Self-aware Early Warning Score System for IoT-Based Personalized Healthcare

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Abstract. Early Warning Score (EWS) system is specified to detect and predict patient deterioration in hospitals. This is achievable via monitoring patient's vital signs continuously and is often manually done with paper and pen. However, because of the constraints in healthcare resources and the high hospital costs, the patient might not be hospitalized for the whole period of the treatments, which has lead to a demand for in-home or portable EWS systems. Such a personalized EWS system needs to monitor the patient at anytime and anywhere even when the patient is carrying out daily activities. In this paper, we propose a self-aware EWS system which is the reinforced version of the existing EWS systems by using the Internet of Things technologies and the self-awareness concept. Our self-aware approach provides (i) system adaptivity with respect to various situations and (ii) system personalization by paying attention to critical parameters. We evaluate the proposed EWS system using a full system demonstration.

Keywords: Early warning score · Internet-of-Things · Self-awareness system · Personalized monitoring

1 Introduction

Patients suffering from life-threatening diseases have a high risk for a sudden clinical deterioration. Research on cardiac arrests shows that indications of deterioration are visible in patients vital signs several hours (often up to 24 h) prior to occurrence [1]. Therefore, prediction of imminent clinical deterioration is possible by paying enough attention to patient status [2,3]. Continuous patient monitoring in such a situation bring forth early detection and rapid response in a form of early treatment and prevention of fatal cases. It can also decrease the stress on hospital resources, reduce the associated costs and, most importantly, decrease mortality. Several scoring methods have been proposed based on vital signs to classify the risk level of patient status and to find the severity of the medical condition. Such methods are mostly scoring methods developed by emergency

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Table 1. A modified early warning score model [4]

Physiological parameters	**3**	**2**	**1**	**0**	**1**	**2**	**3**
Respiration rate (breaths/minute)		0-8		9-14	15-20	21-29	30+
Oxygen saturation (%)	0%-84%	85%-89%	90%-94%	95%-100%			
Temperature (oC)		0-35		35.1-38.0		38.1-39.5	39.6+
Systolic BP (mmHg)	0-69	70-80	81-100	101-149	150-169	170-179	180+
Heart rate (beats/minute)	0-39	40-50	51-59	60-100	101-110	111-129	130+
Level of consciousness				A	V	P	U

* A=Alert, V=response to voice, P=response to pain, U=unresponsive

departments or intensive care units in hospitals in which fast and dependable values are required.

Early warning score is the most prevalent method in medicine which has been in use for several years as a tool for predict the risk level of patients. This model was proposed for the first time by Morgan et al. in 1997 [5] as a paper-based method needing periodical checkups to assign a score based on patients vital signs (i.e., heart rate, respiration rate, body temperature, blood pressure, blood oxygen saturation). The score of each medical sign depends on the deviation from predefined normal limits, and the summation of all scores reflects the patients risk level [4]. Table 1 shows a Modified Early Warning Score guide. Manual data collection is a major drawback of this approach considering the unreliable results due to errors in recording and late response to deterioration due to the manual intervention. This has recently give pressure for hospitals to move towards electronic, computerized, and more intelligent solutions. Another drawback of current EWS systems is the dependency of the medical parameters to environmental conditions making the system limited to hospital strictly controlled environment.

Internet of things [6], as a network of connected physical and virtual things, is propagating in every corner of the world and leading us to smart solutions by constructing a new insightful medium. It enables the things with unique identities to satisfy common goals more efficient by interacting with each other. Considering a wireless body area sensor network (WBAN) for reading patients vital signs and an intelligent cloud service for processing the patients medical information, utilizing the Internet of Things is applicable for continuous patient monitoring to solve the drawbacks of current manual Early Warning Score systems both for eliminating the errors in recording and extending the solution to out of hospital.

We recently presented an IoT-based early warning system and demonstrated the feasibility of remote EWS monitoring using a full system implementation. More details are available in [7,8]. In this paper, we introduce a self-aware EWS system to personalize the system for remote monitoring scenarios and to provide intelligence in decision making process for patients at different situations. In addition, we utilize the *Attention* property of self-aware systems [9] to improve the energy efficiency, sensitivity and specificity of the system via adjusting the priorities of the heterogeneous sensory data w.r.t. changes in the environment or patients state.

2 Self-aware Early Warning Score System

Individuals suffering from acute diseases, such as cardiovascular diseases, might have several physical activities (e.g. sleeping, running and eating) and encounter diverse environments during a day. Unlike the EWS system in stationary hospital situation, the EWS results outside hospital environment might not be that accurate in many situations due to the susceptibility of vital signs to variations. A consistent heart rate more than 100 times per second in hospital might indicate a serious medical state whereas a healthy adult heart may beat 120 times per second during outdoor exercises. Hence, an adaptive and personalized system is required to consider the variants in the analysis and adapt the EWS score for the situation at hand.

Self-awareness can be utilized to reinforce the EWS system to tackle the daily monitoring obstacles. Self-awareness is defined as the ability of a system to be aware its state and surrounding environment and to adapt to new situations [10]. This knowledge enables a system to implement reasoning and intelligent decision making [11]. Similar to the available self-aware computing systems [9,12], the EWS system can be boosted to behave intelligently with respect to diverse situations. This can be realized by enhancing the score calculation process to consider patient state parameters. Moreover, as introduced in [9], Attention is an advantageous property in self-awareness which can provide efficient data acquisition and processing w.r.t. the instantaneous requirements of the system, and subsequently improve data analysis to obtain better results in terms of ambiguity, sensitivity and specificity of the results and energy efficiency of the system. In the following, we introduce our proposed IoT based self-aware EWS system (Fig. 1) constituting situation awareness and attention.

2.1 Situation Awareness

Situation awareness is utilized in our self-aware EWS system to provide adequate information about the patient. It enables the system to detect and predict patient deterioration regardless of the patient condition during daily activities. It can be achieved by considering the dependency of medical parameters to the variations, and intelligently respond to the changes. In this regard, patient state is defined to indicate the situation of the monitored person. It includes constant and variable parameters.

Constant parameters are defined as patient specification. Age, body mass index (BMI), and gender are main examples of such parameters influencing the average vital signs in different group of people [13] and their estimated scores in the EWS system. Physical condition and activity type of the patient are examples of variable parameters. We collect parameters such as position, altitude and pace in order to let the system determine the patient's current state. Machine learning algorithms can be utilized to recognize activity types such as sitting, running and sleeping and, subsequently, the related score ranges are adjusted.

2.2 Attention

Constant system functionality (e.g., data collection and data analysis rate) during the monitoring not only can lead to energy inefficiency and increased decision making latency, but also make the system susceptible in case of emergency because of not paying enough attention to critical parameters. Providing feedback from heterogeneous data coming from the sensory level, our self-aware EWS system is able to implement Attention property. To this end, the system determine priorities for different parameters in order to set a balance for data acquisition, analysis, and decision making.

The priorities make the system personalized with respect to the patient requirements at a time. For example, in case of a patient with a cardiovascular disease, the system should assign higher data collection rate and processing power to heart-related computations while reducing attention to non-related parameters. Moreover, patient state need to be considered in the priority calculation. Monitoring during an exercise makes the system more sensitive and subsequently increases the priorities. Other variables such as a high warning score for a long time and feedback from medical experts can also affect the priorities during the monitoring.

In addition, the attention unit adjusts the data collection for situation awareness enhancement. It eliminates the ambiguity of the results by adding more parameters to the calculation to improve situation awareness and consequently the sensitivity and specificity of the system. On the other hand, it removes the unnecessary data collection having insufficient correlation with the obtained results to enhance energy efficiency and latency of the system.

3 Demonstration and Evaluation

Our implemented IoT-based self-aware EWS system comprises three main components entitled as EWS, Situation Awareness and Attention (Fig. 1). The first part is the IoT-based EWS system including sensor network layer, a gateway and the cloud server. The sensor network layer acquires vital signs via wearable devices (i.e., BioHarness 3 chest strap, iHealth PO3 finger grip and iHealth BP5 device). In the gateway layer, we utilized a smartphone to receive data from sensors via Bluetooth. The score calculation and related emergency notifications are implemented in the server.

The second and third components are specified to implement the two self-awareness properties for the reinforcement of the basic IoT-based EWS system. The situation awareness includes data collection from activity-related sensors and analysis in the cloud. In the analysis, the situation is detected and consequently the related adjustments are applied to the score ranges. In addition, the third component (i.e., attention) considers the system feedback. Attention contributes to removing ambiguity in situation detection by adjusting data collection and updating the importance of each vital sign and encountered situations during the monitoring.

As a case study, the system continuously monitored a 35 years old healthy male subject (BMI = 28.3) for 8 h which in practice should get score 0. As shown in Fig. 2, incorrect (i.e., falsely calculated as high) scores in EWS while subject

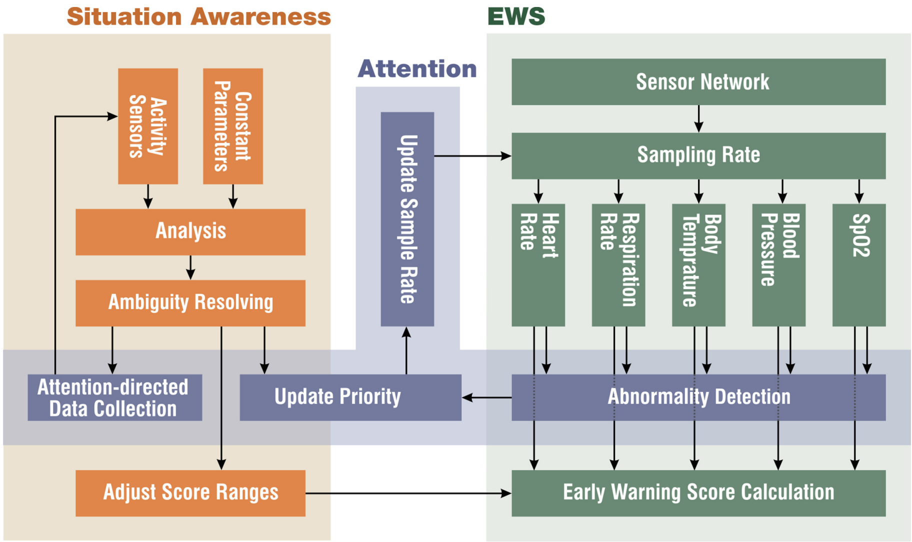

Fig. 1. Diagram of the proposed self-aware EWS system.

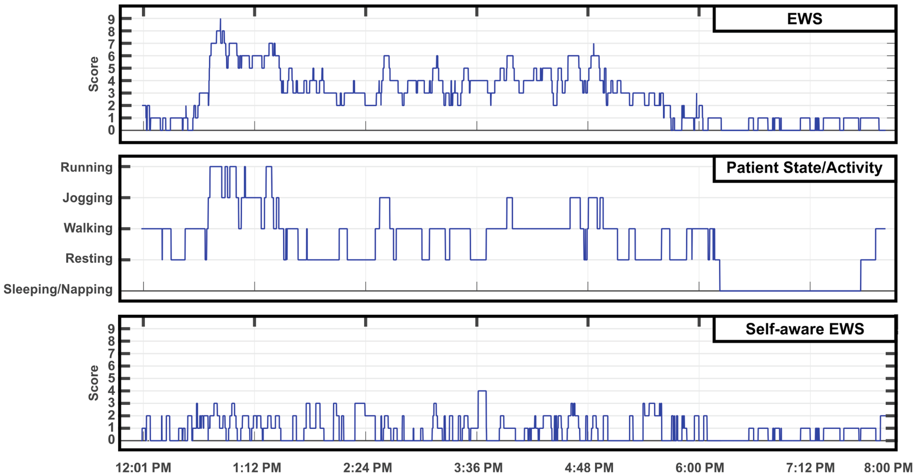

Fig. 2. Self-aware EWS adjustment according to the patient state (activity)

Table 2. A comparison on calculated scores between traditional EWS and self-aware EWS systems

Final score	EWS results	Self-aware EWS results	Emergency level
0	15%	46%	No action
1–3	50%	53%	Low
4–6	30%	1%	Equivocal
7–9	5%	0%	Critical

was having activities such as running and jogging, were corrected in the self-aware EWS system (situation awareness). The obtained scores are reported in Table 2. Conventional EWS system calculated 0 score for 15% of the monitoring period and 0–3 scores only for 65% (i.e., 35% false emergency). Our proposed self-aware EWS system improved the results and calculated 0 score for 46% and 0–3 scores for 99% of the monitoring period (i.e., 1% false emergency). Moreover, the computation rate are adjusted when the vital signs shows sudden changes (attention). The proposed proof-of-concept system demonstrates that IoT-based self-aware EWS system considering situations and feedback provided by attention can offer promising features and enhancements.

4 Conclusions

Conventional Early Warning Score (EWS) systems are designed to address patient deterioration in hospitals. However, there is a need for long-term monitoring of patients with serious diseases outside the hospital environment. Hence, automated EWS systems that can be continuously used in daily life would be advantageous. The dependency of vital signs to the situations variations could make the system inaccurate. In this paper, we exploited the self-awareness concept to create an IoT-based personalized EWS system. The system is designed to be adaptive in various situation and to be able to get automatically customized to the patient requirements.

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