ ∧ $\overline{F210}$; ✓ ∧ F211; ✓ □ F212; ✓)

PL 6. ↝ F25; (F251; ✓ ∧ F252 ✓ ∧ F253; ✓ ∧ F254; ✓)

PL 7. ↝P3; (P31; ∧ P32;)

PL 8. ↝ P31; (F311; ✓ ∧ F312; ✓ ∧ F313; ✓ ∧ F314; ✓ ∧ F315; ✓ ∧ F316; ✓ ∧ $\overline{F317}$; ✓ ∧ $\overline{F318}$; ✓ ∧ F319;✓)

PL 9. ↝ P32; (F321; ✓ ∧ F322; ✓ ∧ F323; ✓)

In the expressions from PL1 to PL9, feature identifiers are used to identify a feature and A;✓and $\overline{A}$;✓ represents the mandatory and optional feature respectively, whereas, ∧ and □ represent the conjunction and choose-one operations respectively. The variability represented through these expressions can play an important role in designing the different variants of MPMS.

6 Product Line Architecture

Product Line (PL) Architecture core assets required for development are identified with an objective to support effective product variability management. During development, core assets can be either shared or reused among the members of the product line with an explicit treatment of variability. The typical objects to be included as core asset are architecture, reusable components, requirements statements, domain models, specifications and documentation, performance models, budgets, schedules, test cases, test plans, work plans, and process descriptions [53]. The elements from feature models are the most effective way to illustrate commonality and variability in products by showing the variation points explicitly [54]. In this section, we provide mapping rules from requirements to features and mapping rules from features to product line [55].

Mapping rules from requirements to features

1. $\exists F_i \in PF, \exists R_J \in PR$, specify $(R_j, F_i) \wedge SC_r(R_j) =$ mandatory $\Rightarrow SC_f(F_i) =$ mandatory
2. $\exists F_i \in PF, \exists R_j \in PR$, specify $(R_j, F_i) \wedge ((SC_r(R_j) =$ alternative$) \vee (SC_r(R_j) =$ mutual exclusion $\vee (SC_r(R_j) =$ *multiple alternatives*$) \vee (SC_r(R_j) =$ optional$))$ $\Rightarrow SC_f(F_i) =$ optional
3. $\exists PF_k \subseteq \exists PF, \exists R_j \in PR, \forall F_i \in PF_k$ specify $(R_j, F_i) \wedge SC_r(R_j) =$ mandatory $\Rightarrow \forall F_i \in PF_k,, SC_f(F_i) =$ mandatory
4. $\exists PF_k \subseteq PF, \exists R_j \in PR, \forall F_i \in PF_k$, specify $(R_j, F_i) \wedge ((SC_r(R_j) =$ alternative$) \vee SC_r(R_j) =$ mutual exclusive$) \vee (SC_r(R_j) =$ multiple alternatives$) \vee (SC_r(R_j) =$ optional$)) \Rightarrow SC_f(F_i) =$ optional
5. $\exists R_i, R_j \in PR, \exists F_i, F_j \in PF, SC_r(R_i) = SC_r(R_j) =$ mutually exclusive $\wedge$ specify $(R_i, F_i) \wedge$ specify $(R_j, F_j) \Rightarrow (i \neq j) \wedge SC_f(F_i) = SC_f(F_j) =$ mutually exclusive
6. $\exists F_i, \in PF, \exists R_j \in PR$, specify $(R_j, F_i) \wedge \exists R_K \in PR$, required$(R_k, R_j) \wedge SC_r(R_j) =$ optional $\wedge SC_r(R_k) =$ mandatory $\Rightarrow SC_f(F_i) =$ mandatory
7. $\exists F_i, \in PF, \exists PR_k \subseteq PR$, specify $(PR_k, F_i) \wedge ((\forall R_l \in PR, SC_r(R_l) =$ optional $\Rightarrow R_l \in PR_k) \vee (\exists R_l \in PR_k, SC_r(R_l) =$ mandatory $)) \Rightarrow SC_f(F_i) =$ mandatory
8. $\exists F_i \in PF, \exists PR_k \subseteq PR$, specify $(PR_k, F_i) \wedge (\forall R_l \in PR_k, SC_r(R_l) =$ optional$)$ $\Rightarrow SC_f(F_i) =$ optional

Mapping rules from features to SPL

9. $\exists A_i \in PA, \exists PF_k \subseteq PF$, specify $(PF_k, A_i) \wedge (\exists F_j \in PF_k, SC_f(F_j) =$ mandatory$)$ $\Rightarrow SC_a(A_i) =$ mandatory
10. $\exists A_i \in PA, \exists F_j \in PF$, specify $(F_j, A_i) \wedge \exists F_k \in PF$, required $(F_k, F_j) \wedge SC_f(F_j) =$ optional $\wedge SC_f(F_k) =$ mandatory $\Rightarrow SC_a(A_i) =$ mandatory
11. $\exists A_i \in PA, \exists PF_k \subseteq PF$, specify $(PF_k, A_i) \wedge (\forall F_l \in PF_k, SC_f(F_l) =$ optional$) \Rightarrow SC_a(A_i) =$ optional
12. $\exists F_i, F_j, \in PF, \exists A_i, A_j, \in PA$, excluded $(F_i, F_j) \wedge$ specify $(F_i, A_i) \wedge$ specify $(F_j, A_j) \Rightarrow (i \neq j)$

Based on these mapping rules [55] [56] [57] [10] [19] elements from an under constrained architecture [39] are depicted in the Table 2 given below mainly consist of core assets of product line architecture.

Table 2 Product Line Architecture Core Assets

Sr. No.	Requirement	Identifier	Type	Map Rule	Feature	Identifier	Type	Map Rule	Identifier	Asset	Type
1	Data loses	NFR12	M	1	Maximized Signal to Noise Ratio	F111	M	10	A1	Noise Ratio	O
2	Easy Wear-ability	NFR9	MA	7	Easy Wearability	F121	M	9	A2	Wearability	M
3	Privacy	NFR5	MA	2	Transparent and Autonomous Operability	F123, F122	O	11	A3	Transparent and Autonomous Operability	O
4	Accuracy	NFR11	MA	7	Accurate	F124	M	9	A4	Accurate	M
5	Biosignals Delivery	FR2	M	2	Hassle Free Connectivity	F125	O	11	A5	Hassle Free Connectivity	O
6	Easy Wear-ability	NFR9	MA	2	Small Size (Compact Design)	F126	O	11	A6	Compact Design	O
7	Easy Wear-ability	NFR9	MA	2	Lightweight	F127	O	11	A7	Lightweight	O
8	Accuracy	NFR11	MA	4	Broad Temperature Range Support	F128	O	11	A8	Broad Temperature Range Support	O
9	Availability	NFR7	M	2	Low Power Consumption	F129	O	11	A9	Low Power Consumption	O
10	Medicine Infusion	FR8	O	8	Medicine Infusion Capability	F1210	O	11	A10	Medicine Infusion Capability	O
11	Response Time	NFR8	M	1	Robust	F1211	M	9	A11	Robust	M
12	Accuracy	NFR11	MA	4	Weather Resistant	F1212	O		A12	Weather Resistant	O
13	Security	NFR2	MA	7	Safe and Secure	F1213, F1	M	9	A13	Safe and Secure	M
14	Availability	NFR7	M	1	24 ×7 Availability	F2	M	9	A14	Availability	M
15	Interoperability	NFR4	M	1	Interoperable	F3	M	9	A15	Interoperable	M
16	Genericity	NFR1	M	1	Generic	F4	M	9	A16	Generic	M
17	Biosignals Delivery	FR2	M	1	Data Delivery	F21	M	9	A17	Data Delivery	M
18	Biosignals Delivery	FR2	M	2	Data Compression	F22	O	11	A18	Data Compression	O
19	Standards	NFR13	M	1	Data Standardization	F23	M	9	A19	Data Standardization	M
20	Biosignal Processing	FR1	M	1	Primary Biosignal Processing	F24	M	10	A20	Primary Biosignal Processing	O

Table 2. (*continued*)

21	Biosignals Interpretation	FR4	M	1	Biosignal Analysis and Display	F251, F252	M	9	A21	Biosignal Analysis and Display	M
22	Graphical interface	NFR10	M	1	User-Friendly	F254	M	9	A22	User-Friendly	M
23	Security	NFR2	MA	2	Biosignal Encryption	F27	O	11	A23	Biosignal Encryption	O
24	Biosignals Delivery	FR2	M	2	Temporary Storage	F28	O	11	A24	Temporary Storage	O
25	Privacy	NFR5	MA	7	User Authentication	F29	M	9	A25	User Authentication	M
26	Biosignals Interpretation	FR4	M	2	Multi-Touch Support	F210	O	11	A26	Multi-Touch Support	O
27	Biosignals Delivery	FR2	ME	5	Bluetooth connectivity	F211, F112	ME	12	A27	Bluetooth connectivity	ME
28	Biosignals Delivery	FR2	ME	5	Zigbee connectivity	F212	ME	12	A28	Zigbee connectivity	ME
29	Response Time	NFR8	M	1	Quick Response	F6	M	9	A29	Quick Response	M
30	Unique Patient Identification	NFR3	M	1	Unique Patient Identification	F7	M	9	A30	Unique Patient Identification	M
31	Intelligence	NFR6	M	3	Data Warehousing	F311	M	9	A31	Data Warehousing	M
32	Intelligence	NFR6	M	3	Data Mining	F312	M	9	A32	Data Mining	M
33	Intelligence	NFR6	M	3	Knowledge Discovery	F313	M	9	A33	Knowledge Discovery	M
34	Intelligence	NFR6	M	3	Decision Support	F314, F5	M	9	A34	Decision Support	M
35	Biosignal Differentiation	FR5	M	1	Biosignal Analysis	F315	M	9	A35	Biosignal Analysis	M
36	Raise Emergency Alarm	FR3	M	1	Emergency Alarm	F316, F26	M	9	A36	Emergency Alarm	M
37	Communication	FR7	O	8	Notifications	F317	O	11	A37	Notifications	O
38	Accuracy	NFR11	MA	2	Signal Loss Recovery	F318	O	11	A38	Signal Loss Recovery	O
39	Intelligence	NFR6	M	3	Threshold Learning	F319	M	9	A39	Threshold Learning	M
40	Data Requisition, Communication	FR6, FR7	M	1	User / Doctor / Clinician Interface	F321, F25, F253	M	9	A40	User / Doctor /Clinician Interface	M
41	Graphical interface	NFR10	M	1	Diagnosis and Prescription Entry	F322, f323	M	9	A41	Diagnosis and Prescription Entry	M

7 Future Directions

The systematic development and deployment of MPMS systems will benefit millions of chronically ill patients by providing better healthcare services at reduced cost. The MPMs have both, promise and potential to change the face of traditional patient care but some issues like system security and patient privacy still needs the attention. User friendliness is another area of MPMS systems which should be improved to achieve better response from the end user. In this chapter we have considered almost every technical issue but non-technical issues such as legal, economical, and managerial that we have not included should also be taken into account for end user deployment of these systems.

8 Conclusion

Patient monitoring is one of the health-care activities for which techniques developed in the field of mobile communications can be effectively used. However, deployment of these techniques poses the challenge of understanding varied requirements. To overcome this challenge, we suggest adopting the *product line approach* for the development of mobile patient monitoring systems. The rationale behind adopting product-line approach is that numerous MPMS surveyed in this chapter exhibit few similarities and variations. By using the product-line approach, system builders develop a common understanding of MPM and they gain the benefits of reusing *core assets* across multiple variants of MPMS. To facilitate the adoption product-line approach, a feature-oriented domain modeling for the domain of mobile patient monitoring is presented in this chapter. A product line architecture which represents variations among features across multiple variants of MPMS and which describes core assets that have presence across multiple variants of MPMS is also presented. The various models and mapping presented in this chapter provides the greater insights about the functional and non-functional requirements of mobile patient monitoring.

9 Case Study

9.1 Mobile Cardiac Wellness Application (MCWA) [60]

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. For the feature analysis we have divided the system into three major parts according to the standard architecture presented in the Figure 1.

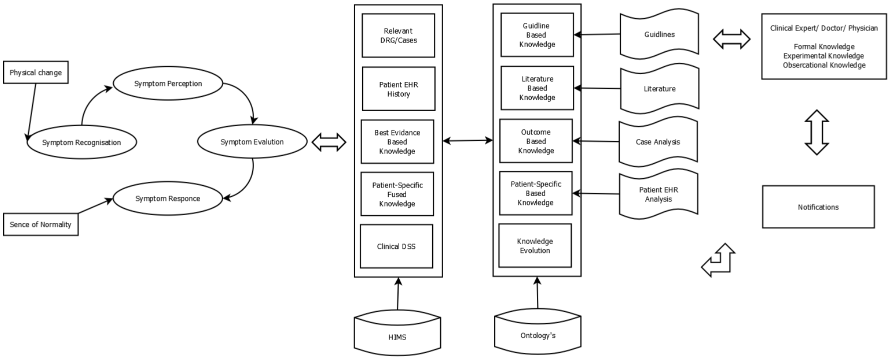

Fig. 7 Mobile Cardiac Wellness Application Conceptual Architecture

Feature Oriented Domain Analysis for MCWA

- **Structural Analysis**
  From the structural perspective the MCWA very clearly defined HIMS, various ontologies, User-System interactions as internal entities to the system in which the system will works but the external entities are not identified in the system. The MCWA also does not provide any type of standards or protocols that are used for data standardization or interoperability.
- **Context Analysis**
  MCWA very clearly recognize every single bit generated in the system. System provides the facility of data collection through patient front end, nurse mobile monitoring devices and patient wearable sensors to improve the clinician's ability to diagnose subtle changes in symptoms which act as a Procedural collection, clinical data collection, instructional feedback and medical situational assessment platform. This information is collected and fused into Systems knowledge base using four forms of case equivalence (structural equivalence, functional equivalence, conceptual equivalence and temporal equivalence) forming new clinical use cases mined for new clinical knowledge.
- **Domain Analysis**
  MCWA provides all the major functional requirements except emergency alarm and medicine infusion but from the non-functional point of view System provide only Intelligence, Response Time, Easy Wear-ability and Graphical interface. The main non-functional parameters such as Genericity, Security, Unique Patient Identification, Interoperability, Privacy, Availability, Accuracy, Data loses and adoption of standards are overlooked in the implementation of the system. Knowledge discovery and Decision support system provides the core strength to MCWA but when it comes to other features the System looks very weak.

9.2 *Intelligent Mobile Health Monitoring System (IMHMS)* [59]

The main objective of IMHMS system is to intelligently predict patient's health status and to provide them feedback through their mobile devices. The IMHMS system is a pervasive mobile health monitoring system that uses Wearable Wireless Body or Personal Area Network to collect data from patients. The system also stores examination and treatment results in the central database. The key strength of the system is its learning capabilities implemented using state-of-the-art data mining techniques. In particular IMHMS provides a flexible and simple MPMS with user-friendly interface however the security mechanisms for the system still require improvements.

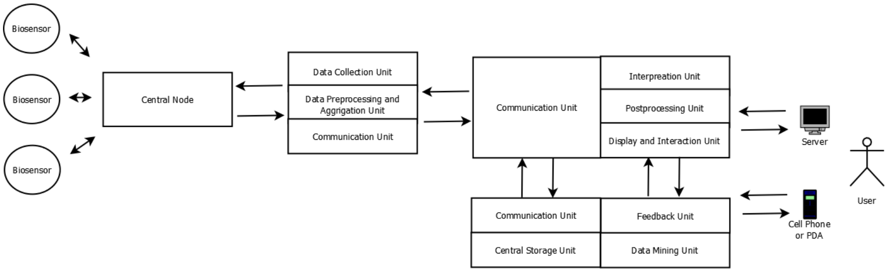

Fig. 8 Intelligent Mobile Health Monitoring System Architecture

Feature Oriented Domain Analysis for IMHMS

- **Structural Analysis**
  From the structural perspective the IMHMS very clearly defined Wearable Body Sensor Network [WBSN], Patients Personal Home Server [PPHS], Intelligent Medical Server [IMS] as internal entities to the system in which the system will works but the external entities are not identified in the system. The IMHMS included RFID tags for unique patient identification. IMHMS does not provide any type of standards that are used for data standardization or interoperability.
- **Context Analysis**
  IMHMS collects patient's physiological data through the bio-sensors. The data is aggregated in the sensor network and a summary of the collected data is transmitted to a patient's personal computer or cell phone/PDA. These devices forward data to the medical server for analysis. After the data is analyzed, the medical server provides feedback to the patient's personal computer or cell phone/PDA. The patients can take necessary actions depending on the feedback.
- **Domain Analysis**
  IMHMS not only provides all the major functional requirements except emergency alarm and medicine infusion but from the non-functional point of view also System provides Intelligence, Response Time, Easy Wear-ability and Graphical interface, Genericity, Security, Unique Patient Identification,

Interoperability. The non-functional parameters such as Privacy, Availability, Accuracy, Data loses and adoption of standards are still overlooked in the implementation.

The characteristics features of IMHMS are described below:

Simplicity: The system architecture of IMHMS is a simple one with no complex system or communication architecture.

Cost-Effective: IMHMS is cost effective. WBSN setup consists of some low cost bio-sensors. The communication from WBSN is also cheap due to the use of low cost Bluetooth or ZigBee adapters. PPHS setup is cost effective due to use of personal computer of normal configuration or low cost cell phones.

Secure: Security is a major issue in IMHMS. The IMS maintains patients profile information with the RFID in the central database. So malicious attacks can be blocked using this information because a patient can be easily tracked using RFID. Moreover large volume of data to is transmitted between the three components of the IMHMS. So the transmitted data will be in encrypted form between the components to protect from security vulnerability.

Flexible communication protocol: The communication protocols of IMHMS are flexible. The WBSN central controller can communicate with the PPHS using any of the three protocols: Bluetooth, WLAN or ZigBee.

The implemented prototype of IMHMS is very user friendly; people with little or no technical knowledge can use it without any difficulties. The communication architecture of IMHMS is very simple and flexible as so there is no complexity in communication between the components of IMHMS. The data encryption is provided with Advanced Encryption Standard (AES) which the system effectively slower.

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Questions

Q1. Define the following terms with reference to Mobile Patient Monitoring Systems.

- Body Area network
- Mobile Base Unit
- Back end systems

Q2. Explain functions performed by various system elements included in the generic architecture of Mobile Patient Monitoring System (MPMs). Why the elements included in the generic architecture of MPMs are separated between product and process perspective?

Q3. What is Feature Oriented Domain Analysis? Explain various steps involved in FODA with output.

Q4. Give the various pros and cons of Feature Oriented Domain Analysis.

Q5. Define fodaA. How the FODA diagrams are converted into the fodaA grammer.

Q6. Defines Software Product Lines and core assets of the software product lines. What are the Benefits offered by the software product lines?