Context-Aware Early Warning System for In-Home Healthcare Using Internet-of-Things

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Abstract. Early warning score (EWS) is a prediction method to notify caregivers at a hospital about the deterioration of a patient. Deterioration can be identified by detecting abnormalities in patient's vital signs several hours prior the condition of the patient gets life-threatening. In the existing EWS systems, monitoring of patient's vital signs and the determining the score is mostly performed in a paper and pen based way. Furthermore, currently it is done solely in a hospital environment. In this paper, we propose to import this system to patients' home to provide an automated platform which not only monitors patents' vital signs but also looks over his/her activities and the surrounding environment. Thanks to the Internet-of-Things technology, we present an intelligent early warning method to remotely monitor in-home patients and generate alerts in case of different medical emergencies or radical changes in condition of the patient. We also demonstrate an early warning score analysis system which continuously performs sensing, transferring, and recording vital signs, activity-related data, and environmental parameters.

Keywords: Early warning score · Internet-of-Things · e-Health · Remote patient monitoring

1 Introduction

Internet of Things (IoT), the world of connected devices, is expanding and hence soon it will step into every area of our life. The presence of this concept in the field of healthcare leads to a new communication channel between health professionals and patients. Several sensors can be attached to patient's body to form a wireless body area network (WBAN) to record medical parameters and patient's vital signs and transfer them by benefiting IoT to a cloud system via Internet [1].

It has been reported that the number of patients with critical illnesses are increasing every year [2] and the patients who leave the intensive care unit are

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still subjected to deterioration. There are some abnormalities in patient's vital signs several hours before deterioration happens. Based on this fact, an early warning score (EWS) system has been developed for early deterioration detection in hospitals. In this system, nurses record the vital signs of patient to find the abnormalities. EWS is often done in a paper-based fashion using manual procedures in hospitals which sometimes leads to misdiagnose or late warning. It is also slow and time consuming which tends hospitals towards using automated electronic early warning systems [3]. IoT-based solutions for remote patient monitoring bring an opportunity to extend the use of EWS beyond hospitals. EWS systems in hospitals monitor patients who are mostly located in a standard environment. However, there are several parameters that affect the value of vital signs outside the hospital (e.g., patient's activities, room temperature, barometric pressure) which should be considered to reach a more complete picture [4]. Moreover, the quality of the environment in which a patient is receiving care and remote monitoring services should be ensured to be almost the same as clinical standards.

In this paper, we propose and demonstrate a context-aware EWS system using a set of medical, activity, and environmental sensors to detect an in-home deterioration prior serious consequences. It reinforces our earlier EWS system presented in [5] with context-awareness features. Therefore, our main objective in this paper is to develop an intelligent and portable IoT-based early warning system considering all affecting parameters around the patient such as environmental and daily activity information.

2 Early Warning Score

Early Warning System is a set of instructions and algorithms for estimating the risk of health deterioration before it happens to reduce the complications or sudden hospitalization. It has designed based on the fact that patients often have signs of clinical deterioration up to 24 h before it happens [7]. In this system instruction and algorithms are based on a process called Early Warning Score (EWS) to assign a value, a score, representing patient medical status according to his/her vital signs. Table 1 shows a typical early warning score model.

The overall score of a patient, even if not be high-enough to trigger an alarm, affects to the treatment orders and recording intervals to be updated. The idea of

Table 1. A typical early warning score model [6]

Physiological parameters	**3**	**2**	**1**	**0**	**1**	**2**	**3**
Respiration rate (breaths per minute)	≤8		9-10	12-20		21-24	≥25
Oxygen saturation (%)	≤ 91	92-93	94-95	≥96			
Temperature (oC)	≤35.0		35.1-36.0	36.1-38.0	38.1-39.0	≥39.1	
Systolic BP (mmHg)	≤90	91-100	101-110	111-219			≥220
Heart rate (beats per minute)	≤40		41-50	51-90	91-110	111-130	≥131
Level of consciousness				A*			V,P or U*

early warning score was presented in 1997 [8]. Earlier versions of the score were simply calculated with five parameters: heart rate, blood pressure, respiration rate, body temperature, blood oxygen saturation and level of consciousness. Further enhancements led to a modified early warning system (MEWS), a standardized early warning system (SEWS), and national early warning system (NEWS). They were mostly different because of the number of medical parameters used in score calculation and the range limits for each parameter. Beside many benefits of using early warning system in hospital to save lives and reducing healthcare costs, there are also some reports regarding misdiagnosis and mistakes due to imprecise recorded data which force the hospitals to move towards electronic early warning solutions [3].

There are some solution commercially available for electronic early warning system in hospitals [9,10]. However, they are designed for in-hospital scenarios and do not provide remote in-home patient monitoring services. The novelty of our solution comes from the development of an IoT-based EWS method for in-home patients with the support of supplementary information such as patient activity and environmental information.

3 System Architecture

The architecture of our proposed IoT-based EWS system is shown in Fig. 1. The system consists of three layers.

At the first layer, there exist a network of sensors which record several types of signals. There are three groups of sensors at this layer: (i) medical sensors which are used to record the patient's vital signs such as heart rate, respiration rate, blood pressure, blood oxygen level and body temperature sensor, (ii) activity sensors which record the movement, sleep time, posture, daily step count and sudden falls, and (iii) environmental sensors which record parameters such as room temperature, light, and humidity. Most of the sensors at this layer are low resolution sensors, while there are also some high resolution sensors such as ECG (Electrocardiogram) and respiration rate sensors (Fig. 2).

The second layer consists of a gateway which collects data from several types and groups of sensors. The task of the gateway is to unify the received data and

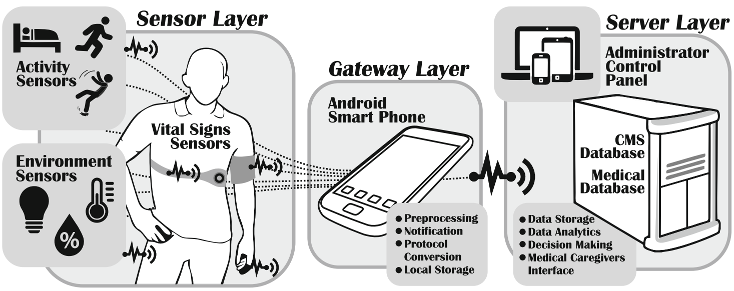
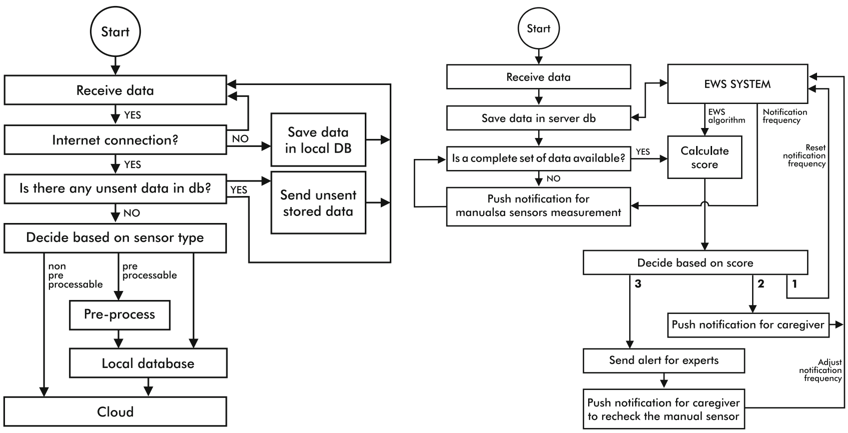


Fig. 1. Architecture of the proposed IoT-based clinical early warning system



(a) Gateway functions (b) Server functions

Fig. 2. EWS system flowcharts

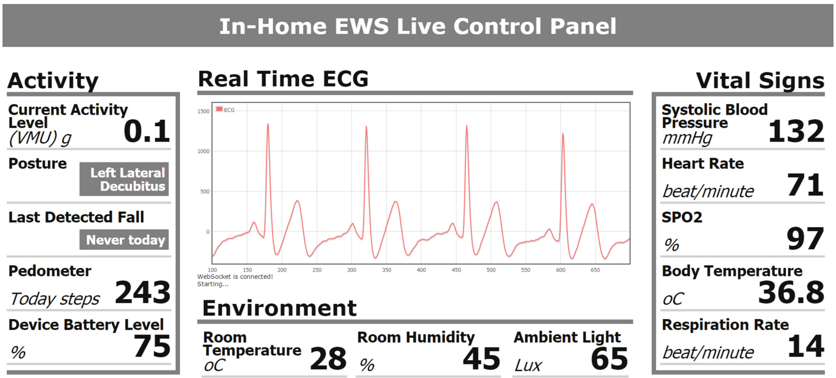


Fig. 3. Live control panel web interface

prepare them to be transferred to a cloud server using some protocol conversion, data compression, and offline storage. It can also handle the situation where there is no Internet access available. When the Internet connection is not available, the gateway records the data from sensors and stores it in its local database and when the gateway is on-line again, it synchronizes the stored off-line data with the cloud and resume sending real-time data. High resolution data are always sent directly while low resolution data are first stored and then sent as a packet. Flowchart of the gateway functions is shown in Fig. 3(a).

The back-end layer consists of a cloud server and user interface for patients, caregivers and medical experts. The cloud server receives and stores data from the gateway. The task of the server is to calculate the early warning score in specific intervals. The frequency of early warning score calculation depends on the patient's medical history and earlier scores. As there are also some manual measurements such as blood pressure and blood glucose, the server is also responsible for sending a notification to patients to enter the manually measured values to the system. The final calculated score shows the status of patient and if an abnormality is detected, the system decides to reconfigure the measurement frequency or fire an emergency alarm. Cloud server also provides an administering panel which provides access to real-time medical, activity, and environmental information of the patient for health professionals. The flowchart of the cloud server functions is shown in Fig. 3(b).

4 Demonstration and Evaluation

Our EWS system prototype consists of a set of sensors, gateway and cloud server. The main sensor for collecting the patient data is the Bioharness 3 [11] device which is a Bluetooth-based wearable chest strap sensor pack. We use this device to collect heart rate, respiration rate, body temperature, patient's activity, daily steps, and posture. A pulse oximeter fingertip grip is used to record the blood oxygen saturation. To measure the blood pressure, we use a Bluetooth-based upper arm blood pressure monitor (iHealth BP5) which can be controlled remotely through Bluetooth communication. Also a Texas Instruments' ADS1192 analog front end is used to read ECG signal. To gather context-related data, we use a DHT11 sensor which senses the temperature and humidity and a photocell to read the ambient light.

The collected data from all sensors are sent to the gateway and cloud server using both Bluetooth and Wi-Fi communication protocols. We send the output data of Bioharness 3 device together with the results of iHealth BP5 blood pressure monitor device via Bluetooth to an Android smart-phone that acts as a gateway. We develop an Android mobile application for patient's smart phone or tablet that operate as the gateway for data transmission between the sensor network and cloud server. It also alerts the patient or caregivers regarding the time for blood pressure measurement. Other low resolution sensors send data is sent directly to the cloud server using ESP8266 [12] Wi-Fi module. This module works originally with Attention (AT) commands, but we made a custom firmware for this module to enable continuous data reading from serial input and sending via Wi-Fi using UDP protocol. The high resolution ECG sensor uses RTX4140 which is a more powerful Wi-Fi module for data transmission with UDP protocol.

Currently our cloud server is a virtual private server with four 3.30 GHz Intel Xeon CPUs and 4 GB RAM. On this server, CentOS Linux runs a web server using Apache which is responsible for storing data in a MySQL database and the EWS score calculation using PHP. When all medical and environmental parameters are available in the database, an EWS algorithm on the server calculates the patient's warning score based on the thresholds of each parameter. Then, according to score results, the server sends notifications to an android device and the web control panel. The web server also provides the administration control panel to display real-time data and reports. There is a UDP server on this Linux machine operated with *Node.js* to receive data from sensors and the Android gateway. The *Node.js* server also sends real-time data to browsers using WebSocket. Our in-home EWS live control panel is shown in Fig. 3. The user interface is divided into four parts: it streams the real-time ECG signal in the middle, patient's vital signs in the right sidebar, patient activity in the left sidebar, and environment properties in the footer section. The data reported in the Fig. 3 was captured from a 34 years old healthy male volunteer during walking, sitting and lying on the left side.

5 Conclusions and Future Work

In this paper, we presented a context-aware Early Warning Score (EWS) system using an IoT-based solution. We showed the feasibility of implementing an EWS method for in-home patients while monitoring the activity level of patients and environmental properties to ensure that patients are given care in a standard situation and the EWS scoring data is captured in a suitable condition. We demonstrated an IoT-based EWS system for collecting, transferring, and displaying patient's information including vital signs, activity level and environment attributes. The collected information is used to calculate the early warning score in an automated and realtime fashion. In the future, the aim is to make the system more intelligent and autonomic. In addition, we intend to integrate the body area sensors network in an all-in-one wearable device to be conveniently used by different patients. We plan to validate the system for different kind of illnesses to validate the EWS algorithm in a real field trial.

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