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An Advanced Mobile System for Indoor Patients Monitoring

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Abstract— The benefits of health monitoring solutions continue to be validated in terms of cost effectiveness and improved clinical results. Infact, use of medical devices and wearable sensor-based system to monitor patients' health conditions are continuosly increasing both internally to hospitals and home. In this paper we proposed a system that is intended to monitor patients' physiological parameters to detect abnormal cardiac accelerations and patient falls in real-time. The core of this paper is the realization of an advanced mobile monitoring system based on a modular software architecture that simplifies technological or functional changes. Thanks to this architecture, it was easy to introduce a software module dedicated to the fall detection based on threshold-based algorithm. The paper also describes a case study where the system has revealed important benefits both for patients and medical staff.

Keywords-Mobile System; m-health; Wireless Monitoring; ECG; Fall Detection; Software Architecture;

1. Introduction

Recently, there has been increasing interest in wearable and mobile health monitoring devices, both in research and industry. These devices are particularly important to the world's population, in particular for people that have to be monitored continuously.

The implications of these wearable health monitoring technologies are paramount, since they could enable the detection of early signs of health deterioration, notify health care providers of critical situations, find correlations between lifestyle and health, or bring healthcare to remote locations and developing countries, and transform health care by providing doctors with multi-sourced real-time physiological data.

Lately there has been a proliferation of consumer health monitoring devices. These are sophisticated devices available today that provide real-time heart rate information, and let users store and analyze their data on their home PC [1]. Bodymedia has developed a device that has multiple sensors (galvanic skin response, skin and near-body temperature, two-axis accelerometer and heat flux) to continuously collect physiological data for a few days at a time. Once the data is downloaded to a PC, their software derives what they call "lifestyle" information, such as energy expenditure, duration of physical activity [2]. However, in all cases the physiological data is analyzed on a home PC at a later time. Traditionally, personal medical monitoring systems, such as Holter monitors, have been used only to collect data for offline processing.

One of the most popular remote health systems is perhaps the AMON system [3], a wearable medical monitoring and alert system targeting high-risk cardiac/respiratory patients. Use of wearable monitoring devices that allow continuous or intermittent monitoring of physiological signals is critical for the advancement of both the diagnosis as well as the treatment of cardiovascular diseases. The usual clinical or hospital monitoring of physiological events such as the electrocardiogram or blood pressure provides only a brief window on the patient's physiology because they are likely to fail in sampling rare events that may have profound diagnosis, and they cannot monitor the patient during rest or sleep. The continuous measurement of blood pressure serves as one example. Most ambulatory blood pressure monitoring devices rely on the repeated measurement of systolic and diastolic blood pressure at predetermined intervals but do not provide a continuous reading of blood pressure. Although efforts have been made to supply such information by invasive monitoring schemes, they are limited by the potential of untoward events such as arterial damage and infection. Therefore the development of devices that can acquire such information in a non-invasive manner is essential.

The health care is seeking to reduce some of the problems of hospital health care by using medical monitors, such that health care providers can conduct a check-up on the patient's vital signs such as pulse rates, blood oxygenation and body temperature, or by uploading ECG (Electrocardiogram). This type of technology could be used with video-surveillance systems to health monitoring in particular cases like the monitoring of radioactive patients in a department of nuclear medicine.

This paper focuses on a smart solution for a lot of patients with heart disease that every day in a Nuclear Medicine department are examined under stress by using particular injections that cause elevated heart rate and boost of body temperature with frequent fainting.

Currently, patients are accompanied by nurses when moving within the department. The goal is to have an automatic system that provides to have all patients under control and to intervene when necessary. To do that, we propose a system able also to monitor heart rate and accelerometer data continuosly to detect both abnormal cardiac accelerations and abnormal movement of patients.

The abnormal movement detection philosophy can be extended to more types of dangerous events, like human fall detection [5][6]. It should be noted that the events that can be detected by an accelerometer paired with the algorithms used in our system could be accurately detected with conventional medical technologies such as EEG.

However, conventional technologies are intrusive to a person’s lifestyle, with many wires and possibly requiring surgical implantation, so they are not scalable monitoring solutions for general populations.

2. Software Architecture

The architecture of the proposed advanced mobile system is based on the architecture presented in [8]. It is divided into three different layers, namely *Data Layer*, *Decisional Layer* and *Action Layer*.

The Data Layer provides user interfaces and mechanisms to manage sensors data and patient information that will be processed by Decisional Layer. In the current implementation, Data Layer is in charge of collecting information about the patient monitored. Furthermore, Data Layer is also responsible for collecting data from an ECG device or Oximeter Monitor device and calculating more complex parameters such as the peak of QRS – for ECG device – or the peak of plethysmography – for Oximeter device – to estimate Heart Rate. This layer is demanded to collect data from an accelerometer device with the final aim of recognizing the patient's posture and especially to implement fall detection module. Finally, it handles the connection with the camera IP on a specific URL.

The Decisional Layer represents the “intelligent” core of the system. In this layer, data coming from the Data Layer are elaborated, so recognizing the possible critical situations and determining the most appropriate actions to be performed by the Action Layer.

Finally, the Action Layer executes the actions inferred by the Decisional Layer by implementing mechanisms to produce reactions like the generation of alarms and messages or starts the video streaming by camera IP.

Figure 1 shows the Component Diagram of the system designed to give a view of the high-level software design.

According to the architectural model described in [8], the component diagram of the system is organized on three levels. For each module of each level at least one component was expected, and if necessary more than one have been provided.

The improvement here introduced, compared with [8], is the software module dedicated to the fall detection. In the software details section we going to show in deep the algorithm used for fall detector module.

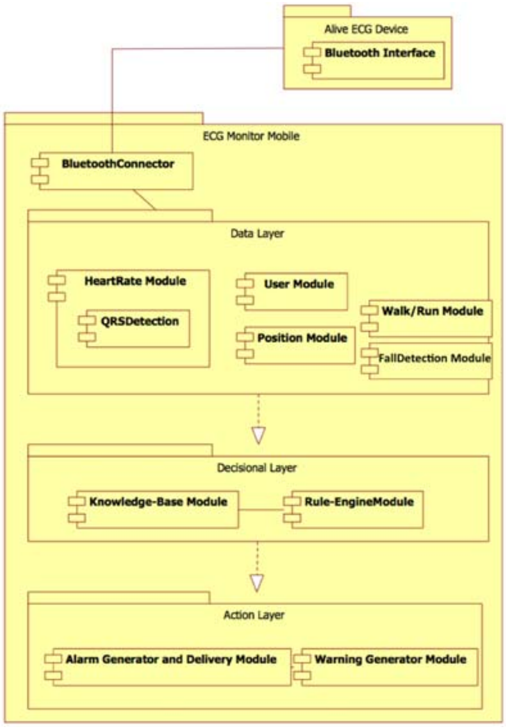

Figure 1. Component diagram of the proposed advanced mobile system

3. Implementation

All layers are implemented for resource-limited mobile devices, such as PDAs and smart phones, by using the java programming language. In particular, they were developed by using Java 2 Platform, Micro Edition (J2ME) in accordance with the Mobile Information Device Profile 2.0 (MIDP) and Connected Limited Device Configuration 1.1 (CLDP).

3.1 Software Details

The fall detector module is based on threshold-based algorithms [4], which attempt to identify movements that are potentially harmful or indicative of immediate danger to a patient.

The first step of the algorithm is the signal aggregation to combine the values of the three axes into a single value.

The root-meansquared method for taking the magnitude of a vector provides the desired global view:

$$\text{global\_g} = \sqrt{g_x{}^2 + g_y{}^2 + g_z{}^2}$$

The current global_g value provides an instantaneous reading of the net acceleration that the accelerometer is experiencing. The abnormal movement detection algorithms require information about the change in acceleration; therefore, in this processing step the difference of the current sample is taken from the last sample.:

$$\Delta\text{g\_rms} = \left|\text{global\_g}_{current} - \text{global\_g}_{last}\right|$$

The final step of signal processing is to detect a quick change of the Δg_rms value over the chosen period, in our case 1 second:

$$\text{Avg\_}\Delta\text{g} = \frac{\sum_{i=1}^{sps} \Delta\text{g\_rms}_i}{sps}$$

where sps is samples per second.

3.2 Hardware Details

To verify the system performance we conducted a number of tests using the set of hardware devices shown in Figure 2.

Monitor ECG and Accelerometer are part of the Alive Heart Monitor™ [9] sensor, which is a wireless health monitoring system for screening, diagnosis and management of chronic diseases, and for consumer health and fitness. The monitor uses wireless Bluetooth networks to immediately transmit ECG and accelerometer data to a personal computer, a PDA, or a remote monitoring station. ECG and accelerometer data is transmitted in real time over a Bluetooth Serial Port Profile (SPP) connection.

The Alive Pulse Oximeter Monitor™ [9] is a wearable medical device which uses wireless technology instead of inconvenient cables. It reads oxygen saturation data from a sensor on the finger or earlobe, and transmits the data via Bluetooth wireless technology to a mobile phone, PDA, laptop PC, or other Bluetooth-enabled device. The device can transmit the data in real-time or store the data for later download, as required.

The camera IP used is an AXIS 210A IP Network Camera™ [10], which is a professional network camera for indoor monitoring over IP networks. The built-in power capability over the Ethernet allows the camera to receive both data and power through a single Ethernet cable. The AXIS 210A camera provides superior video quality at up to 30 fps in full VGA 640x480 resolution. It also supports simultaneous Motion JPEG and MPEG-4 for image quality and bandwidth optimization.

Finally, we used the Datrend AMPS-1 [11] (Advanced Modular Patient Simulator) to test the overall system. It is a compact Simulator that operates from the single 9 volt alkaline battery and is equipped with 2 leads for ECG simulation with 9 independent outputs for each signal lead.

This simulator can be used to reproduce 52 different kinds of Arrhythmia, so simulating a great number of potentially dangerous situations for testing purposes.

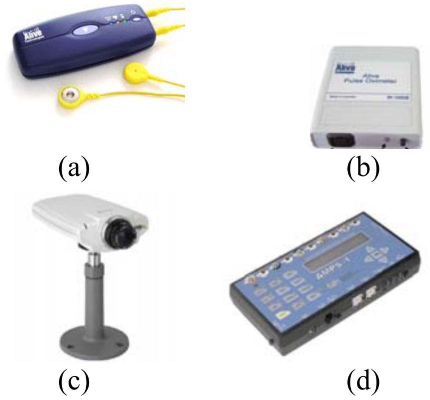

Figure 2. Hardware devices used to test system performances : (a) Alive Heart Monitor; (b) Alive Oximeter Monitor; (c) Axis 210A IP Network Camera; (d) Datrend AMPS-1 Patient Simulator

4. Case Study

In this section, a case study is presented. The system designed is an advanced mobile system for indoor patient monitoringand and will be used in a department of nuclear medicine of a city hospital.

Every day in this department many cardiac patients are examined under stress by using.

Within the Department, patients are injected with a small amount of a particular radioactive substance in order to undergo specific examinations (e.g. Blood Volume Study, Bone Scan, Brain Scan, etc.). These injections cause elevated heart rate and boost of body temperature with frequent fainting.

Once injected, patients have to stay in a specific room to wait for the examination to be performed. The time patients have to wait depends on the kind of examination that has to be performed and on the time the substance takes to propagate -within the body- and to decay to the right level. This substance provides for increase heart rate, because examinations can be executed only if the hearth rate is in a certain range. After the examination, patients return to the waiting room until the level of radiation becomes less than a specific threshold and, so, harmless.

When the patient is injected his Heart Rate increases dramatically, but it must always be in a given interval. This increase also causes the elevation of patient's body temperature, resulting in low pressure and frequent fainting.

Figure 3 shows the department's rooms: 1) Acceptance Room - This is the room where patients are accepted within the department and wait for injection; 2) Injection Room - This is the room where patients receive the injection; 3) Hot Waiting Room - This is the room where patients wait for the examination after having been injected and until the radiation level reaches the correct range; and 4) Diagnostic Room - This is the room where examinations are performed.

Figure 3. Case Study: Rooms of Nuclear Medicine department

Currently, patients are accompanied by nurses when moving within the department. The goal is to have an automatic system that could lead them. The system will adopt the same cameras IP used for the video-surveillance of patients within the department. ECG Monitor devices is in use at monitor Heart Rate and Accelerometer data for fall detection and mobile devices will also be used to communicate with patients in order to alert them in case of dangerous situations.

In this way, nurses will no longer be necessary for the surveillance of patients within the department. This will have two benefits: lower costs and fewer people exposed to radiation.

To understand the utility and the benefits of the proposed system let us analyze three of the most frequent scenarios occurring in a department of nuclear medicine of a city hospital.

In the first scenario, the patient, finished the stage of acceptance, accesses the Injection Room. The operator performs the injection and gives the patient an ECG monitor or OximeterMonitor and a PDA. The patient injected with radioactive liquid is asked to wait in the Hot Waiting Room until the level of radioactivity and her/his Heart Rate is at the desired and necessary levels to perform the analysis. While the patient waits in the Hot Waiting Room, her/his heart rate exceeds the maximum threshold allowed thus risking a heart attack (myocardial infarction).

The system, through the ECG monitor that continuously monitors her/his heart rate, detects in real time the emergency situation and sends an alert to medical personnel for a first aid.

In the second scenario, like in the first, the patient injected with radioactive liquid is asked to wait in the Hot Waiting Room. While the patient waits, her/his body temperature increases resulting in decreased blood pressure. This situation may lead to a fainting patient. The system, through the ECG monitor that has an embedded 3-axes Accelerometer continuously monitoring her/his acceleration, detects in real time the fall.

The system alerts the operators and provides switching context to enable the camera IP localized in the Hot Waiting Room to show video-stream from this camera and to verify that it is not a false positive alert. Finally, in the third scenario, like in the first and second scenario, the patient injected with radioactive liquid is asked to wait in the Hot Waiting Room. While the patient waits, her/his Heart Rate does not reach the desired level. So, the system, through the ECG monitor, detects this situation and alerts medical personnel, and provides for the patient being invited to go into the Injection Room for another injection.

5. Conclusions And Results

Mobile Health Monitoring is not just a trend, but also a vast area to explore and extend. In addition to this, there is a proliferation of video surveillance systems, or any other use of cameras IP. This work was a first attempt to merge these two fields of technology, trying to use the advantages of video surveillance with the fusion of data from biomedical devices to promote health care.

The testing of algorithm for fall detection has been extremely successful. Even when attempting to trigger false positives with normal but exaggerated movements, the algorithm generates no alarms. Since no test data was available from a subject who had a seizure while wearing the prototype device several testers were asked to wear the device and emulate seizure-like shaking to the best of their knowledge and ability. The algorithm was able to detect each person's suspicious movements with no need for individual calibrations.

The most important thing was to spotlight that proposed architecture is well suited for simplifies technological or functional changes.

6. Acknowledgment

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