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Continuous Vital Signs Monitoring is Going Wireless in Urgent Medicine

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Abstract

In this paper we present a wireless solution for continuous monitoring of vital parameters by using the leverage of both the biosensors and the smart technology. The proposed solution is based on the expanded technology which has been initially developed for NATO Science for Peace & Security Program for optimization of first aid treatment of soldiers wounded at the battle field. A new functionality was added to improve the existing procedures. Intelligent algorithms were developed to provide automatic triage of the wounded person for faster and more reliable categorization of his vital status and to select the optimal first aid. In addition, the continuous monitoring of the relevant parameters of his medical status provides valuable information to the physician to select a proper treatment and consequently improves the patient survival chances.

Keywords: Emergency; Vital signs; Biosensors; Triage

Introduction

Nowadays it is estimated that there are few hundred million people with chronic disease [1]. The majority of these patients could benefit from technology offering the real time monitoring of their vital parameters from home [2]. Another benefit of the nowadays technology is the integration of the existing medical resources into their mobile phones. In Europe, there is a large group of people with some type of chronic disease such as diabetes or cardiovascular disease. Only those two groups of patients generate 80% of healthcare spending's. For example, over a period of one week, an electro-cardiogram can collect information about the behavior of the heart during daily physical activity of the patient, which would otherwise not be reproduced in a clinical trial at the medical Centre [3]. The medical tools could help patients to continuously monitor their vital signs from the comfort of their homes. This idea was realized in the project Smart I (eye) Advisory Rescue System (SIARS) for the injured soldiers in the case of military conflicts. In the paper we present an architecture with embedded agents and sensor networks. We developed services that can be of great interest of urgent medicine, hospitals, remote home care and generally useful to society.

Telemedicine is expanding in the use of the newest technologies like VLSI, communication technology, artificial intelligence in signal and image processing and others in health care, disease management, home health care, long-term care, emergency medicine, and other applications.

Few years ago researchers from Slovenia and FJR Macedonia, directed by prof. Dr. Janez Trontelj, started the project for continuous vital parameters monitoring by biosensors supported by NATO Science for Peace & Security Program, SpF 984753. This project enables to design a secure multimedia transmission (medical telemetry, digital Images, captured data and text). The main objective of this project was to enable automatic personalized identification of the triage level, real time patient vital signs data collection and transmission to the nearest first aid responder and to the hospital. We have designed and developed a real-time patient monitoring system that integrates vital signs sensors, electronic patient records, and technology to allow remote monitoring of patient status. This system shall facilitate communication between first aid providers at the military field, medical professionals at local hospitals and specialists available for consultation from distant facilities.

In this paper we present our smart solution, mainly focused to expand the application to a large number of civilian casualties at natural disasters, traffic accidents involving large number of injured persons. The main difference to the project SIARS is changed application from military to civilian. This means that the soldiers can foresee the danger of being hurt and consequently put on the belt with personal sensors on the chest. In the case of civilian victims the first aid personnel must be able to use a multisensory set-up available in ambulance vehicle or at some sort of first aid transportable storage. The sensor set-up has to be adaptable to the part of the body with exposed skin or to be able to perform the sensing. The sensor signals need to be processed faster and the decision of first aid procedure to be determined in shorter time. At that moment the triage algorithm should be activated as a part of a complex telemedicine system which provides continuous monitoring of vital sign data gathered on-site using unobtrusive set of sensors.

It comprises multiple sensors into one application providing continuous wireless monitoring of the heart rate and the respiratory rate, wireless monitoring of the blood pressure and the oxygen saturation, additionally providing history charts of the four parameters as well as information of the shock index. The solution proposed is original since it provides additional functionalities like mentioned Glasgow comma scale/score (triage), save the information of given medicaments, or mark the injured body parts in case of incident.

Such set of sensors can be used in any environment such as in natural disaster situations, traffic accidents or the sports field. It maintains its performance under extreme activity. Offering fast, accurate collection and analysis of high-quality, in-depth data, the mentioned set of integrated sensors is the definitive product for remote physiological monitoring in all conditions. The sensors system can be used for

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capture and transmission of comprehensive physiological data on the wearer via mobile and fixed data networks – enabling genuine remote monitoring of human performance and condition in the real world.

The Important Vital Signals

Our sensor system is monitoring four important signals for vital body functions. The parameters of these four signals help the medics to assess the health status of a patient. It helps also to identify the patient's progress towards recovery.

The four primary vital signals are: blood pressure, heart rate, body temperature, and respiratory rate, notated as BP, HR, BT and RR, respectively. However, depending on the clinical setting, the vital signs may include also other vital signal measurements. In our project the Blood Oxygenation is the "fifth vital sign" introduced.

Primary four vital signals in our project are primary vital signals which are also standard in most medical settings extended with blood oxygenation data. The primary vital signals integrated in our system are:

1. Blood pressure (BP) - The blood pressure is recorded as readings at a high systolic pressure, which occurs during the maximal contraction of the heart, and at the lower diastolic or resting pressure. The difference between the systolic and diastolic pressure is called the pulse pressure.
2. Heart rate (HR) - is the rate at which the heart beats while pumping blood through the arteries, recorded as beats per minute (bpm). It is also called "heart rate".
3. Respiratory rate (RR) – is the number of breaths per minute. In practice, the respiratory rate is usually determined by counting the number of times the chest rises or falls per minute.
4. Oxygen saturation (OX) - Oxygenation is the fraction of oxygen-saturated hemoglobin relative to total hemoglobin in the blood. Normal blood oxygen levels in humans are considered 95–100 percent.
5. Body temperature (BT) - this recording gives an indication of core body temperature. Body temperature is a balance between the heat produced by the body and the heat lost from the body.

The heart rate is by far the most important parameter to be monitored so we decided in our project to continuously sample the electrocardiogram (ECG) signal with one lead holter, which enable continuous monitoring heart rate and heart activity. This is realized by measuring bio potential with an electrocardiogram (ECG). Analysis and knowledge of the electrocardiogram (ECG) signal help us to identify the number of beats per minute which helps to check the behavior of the heart as a function of activity. The Heart Rate Variability is important, because a rapid variation of heart rate is a sign of cardiac disease. Understanding the heart rate is the most informative metric that give us how much the heart rate varies

System Architecture

The overall system architecture represents a data network, over which collected data packets can be transmitted from e-health sensors up to the main database servers in the cloud. The architecture has been originally developed to take the advantage of the existing military communication equipment on the battlefield as a standing point that needs to be upgraded.

In this system architecture we have used the radio communication technology to transmit collected data packets over the radio channel to the First Responder (FR) or Team Leader (TL) platform and from this level to medical support units or to the cloud units' infrastructure. From here, the data packets are transmitted to the hospital or mobile transportation unit.

Client and server applications capable of exchanging the sensor data were developed. The client application, deployed on each tablet was running as a background service, which makes it more reliable. It was aimed at the real-time acquisition of the vital signs and their broadcasting (transmission) to FR, TL, as well as to cloud infrastructure. To accomplish real-time communication with multiple clients, we used multiplexer technique. The server application, deployed on FR and TL tablets, was composed of two parts, or to be more specific the background service and the Graphic Unit Interface (GUI). Background service was used to listen for any received data and was immediately processed and stored in the local database.

Integration of Wireless Biosensors

The presented solution integrates three commercially available biosensors. For extracting heart rate and respiratory rate we use the Zephyr bio harness sensor [4] that streams data at a frequency of 250 Hz. The automatic MyTech Wrist Cuff Blood Pressure Monitor sensor [5] is used for measuring blood pressure and Nonin Saturated Blood Oxygen device for measuring oxygen saturation (SPO_2) [6]. The integration scenario of the three biosensors is shown in Figure 1. MyTech Wrist Cuff Blood Pressure Monitor sensor and Nonin Saturated Blood Oxygen device communicates with Zephyr Bio harness bio-module by their MAC addresses. The data from these biosensors are first sent to Zephyr Bio harness sensor which is directly connected to the medic smart device by using the Bluetooth protocol. Zephyr Bio harness sensor is responsible for sending all the data to the medic smart device. The data received can be sent to remote server and used for further analysis of the patient's health condition.

Novel Approach for Automating Medical Emergency Triage Protocol

Abnormal vital signs are strong predictors for intensive care, therefore the automatic triage is important for effective intensive care of patients and consequently for lower mortality. These requirements are increasingly urgent in hospital intensive care departments, in cases of man casualties. Therefore the assessment and treatment of the injured patient have to be improved by introducing systematic and automatic assessment and accelerated protocols for categorization into the triaged patient groups, based on mentioned four vital parameters.

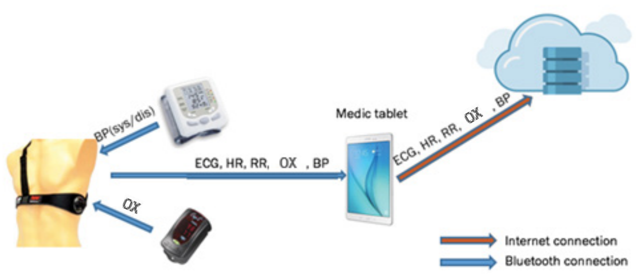

Figure 1 Biosensors system architecture.

There was a necessity for developing new algorithms and systems for automated triage in abnormal conditions of various accidents. An application of fuzzy logic classifiers was used for automatic processing of the injured person's vital signs and supports the process of evacuation of casualties. The developed algorithm takes the four vital signs as input variables and outputs the level of risk as a single variable. Identification of the input and output variables is performed in line with the current medical practices.

The developed automatic triage systems can be widely used, to support first aid and health care to persons in the hospitals or at the place of the accident. In a disaster or mass casualty situation, different systems for triage have been developed. In our approach we followed the triage system known as START (Simple Triage and Rapid Treatment). In START, victims are grouped into four categories, depending on the urgency of their need for treatment. The categories in START are presented in Figure 2.

Categorization of the mass casualties in accordance with medical care priorities is crucial in all cases. Automation of the triage process is a challenging task. One of the goals of the project was also the development of a novel algorithm for automation of medical emergency protocol, by the creation of classifiers that can provide accurate prioritization of injured victim cases. The triage is a part of a complex urgent telemedicine system that provides continuous monitoring of victim's vital data gathered on-site using an unobtrusive set of sensors.

During research activities a novel algorithm for automation of medical emergency protocol in the disaster or military environment was proposed by the creation of classifiers that can provide accurate prioritization of injured victims' cases. It is a part of a complex urgent medicine system that provides continuous monitoring of victim's vital data gathered on-site using unobtrusive set of sensors. After the pre-processed physiological data and eliminating the outliers using Naïve Bayesian Classifier, the developed algorithm is capable to calculate the risk level and to categorize the patients or victims based on Markov Decision Process. The Naïve Bayesian Classifier has been trained with a dataset described in [7-9]. The proposed algorithm was verified on several randomly created evaluation scenarios. The obtained correlation result of the proposed algorithm and medical physicians' classifications confirms that the system can be implemented in real time in emergency medicine.

Vital Parameters Monitoring

The system hierarchy comprises three layers: sensing, communication, and presentation with decision making. The core of the sensing layer represents a set of sensors, including cordless sensors data collection mobile platform, suitable for vital signs real-time monitoring. The communication layer performs uni-directional data exchange via wireless low power channel to connect sensor layer and presentation mobile platform layer. The presentation layer conducts comprehensive data analysis for triage classification of victims and evidence-based health management. This platform also presents all the data of each victim equipped with the sensors. This platform can communicate also with remote hospital by cloud technology or by accessible communication channels. For first aid responders as well for medical doctors in hospital all vital parameters are important for successful treatment. Therefore all the vital signs are stored and they can be graphical presented on the screen of each in system platform. Several screens [8] for remote monitoring of the patient is vital parameters are shown in Figure 3. Real time measured vital parameters are shown on the screen 3a. The top menu provides option for taking picture of the patient injured body parts and buttons for connecting/disconnecting from the sensor. There are two other available options provided on level of injury and medications. The history from the last hour of the heart rate, respiratory rate and shock index are presented on the screen 3b. Shock index is calculated as a ratio of heart rate and systolic blood pressure. If a Level of injury tab is selected, the Glasgow coma scale and injured body parts tabs became available. Glasgow coma scale (GCS) calculation is shown in the screen 3c and it contains groups of radio buttons for eye opening, verbal response and motor response. Each item in the corresponding group has proper value and the label below shows the sum of the selected items. Injured body parts tab shown in the screen 3d contains an image of human body where injured body parts can be marked with different level of injury. Additionally, the user can enter medications that were given to the patient. All the data are stored locally on the smart devices and in a remote database in cloud (Figure 4).

Biosensors implementation has both advantages and disadvantages. It can be beneficial in terms of:

→ Real time vital parameters monitoring – the patient's parameters can be continuously monitored and transferred;

→ Vital parameters history – the data obtained are saved and can be easily accessed by whoever needs them;

→ Wireless solution – it is practical and user-friendly in all circumstances;

Red tags	(Immediate) are used to label those who cannot survive without immediate treatment but who have a chance of survival.
Yellow tags	(Observation) for those who require observation (and possible later re-triage). Their condition is stable for the moment and, they are not in immediate danger of death. These victims will still need hospital care and would be treated immediately under normal circumstances.
Green tags	(Wait) are reserved for the "walking wounded" who will need medical care at some point, after more critical injuries have been treated.
Black tags	(Expectant) are used for the deceased and for those whose injuries are so extensive that they will not be able to survive given the care that is available.

Figure 2 Triage Tags.

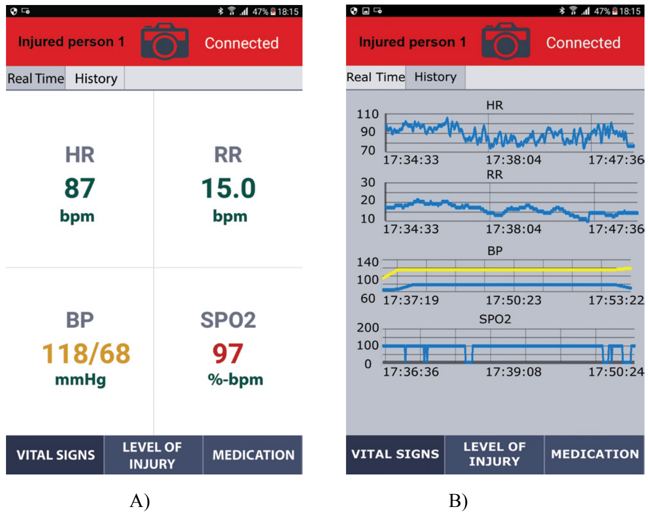

Figure 3 Screen forms on mobile phone: A - measured vital parameters; B - respiratory rate and shock index.

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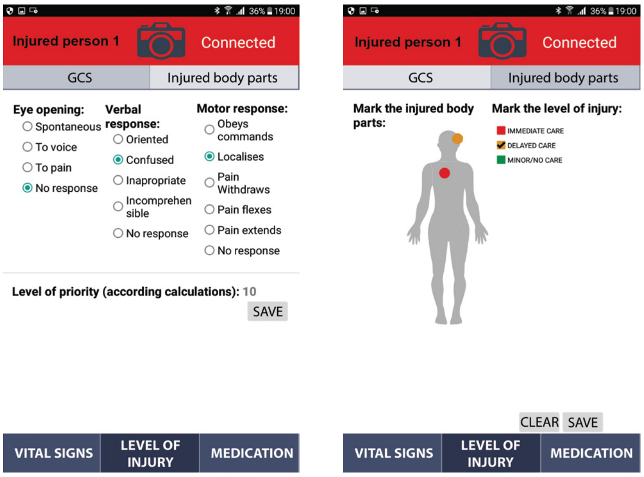

C) D)

Figure 4 Screen forms on mobile phone: C - Glasgow coma scale; D - injured body parts.

→ Portable solution – it is built for smart devices that can be either tablets or mobile phones;

→ Aids the secondary triage – support for Glasgow comma scale computation;

→ Cost-effective – all the biosensors used are commercially available and are affordable.

The main disadvantage is the battery capacity of the smart devices. The sensor device used in this research was Zephyr Bio-Harness specified to operate with the provided battery 35 hours when data logging and only 12 hours min. when transmitting. If the case demands longer continuous monitoring, then the device needs to be recharged periodically. No other constraints are noticed.

Conclusion

The described solution is based on three biosensors able to capture the heart rate, respiratory rate, blood pressure and oxygen saturation, and to transfer the data via Bluetooth to the portable smart device. The developed application provides additional features as the history of the vital parameters, the shock index, the Glasgow comma scale/score, the possibility to input the given medicaments, and even the ability to select the level of injury according to the medical protocols. Those additional features make the application to be suitable not only for personal/hospital monitoring, but also in pre-hospital circumstances in cases of incidents, or in the ambulance during transport.

The obtained results of the described project and virtual medical physician's triage are strong evidence that the system can be implemented in emergency medicine.

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