Real-Time Multiple Patient Telemonitoring using a Wearable Sensors and Smart Phone

M.Arunanand[1], T.Viswanathan[2]
[1, 2] Department of Electrical and Electronics Engineering
[1, 2] Kumaraguru College of Technology, Coimbatotre, India

Abstract- *A new modeling methodology named MedPRO for addressing organization problems of health care systems is proposed in this paper. This methodology is based on three different views of metamodel: process view (care pathways of patients), resource view (activities of relevant resources), and organization view (dependence and organization of resources). This model can be be converted into an executable model for simulation by means of a special class of Petri nets (PNs), called Health Care Petri Nets (HCPNs) and instantiated for a specific health care system. HCPN models serve as a basis for short-term planning and scheduling of health care activities. Many devices and solutions for ECG and Accelerometer remote monitoring system is dedicated to non-technical users who is in need of long-term health monitoring systems in residential environments and is integrated in a broader Internet-of-Things (IoT) infrastructure.*

Keywords- MedPRO Technology, ECG, ZigBee, IoT, TeleMonitoring, Cloud Database

I. INTRODUCTION

Wearable biomedical devices can take advantage of two concurring technology trends. On the one hand, the cost per function enabled by semiconductor technology is exponential reduced, popularized as “Moore’s Law”, makes low-power and high-performance microcontrollers and radios available at low cost. On the other hand, in large sectors of the population, broadband penetration is very high especially in OECD (Organization for Economic Co-operation and Development) countries. The very same trends are the enabling factors of the so-called “Internet of Things” (IoT).

Many devices and solutions for health monitoring have been proposed which typically consist of monitors of vital signs, wirelessly connected to a smart phone or to a computer that often enable data logging and visualization through a web or mobile application. The optimization obtained by the use of the dedicated front-end has limited effects on the power performance of the complete sensor as the power consumption mostly in such sensors is mainly due to the radio link.

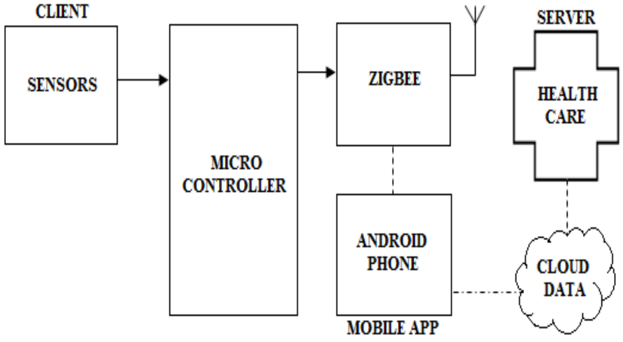

Figure 1. Block diagram of the system

In order to overcome this drawback, we here propose an ECG and Accelerometer remote monitoring system using three views MetaModelling that is dedicated to long-term health monitoring systems for the users/patients in residential environments without assistance, and is integrated in a broader IoT infrastructure.

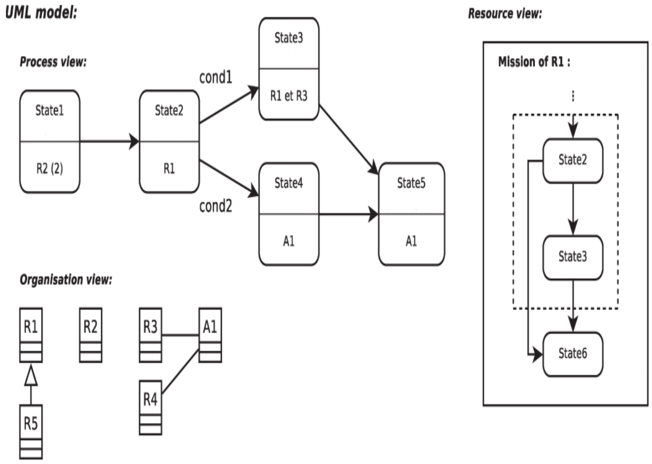

Figure 2. UML Model of MetaModelling

Telemonitoring in health care can be performed using various telecommunication and information technologies. In general, the tele-monitoring systems can be categorized based on the following properties: a) type(s) of collected data; b) modality and frequency of data collection (e.g., continuous versus periodic monitoring) c) means of data transmission (e.g., phone call, internet connection, etc.) d) type and number of devices used (e.g., a network of distributed sensors, a single device, etc.); and e) level of real-time operation. Patient’s physical activity and vital signs data are being collected via a smartphone and reported to a central server. The central server in turn analyzes the data and makes the results of the analysis available to the medical care team. The medical care team assesses the health status of the patient based on the processed data and intervenes if necessary. As opposed to the traditional health care model, where such information is reported to the caring physician only intermittently, the tele-monitoring technology can support automatic analysis of the data in real-time and alert the physician when significant changes are detected. Although several tele-monitoring systems have been proposed in the past, the majority of the research systems have been deployed only in a controlled (laboratory) environment or used only by healthy individuals. When deploying such a system to actual patients in a real environment (e.g., home, work place), there are several new challenges that need to be addressed.

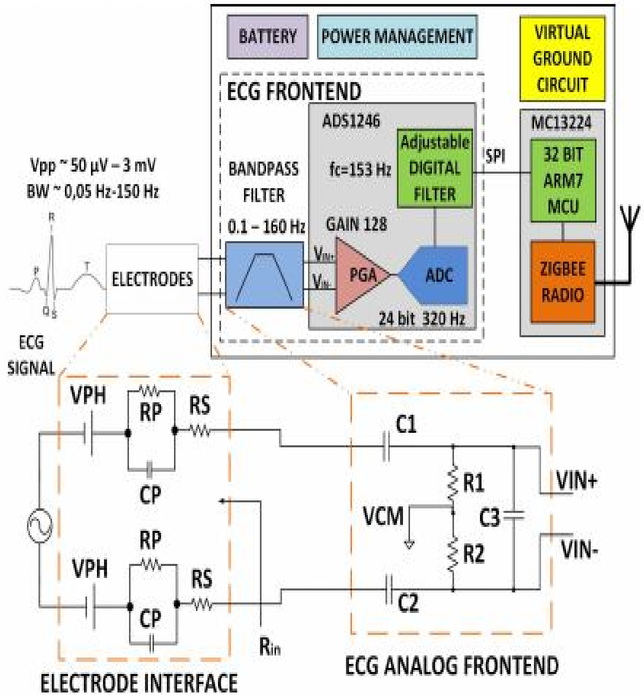

Figure 3. ECG circuit block diagram and analog circuit schematic

The primary focus of this paper is to present the outcomes of

1) The implementation of a tele-monitoring system based on a smartphone that a) collects continuous estimates of EE in real-time, daily self-reported vital signs and cardiovascular symptoms, b) performs data analysis, and c) provides alerts to the medical staff.
2) Lessons learned from the deployment of the system to patients with CHF in their everyday environment.
3) Observations of the medical intervention in the context of the collected data. Such observations can be used to formalize hypotheses that can be tested in future randomized controlled studies.
4) Acceptability of the continuous tele-monitoring and data sharing with various stakeholders.
5) Analysis of the battery performance over the course of several weeks of continuous monitoring.

II. METHODOLOGY

After a preliminary domain analysis (step1) of the health care system under consideration, a metamodel is built using a specific UML toolbox (step 2). The model is then validated with health care professionals (step 3) and eventually modified to fit reality. Then, an automatic conversion into a formal PN model is done (step 4).Using the properties of this formal model, planning and scheduling optimization can be performed (step 5), as well as discrete-event simulation (step 6). Discrete-event simulation is used to observe the behavior of the model, test new organization scenarios, and extract and present results.

Key features of the MedPRO approach:

1) A flexible multiview high-level modeling formalism (BPM approach via UML). UML has been chosen in order to propose a simple and yet formal model for health care professionals. Multiple modeling views are used for ease of modeling and understanding. Relevant information (processing times, resource organization, and arrival rates) are integrated in the model through an internal information system.

2) Automated conversion of UML models into rigorous PN models. Taking advantage of the literature, PNs are used to:
    - analyze the model and identify bottlenecks and inaccuracy;
    - provide optimal planning
    - run relevant simulation scenarios.

3) Integration of special features of health care systems such as specific decision processes, medical diagnosis models, competencies of human resources, and teamwork. To summarize, the MedPRO approach uses UML models for description and discussion purposes and rigorous PNs models for formal analysis and simulation purposes. Although using both models requires conversion procedures, the resulting framework remains light and covers the whole analysis process from specification to planning/scheduling and simulation. The following sections of this paper detail both BPM and PN models.

A. ECG

The wearable ECG sensor consists of a battery-powered chestbelt enabling the measurement and streaming transmission of electrocardiogram signal during daily routines. Two dry plastic electrodes and the electronic printed circuit board are contained in the belt (Fig. 3). The ECG signal is extracted, filtered, amplified and digitized by the circuit, which is then acquired by the microcontroller and wireless sent to the IoT server (Fig. 1). In the first prototype we used the ZigBee communication protocol.

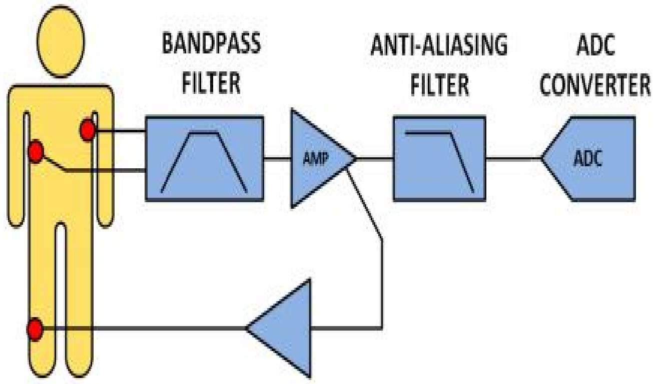

Figure 4. Typical ECG Analog Frontend

B. Server Implementation Details

The server in our tele-monitoring framework performs several tasks, which include communication with the client application to receive data, data storage, data analysis for determination of risk scores, access to the data via web based dashboard, and delivery of daily surveys.
The server has the following four key components:

C. The Backend

The backend is responsible for providing a server-side interface to the cell phone application. The backend both collects data from the monitoring component and provides server requests back to the application when needed.

D. The Database

MySQL- based database system responsible for data storage and management.

E. The Data Analysis Component

This component performs basic data analysis in the background in order to support visual review of patient's data by the medical staff. For example, this component calculates the risk scores based on the survey responses which in result help the medical staff to assess the symptoms related to CHF. The risk score calculation formula, for each completed survey, was designed based on experts' knowledge by the cardiologists involved in this project. The risk score was designed to capture existence and severity of symptoms related to chronic heart failure such as dizziness, shortness of breath and fatigue [26], [27]; absolute values of some vital signs such as systolic blood pressure; and relative values of some vital signs such as accelerometer.

The score is computed as follows. A score is first assigned for each symptom related question and answer. A score is also assigned for each vital sign entry as reported by the patient:

a) for blood pressure and heartbeat rate: based on their absolute value;
b) for motion detection: based on the relative accelerometer value and
c) for symptoms: based on whether symptoms, such as dizziness, shortness of breath or fatigue are present and their severity.

Finally, all the scores are accumulated into the final daily score. Depending on the range of the final score, patients receive a predefined message at the end of the survey. Note that the assigned risk scores per question may be positive or negative; therefore, the feedback is only presented after completion of the survey in order to reflect the complete score. The feedback messages range from encouraging the patient if the risk score is below a certain threshold to checking in with their clinic or advising the patient to call the emergency number (911) if the patient's risk score is too high. In addition to the feedback, this component will flag the patient and notify the medical staff if the score is higher than a preset threshold. We investigate this component in more detail in Section 4.3. Additionally, this component performs classification of the phone state based on the data received. More information about the classification is provided in Section 4.2. The existence of a data analysis component in every tele-monitoring system is in our opinion vital in enabling the deployment of the system to a large number of users.

F. The Dashboard

The dashboard is a web-based user interface that allows the medical staff to monitor the status of the enrolled patients. A screenshot of the main page of the dashboard is depicted in Fig. 4a. The medical staff can access patients activity and related geographical information (obscured for privacy by shifting GPS data as described previously) by clicking on the "View" link under "Data" for the corresponding subject. Examples of the possible plots that can be viewed using this link.

III. OPERATIONAL SYSTEM MODELING

The MedPRO approach models a health care system from three views: process view (patient flow), resource view (health care activities of resources), and organization view (competencies, team formations, and relations between resources).

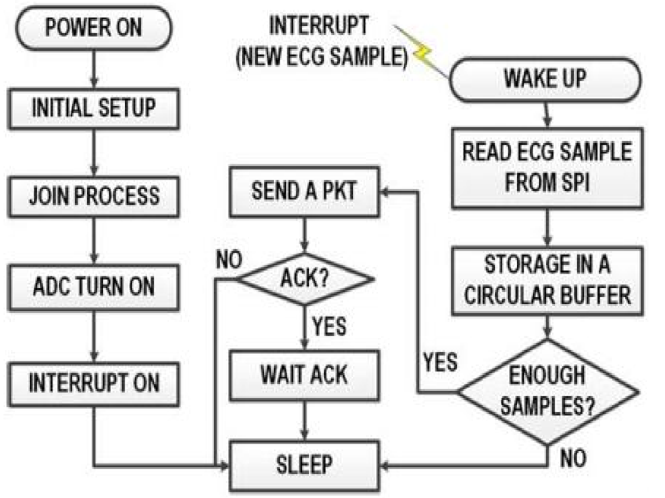

Figure 5. System flowchart

A. Process View

The process view is a set of flow diagrams modeling the care pathway of entities (usually patients) through a medical unit. The goal of the process view is double: 1) offer a precise representation of relevant care activities and care processes of each patient and 2) propose a patient-centered model designed for communication and/or medical education. A state of the process view (P-state) models an operation performed by/on the entity considered in the SC. Resources are eventually needed. A state can model a static situation ("wait for the porters") or a dynamic one ("take a meal"). In the latter case, the state has a processing time.

B. Resource View

The resource view models represent health care activities performed by various resources. In this paper, the resource view model of each resource is represented by SC models for all needed missions. Each mission corresponds to a set of health care activities identified in the process view models and some other activities that are needed but are not seen by patients. A resource may have several missions depending on its involvement in the patient care process. This representation allows each health care professional to define accurately his own activities.

C. Organization View

The organization view offers a global representation of resource definitions, interactions, scope of actions, and specialties. UML class diagrams are used to model such relations. Three types of relations have been identified in health care systems: 1) inheritance, to model resource specialization and hierarchy; 2) association, to model resource sets or teams; and 3) ability, to model medical abilities or competencies of resources.

IV. CONCLUSION

A wireless wearable ECG monitoring system embedded in an IoT platform is integrating heterogeneous nodes and applications, having a long battery life, and providing a high-quality ECG signal is proposed in this paper. The system allows monitoring multiple patients on a relatively large indoor area (home, building, nursing home, etc.). Our ECG sensor exhibits the record-low EEQNL figure of merit (energy per effective number of quantized levels) of all solutions with both discrete and integrated frontends available in the literature. The fact that we would like to stress that a dedicated front-end chip is not enough to achieve an advantage in terms of overall sensor performance. Future work will focus on monitoring additional health related parameters transducers, sensors, and correlation techniques, and on improving system reliability and robustness to patient movement and connectivity losses using a broader combination.

We have proposed in this paper an integrated approach for modelling and analysis of health care systems. It started with a multiview UML modelling approach to represent patient care pathways, resource behaviors, and relations between the different resources. The multiview UML models can be also extended: team and ability concepts are too restrictive, and models of absenteeism and replacement of resources are needed. More generally, deadlock prevention and avoidance are not addressed, and appropriate techniques are needed to manage resource assignment in order to avoid deadlock situations. Finally, holonic systems may be a relevant tool to complete the control strategy.

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