Research Paper ■

PICAMS: Post Intensive CAre Monitoring System

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Abstract. Medical staff on duty in hospitals provides high quality care for high-risk patients, especially those situated in intensive care units. Such care may present, in addition to great psychophysical pressure to the staff, considerable expenses for the hospital in question. In the paper we propose a Post Intensive CAre Monitoring System (PICAMS), based on the emerging technologies, which may eventually diminish the requirement for the doctor's non-interrupted presence, and allow for a faster transfer of the patient from the intensive care unit to the ordinary ward. What is more, it would also give patients the ability to move freely, which can be only positive for them in terms of better mood, quicker rehabilitation and indirectly lower costs for the hospital in question.

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Introduction

According to the American Heart Association[1] (AHA), the cardiovascular diseases are, with the ratio of one third, the leading cause of mortality in the developed world. Second most common cause are respiratory system diseases. More than 50% of hospitalized patients die of one of the two. What makes the costs higher are also the negative demographic trends and the constant changes of the nature of the diseases.

Patients with haemodynamically important cardiovascular and respiratory system diseases are usually hospitalized in Intensive Care Units (ICU). There they are connected to numerous devices (ECG, pulse oxymetry, non-invasive blood pressure and invasive monitors) that constantly measure the condition of their important physiological parameters. In this way constant supervision is provided, and in the case of emergency immediate help is available. Although the doctor on duty is in such a case usually alarmed by a pager, which allows them full mobility in the hospital, the mobility of the patient is neither desired nor possible, since they are connected to the monitoring devices. This does not at all help the patient's psychological condition. It makes them dependent upon the medical staff. And last but not least, providing constant 24h per day supervision increases the costs of treatment dramatically. This is why the health care policy is to find a way for faster transfers to ordinary wards of the patients hospitalized in the ICU without compromising the quality of the treatment. The moment of the patient's transfer from the ICU to the ordinary ward is of crucial importance for their health since it presents a consistent drop in the level of monitoring and cost of treatment (see line in Figure 1).

Short-Range Wireless (SRW) networks[2] (such as Bluetooth[3,4,5] or wireless LAN[6]), which are gradually becoming more and more widespread in modern information systems, enable us exactly that. Wearable computers, which used to be very rare in the past, are possible to get nowadays[7] and not far is the day when we will not even notice them since they will be so small and we will get accustomed to them[8]. These qualities exactly will enable us to set the patient free from the wires, thus allowing them full mobility. Later on, when the sensors are so small to be sewn in the clothes[9], it will be possible to measure their vital functions constantly. By adding some local processing and the use of a combination of SRW and LAN networks, we will enable the patient to move freely and yet be in constant high quality ICU type of supervision. Therefore the niche for our system is the phase when the patient is being transferred from the ICU to the ordinary ward. By using our system we can shorten the ICU hospitalization time and simultaneously lessen the drop in the level of monitoring (see curve in Figure 1).

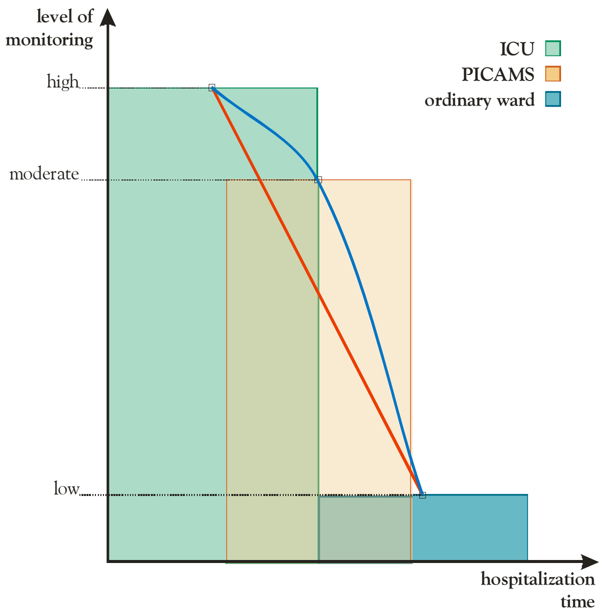

Figure 1 PICAMS niche

Not only that the PICAMS system will enable high quality ICU type of supervision of fully mobile patients; it will also allow virtual visits. For example, let us imagine a doctor on duty on one of their morning visits to the patients. They stop at a patient and check the display of their Personal Digital Assistant (PDA). There they can see the current values of the patient's vital functions (heart rate, blood pressure, blood oxygenation, hemodinamically important arrhythmias, chest expansion, etc.), which are acquired by means of sensors sewn in the patient's clothes. Using the PDA the doctor can view the history of the patient's vital functions and a list of experienced critical situations. They can also view the progress of the medical treatment (list of prescribed medicines, digital medical imagery such as angiograms, test results, etc.). Such help enables the doctor to concentrate on the patients themselves, and not on the memorizing large quantities of data. All of the information shown via the PDA helps to illustrate the patient's current condition better.

To continue with, we try to explain the ideas behind the integration of the SRW technology into the information system of the hospitals in the form of a Post Intensive CAre Monitoring System (PICAMS), concentrating on a rough description of the concept of the system in its second part. In the third part we discuss the parameters, which are of the greatest challenge to the development of the system, and we finish with a short overview of the current status and future work on the system.

PICAMS

Our goal is to develop an intelligent monitoring system that would enable non-invasive monitoring of vital functions (heart rate, blood pressure, blood oxygenation, haemodinamically important arrhythmias and chest expansion) and at the same time allow the patient to move freely. The patient's ability to move freely would make them feel more secure and have a positive psychological effect. The latter, although welcome, represents a big challenge, particularly because the current state-of-the-art in the field of monitoring of vital functions is the following:

- *Clinical intensive care monitors*, the weight of which is more than 10kg and are thus not portable at all.
- *Holter monitors*, which are portable, but restricted only to ECG, and do not allow remote access of the acquired data.
- *Multi-channel patient recorders*, which weigh a little more than 1kg, and could thus be treated as portable, but have primarily a scientific function.

Besides the already mentioned patient's full mobility we want to give the doctor on duty a means of insight into the patient's current condition of vital functions regardless of the doctor's current location. Our aim is also to keep the ICU care standard and enable alarming of the medical staff in case of the patient's critical state. We have designed a modular system consisting of the following:

- PDD - Personal Diagnostic Device, which is dedicated to acquiring, local storage and basic analysis of the patients' vital functions.
- Combination of Bluetooth SRW and LAN networks used for data interchange.
- AP - Access Point server is intended for bridging between Bluetooth SRW and LAN networks.
- MD - Main Display is situated in the main monitoring room, enabling the medical staff on duty the insight into the current condition of the patient and representing a possible way of their alarming in case of emergency.
- IAS - Intelligent Analysing System is used for a thorough analysis of the received data of the patient's vital functions and setting off alarms in case of a detected critical state of one of the patients.
- PDA - Personal Digital Assistant enables the doctor on duty an insight into the patient's current condition and represents an efficient way of their alarming in case of a critical state of one of the patients.

- HIS - Hospital Information System is the existing information system of the hospital, used for storing the information about the hospitalized patients (treatment, list of prescribed medicines, digital medical imagery such as angiograms, test results, etc.).

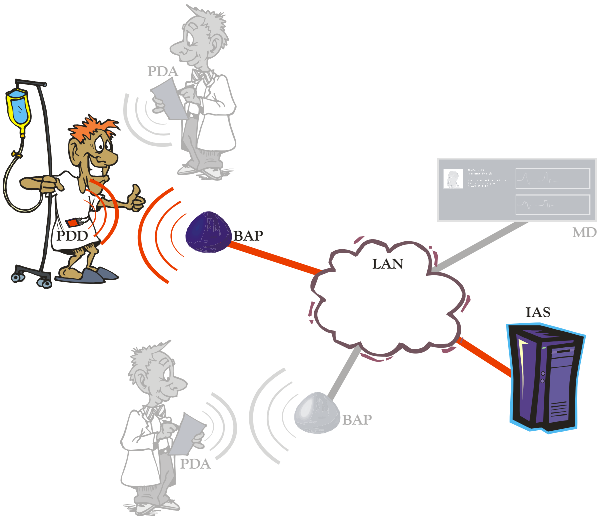

Figure 2 PDD detects unusual values of the patient's vital functions

A brief functional description

Patients with clearly expressed signs of cardiovascular or respiratory system diseases will be given a PDD and they will be hospitalized in ordinary wards. This will enable the patient the freedom of movement, which may have a positive influence on the patient's psychophysical condition and will accordingly shorten the hospitalization. A PDD will be constantly non-invasively acquiring the current values of the vital functions of the patient and storing them locally. Once stored the data will be analyzed by means of Soft Computing (SC) methodologies[10] based on Fuzzy Logic[11], Probabilistic Reasoning, Neural Networks[12,13] and Genetic Algorithms. Due to the limited processing power of the PDD this analysis will be above all dedicated to the detection of unusual values in the acquired data[14]. In case of such detection the PDD will, by means of AP, connect to the IAS and upload all of the stored data, followed by the continuous uploading of current values (see Figure 2).

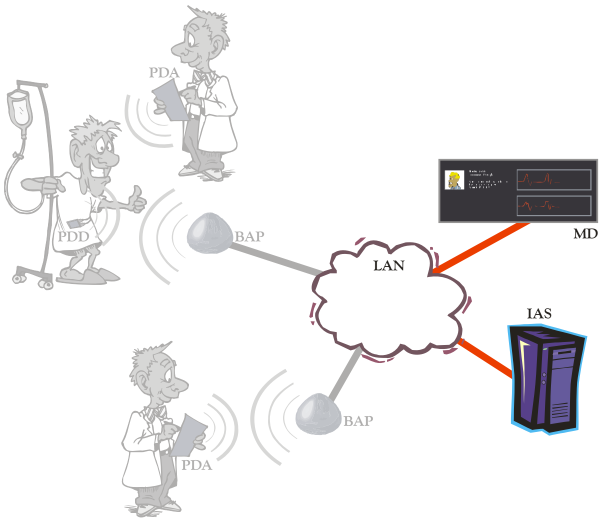

Figure 3 IAS alarms the medical staff on duty

IAS will store the uploaded information locally and with the help of SC methodologies analyze them thoroughly. Such analysis will be more accurate due to the processing power of IAS, and it will enable the detection and diagnoses of certain irregularities, e.g. arrhythmia, fibrillation and ischemic episodes, and detection of still unknown phenomena. In case of the detection of the aforementioned irregularities the IAS will, by means of AP, connect with the MD (see Figure 3). The MD will display the current condition of the patient, the history of irregularities and all additional information about the patient that is stored in the HIS (progress of medical treatment, list of prescribed medicines, digital medical imagery such as angiograms, test results, etc.).

At the same time the IAS will, by means of AP, establish a connection with the PDA of the doctor on duty. They will be able to see the alarm message with the patient's name and location (see Figure 4). They will then have the option to connect to the IAS and thus get the insight into the patients' current condition, history of irregularities and via HIS all additional information about the patient as well. So the doctor will, on the basis of the available information, be able to make a decision about further actions concerning the patient.

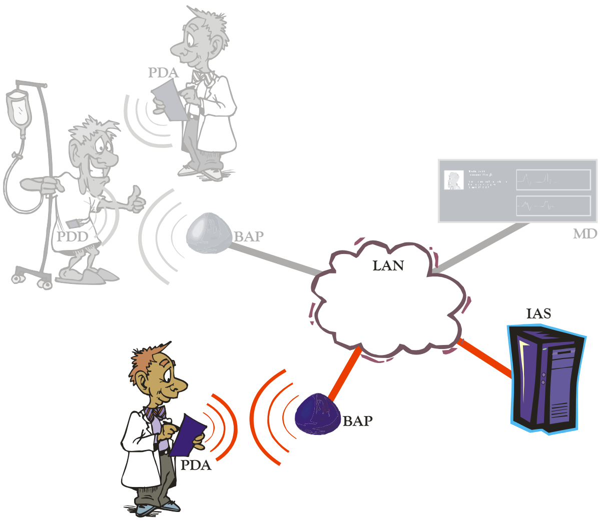

Figure 4 IAS alarms the doctor on duty

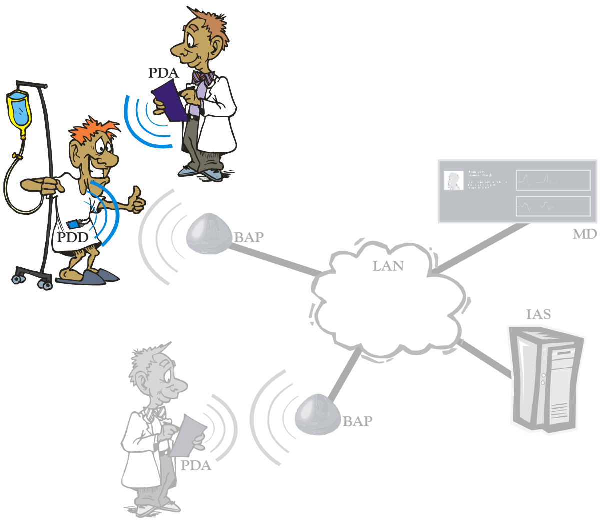

Figure 5 Doctor on duty performing a morning visit

On the other hand, on his morning visits the doctor on duty will have direct access to the PDD (see Figure 5) of the patient and see the current values of the patient's vital functions on their PDA. They will also be able to request the history of any irregularities as well as all the additional information concerning the patient. The latter will be received from IAS and HIS respectively.

Challenges

There will most definitely be challenging situations in the evolution of the PICAMS system. In the following paragraphs we enumerate the foreseen challenges with the possible solutions.

Integration of the doctor's knowledge into the PDD and IAS

Integrating the doctor's knowledge about the analysis of the fluctuations of the patient's vital functions presents a challenge by itself since it is usually based on "common-sense" reasoning. That is rather difficult to specify and thereafter to implement. It demands the use of SC methodologies[10], which consider inexactness and indefiniteness of the time dependent parameters and knowledge, and represent them in a humanly readable form.

Data safety

Safety in connection with remote monitoring may appear as a problem[16], but the Bluetooth SRW technology speaks in favour of this, because it per se enables authenticity and selection of the level of data encoding[4,5].

Reliability and range of the Bluetooth SRW network

At first we will reach the reliability by means of setting up periodical connections with the patient's PDD and checking for the proper functioning, the latter probably with the implementation of watch dog timers[17] (WDT) which are used to detect deadlocks. Later on we will concentrate on the range of the Bluetooth SRW network in the sense of Bluetooth aerials, spatial arrangement of AP servers and upgrading of the 7th level protocols of the TCP/IP protocol with special case handling algorithms (temporary loss of connection, implementation of Bluetooth roaming, etc.)

Reliability of the sensors

The largest obstacle here is how to ensure the patient's mobility but retain the reliability and accuracy of the measurements acquired. That was the reason we decided to try implanting (sewing in) all the aforementioned sensor systems into clothes the patients are wearing. In some cases (chest expansion measurements when the patient is talking) it can also happen that certain received values cannot be used, what expresses the demand for use of intelligent measurement acquiring algorithms.

False-positive and false-negative detection

The number of false-negative detections (the system does not trigger the alarm in case of a haemodynamically important arrhythmia) can be minimised to an acceptable level by means of parallel signal analysis (e.g. the analysis of multiple differentials of ECG signal) or multiple successive signal analysis.

The false-positive detection (the system determines a heart rhythm disorder when it did not occur) is not of vital importance for the patient, but rather a nuisance for the medical staff on duty. We can do away with it by using the classic medical monitoring systems with half the patients in the testing phase. By doing this we will attempt to achieve a shorter learning time of the system.

Testing

Testing of the system and the evaluation of its results is of great importance for the development of the project, due to it being of medical nature. The testing process will include the system tested in real life situations, for instance with patients with acute coronary syndromes, breathing irregularities with a considerate drop of oxygen level, etc. While testing, we will have to comply with all the required medical certificates and standards before actually deploying the system in hospitals.

Current status and future work

As mentioned before, the PICAMS system will enable non-interrupted, non-invasive monitoring of vital functions of the patient with expressed symptoms of haemodinamically important cardiovascular or respiratory diseases. It will enable the medical staff to transfer the patients from the ICU to ordinary wards faster without compromising the quality of treatment (see Figure 1), and thus reducing the cost of treatment while maintaining the ICU level of monitoring. The patients will therefore retain the best achievable level of treatment. What is more, a shorter reaction time of the medical staff may be achieved.

Currently we are working on signal analysis[14]. Following the Work-Centred Analysis (WCA) method[18] used in the design of information systems we are defining the system concept and the measurable characteristics and grading scales of the system that present the performance perspective of the WCA framework of the PICAMS system.

The PICAMS system is based on the current state-of-the-art technology and in the process of its evolution requires the development of yet unknown solutions. In spite of that we can already envisage the further expansion of the system. An optional GSM/GPRS mobile telephone with integrated Bluetooth support would enable the use of the PDD even outside the accordingly equipped hospital and thus enable the constant supervision and nearly ICU level of monitoring for the non-hospitalized patients.

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