

## ORIGINAL RESEARCH

## Wearable smart blanket system model for monitoring the vital signs of patients in ambulance

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### Abstract

**Introduction:** The timely and managed intervention reduces the consequences of disease and sudden death among the patients in emergency conditions. Monitoring the patients in emergency conditions requires rapid and appropriate decisions to save their lives. The present study aimed at modeling the wearable smart blanket system for monitoring the patients in the emergency conditions of ambulance.

**Materials and Methods:** The present study was based on an applied and descriptive-developmental design. Firstly, the requirements and features of wearable smart blanket system were elicited and secondly a smart blanket system was modeled by using the UML charts and elicited requirements. Finally, the designed architecture was evaluated using ARID scenario-based method.

**Results:** The functional requirements of wearable smart blanket system with its data elements and physical-structural features of this system as well as non-functional requirements were elicited. Based on the requirements and data elements elicited from the questionnaire, class diagram, activity, use-case diagram, sequence, deployment, and component were drawn. Then, using the UML and the relationships between components, systems, and users from the structural and behavioral perspectives used the ARID scenario-based evaluation method to indicate that the designed architecture could provide the expected scenarios from the proposed system.

**Conclusion:** Wearable smart blanket system collects the data related to medical signals by the sensors installed on the blanket and such data are processed by the smart system. Therefore, it can be concluded that the design of this system makes it possible to monitor and control patients in risky conditions with better quality and to integrate vital signs. The analyzing biological data makes it easy for doctors to take early diagnosis and interventions.

**Keywords:** Wearable technology, Physiological parameters monitoring, Modeling, Smart systems

## Introduction

Since many diseases and disabilities require continuous monitoring in the present era, the continuity of patient monitoring for timely intervention seems essential. The patients in emergency conditions have unstable conditions. The momentary monitoring of such patients helps the medical team to take the necessary measures without delay. Today, the smart systems and developed tools are significantly increasing to monitor the patients and control their conditions. The ability of such smart systems on data storage and transfer in different health and medical branches such as telemedicine is significant. Wearable technology is one of the recent technologies in this area [1,2].

A monitoring wearable blanket in the health area should have the following requirements based on the definition of the IEEE organization:

- Supporting the basic health monitoring operations such as monitoring and warning, safe for being used everywhere
- Having the least invasion, causing no disturbance to the system users, and no provoking stress in specific conditions
- Being completely scalable for more monitoring operations such as wireless communications with medical centers and local signal processing
- Putting on and taking off the blanket easily, separating the different pieces such as sensors and circuits from the non-sensitive parts, and performing then operations such as washing and disinfecting [3,4].

Wearable systems are typically used for monitoring of patients' signs and status, follow up, telemedicine, monitoring of nursing systems and medical team, surgeon robots, and many other systems [5]. Such systems are always with the patient and let the physicians have an access to their patients and inclusively receive the information about them everywhere [6]. The major features and objectives of using the wearable blanket system include the ease and speed of installment, the precision for monitoring and measuring, low blanket volume (operation in form of low-volume ambulances and easy

traffic for emergency conditions), utility, and preparation by individuals at home.

Monitoring the status of patients is one of the most important areas of wearable technologies in health and medical area. Monitoring the status of patients in ambulance and emergency conditions is one of the very significant and sensitive factors. Emergency conditions refer to the sudden changes occurring in the health conditions of the person or changing his physiological and biochemical parameters [6,7]. If a person is in emergency conditions, the timely and managed interventions will reduce the consequences due to disease and sudden death. Monitoring and caring for the patients in emergency conditions require the rapid and appropriate decisions to maintain their lives. Thus, the continuous monitoring of patients in ambulance is highly critical while there are modern systems in modern ambulances providing services for the patients [2]. In the study of Anliker et al., a multi-parameter wearable medical monitoring and alert system called AMON (A Wearable Multiparameter Medical Monitoring and Alert System) was specifically described for the heart and respiratory patients. The designed system performed continuous evaluation and monitoring of various vital signs and analyzed multiple evaluation parameters. The AMON system included sensors, extended communications, and processing devices, and all of the main components were designed within a wristband-shaped ergonomic system. This system displays the measured symptoms to the patient and the remote control unit appropriately. The system can integrate with other alert systems and can easily be optimized with extended transmission protocols [8]. In another study, Yokohomon et al. introduced the wearable system called Smart Blanket including a set of wireless sensor units recording and transmitting the vital parameters on the body. The components of this blanket are actuators, sensors, and microelectronic devices forming a wearable wireless sensor network. Such a blanket was designed as a rug and flexural-shaped sheet that was developed as a wearable body for monitoring and remote control. Multiple sensor units fitted on the body can record information and send alerts to decision makers where necessary, based on the received critical information, and provide treatments for the patient [9]. The

Wealthy project was made in form of a shirt made of yarns with embedded fabric sensors. Such a wearable shirt is capable of recording heart signals, respiratory rhythms, heart rate, and muscle activity. The above-mentioned system includes the integrated sensors for monitoring as well as processing hardware, data collection, and the remote control center. Microcontrollers, wireless communications, or global system modules design data collection systems. The smart clothing system has several different functional modules: the reception module, the pre-process module, the transfer module, the processing module and the data management. The central monitoring system of this smart dress has the following duties [10]:

- Controlling and coordinating the flow of data among different activists
- Collecting and storing data transmitted by integrated sensors in wealthy smart clothes through portable unit
- Monitoring the patient's vital parameters continuously
- Generating some warnings based on individual health conditions in order to alert the health personnel
- Providing the access for physicians and other specialists to the central database
- Displaying the health conditions of users with user-friendly interface environments

The present study aimed at modeling a wearable smart blanket system by using the UML based on functional and non-functional requirements. In addition, the relationships between components, systems, and users were designed in the proposed system. In fact, the structural and behavioral aspects of the proposed system were modeled by using the UML diagrams. In other words, the present study aimed at modeling a wearable smart blanket system for monitoring the vital signs of the patients in emergency conditions. In the present article, the method of research, the findings and the results obtained and the conclusions are presented.

### Materials and Methods

The present study was based on an applied, descriptive, and developmental design. Firstly,

the library method was used to elicit the functional and non-functional requirements of wearable smart blanket system. The relevant studies were studied through searching in valid scientific references such as PubMed, Science Direct, IEEE, Springer with the keywords of "valid wearable system design requirements" and "wearable system capabilities" during 2000-2017. Then, a researcher-made questionnaire was designed to elicit the modeling requirements and capabilities. Such a questionnaire had the main subjects of system software functional features, smart blanket structural features, patient portable unit, and system software non-functional requirements. The questionnaire validity was confirmed by some groups of informatics experts and emergency physicians. The above-mentioned questionnaire containing 60 appropriate items was distributed among 20 emergency physicians and ambulance technicians through simple non-probability sampling. The items with scores higher than 80 were in priority of modeling requirements and the data obtained from the questionnaire were analyzed by SPSS software. The Cronbach's alpha value of the designed questionnaire was 0.92. Thus, the questionnaire reliability was confirmed.

All requirements elicited from the previous steps were developed in form of SRS (Software requirements specification) [11]. Thus, the wearable smart blanket was designed and modeled based on the standard document format of UML (unified modeling language) and used for designing and modeling. The class diagram of the system components and their relationship with the use-case diagram designed the interaction of the system with its environment. Furthermore, using the activity diagram and sequence diagram for the sequence of events drew the activities in important processes. Finally, the deployment diagram was used for showing the system modulus deployment while the component diagram indicated the relationship between the system components.

### Results

The functional requirements of wearable blanket system software included a) registering, logging in/out, b) establishing the relationship between the system software and

health electric file, c) adjusting the maximum and minimum vital signs of each person based on age and gender, d) activating the monitoring command by physicians, e) wearing by the software, f) saving all vital signs of the person, and g) analyzing the recorded data numerically and graphically. The structural features of smart blanket and sensor fibers are as follows:

- A. Receiving the medical signals by sensors
- B. Selecting the exact number of signals
- C. Not having the allergic sensors and fibers
- D. Selecting the type of fibers and sensors
- E. Selecting the ideal size and material of blanket
- F. Selecting the fibers and sensors with relative conductivity
- G. Installing the sensors and fibers on the anatomic areas of the body

The non-functional features of wearable blanket system software include the authentication of entities, encoding techniques, response time, and delay in sending the messages, accuracy and precision in recording the vital signs, interactivity, storage and re-storage of data in order of time, energy use, and reliability. Data elements of wearable smart blanket system are listed in table 1.

Table 1. Data categorization based on the elements and wearable smart blanket system

Functions and data elements	Subcategory of each function
Functional: Ability to log in and out of the assistant system	Registration, log in, log out
Functional: the ability to record information by the physician	Log diagnosis, edit, save, final confirmation, registration of medical offers
Functional: the ability to receive medical signals by installed sensors	Non-invasive sensors, number of sensors, sensor types, correct location of sensors
Functional: Ability to record and store vital data locally	Recording, storage, signals such as electrocardiogram, rhythm-symmetry, heart rate, etc.
Functional-processing of data instantaneously	Instant processing, non-delays, required conversions

Functional: Ability to interpret vital data and preprocess them	Extracting acceptable knowledge and information, symptom analysis, instantaneous feedback and alert notification
Physical Properties	Ideal size, proportional weight, flexibility, relative resistance, moisture absorption
Physical Properties - Precise Sensor Locations	ECG, SPO2, .BP sensor location
Non-functional requirement	Maintenance, easy to use, privacy, accountability

### Modeling definition

A model, an imitation, a pattern, a type, a template is an ideal object that represents the actual virtual object or physical object. In other words, a model is a virtual or real object, which is replaced by real or virtual objects based on some behavioral, functional or structural comparisons and in order to solve problems. . The reasons for using a model are the impossibility or very costly to work with the original object (12).

In this research, the system is modeled from 3 points:

- 1- Logical
- 2- Physical
- 3- Development

### Logical model of a system

This model is similar to the logical view of the system, and it describes the structure and interaction of the various components of the system. Each model consists of its constituent elements that are charts. In the most references, this model is expressed using class diagrams, because this diagram can be a structural aspect of the system and all communications within the system, and depicts a variety of real objects. In order to complete the logical model of the system and to demonstrate its full implementation in the phase of the logical model, we use the machine state diagram. This diagram shows the behavior of the model and its behavioral aspect. This diagram is also used to express the logical requirements of each occurrence. The following diagrams are required for the proposed physical model [12].

### The physical model of a system

In this model, using logical, processing, and development perspectives express the design

of the system. In this model, the class diagram is displayed the general scheme of the system, but in order to complete this view, two packaging and component diagrams are also used. This model shows how the components and modules of the system are placed together, and because this system is a distributed system, this model is important and will be useful in optimizing the qualitative factors.

Component diagram: In this chart, the characteristics of the system modules are expressed. This graph displays the interface of each module and displays the specifications. These components are not necessarily a physical entity, but their expression and description. This diagram is used to express the details of the components of an application system [12]. In the last section, the development model and complementary diagrams of these three models are discussed.

**Development model of a system**

In this model, the organization of the various modules and components of a system is discussed. This model is used to express and manage the layers of a system and its architecture used in this phase of the deployment diagram. This model is important due to the distribution of the system and the location of different components in different locations. Activities are also designed to complete the proposed models and ensure the expression of all aspects of the proposed system of applicable diagrams.

In the use-case diagram, the interaction of the system with the outside environment and the manner is described and this type diagram is the basis of all models. The use-case diagrams consist of use -cases, actors and their relationship. These diagrams actually depict the use of a system. In other words, the function of the system presented by the system in the form of the actor and their intended purposes are displayed and applied to the dependence between the application forms. The activity diagram is proposed to provide flowchart and work process in the system, which can make logical understanding of the system and its analysis easier. The activity diagram is used to describe and describe the step-by-step of the workflow or operational flow of the components of the system [13].

**Unified modeling language**

A language provides a dictionary, and rules for combining the words in that dictionary to communicate. A modeling language is a language whose vocabulary and rules focus on the physical and conceptual representation of a system. Therefore, a modeling like UML is the standard language for software projects. Most graphical models are very useful for showing how to change the state or to describe the sequence of activities. UML is the actual standard for object-oriented modeling. In other words, UML is a standard language for writing software designs. UML may be used to visualize, specification, build, or document the products of a software system [11].

UML provides graphical symbols for displaying a system. Graphic models are usually used for three purposes [11]:

- As a tool to facilitate discussion of an existing or proposed system.
- As a way to document an existing system
- As a partial description of the system that can be used to implement a system.

In order to model a wearable smart blanket, the case-application charts, component, deployment, class, activity, sequence, and UML software are plotted. Some of these graphs are illustrated by the example below. All classes related to wearable smart blanket system described in figure 1. Figure 1 illustrates all classes related to wearable smart blanket system.

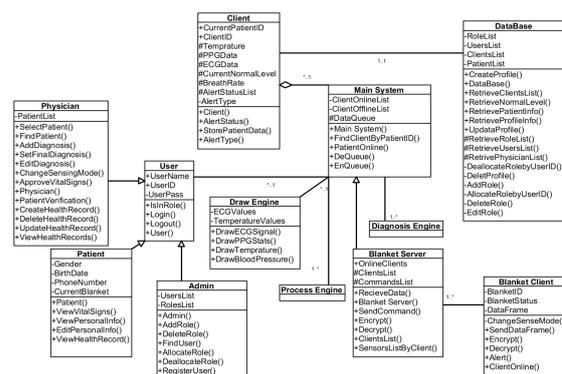


Figure 1. The classes and relationships between the variables

The component diagram in this study showed the relationship between the system components. Component is a changeable unit of the system with hidden details and its

behavior is shown through some interfaces. Component describes a set of classes, which are packed physically in the object-oriented method [11]. The Components of wearable smart blanket system are illustrated in figure 2.

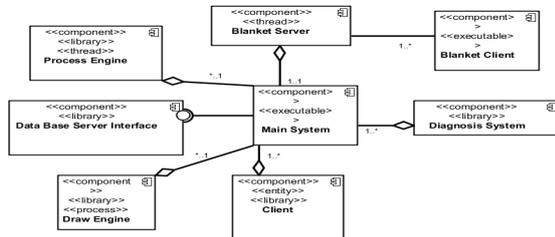


Figure 2. The component of the proposed system

The deployment diagram shows the deployment of software and hardware systems in physical modes and technology context [13]. Such a diagram is used for modeling the deployment of systems (configuration) at the implementation time. The deployment of WSBS (proposed system) is shown in figure 3.

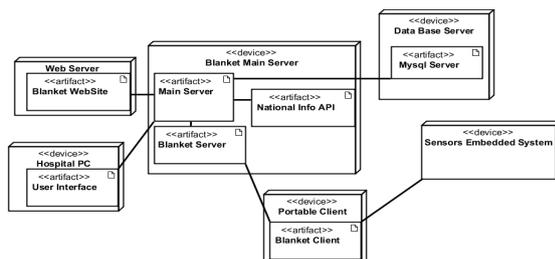


Figure 3. The deployment of the proposed system

The use-case diagram was used for showing the dynamic behavior of the proposed system [11]. Those who use this system include physicians, ambulance technicians, and patients. The use-case diagram can be considered as simple scenarios describing the expectations of a user from a system. Every use-case diagram shows a separate task in the system including the external interactions with a system. A use-case diagram is presented in figure 4.

- Interpreting the medical signals: In this diagram, all vital signs of the patient such as PPG, ECG, body temperature, respiratory rate, heart rate, and blood pressure are interpreted by the system processing engine.

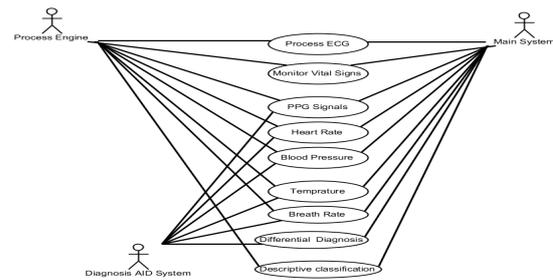


Figure 4. The use case diagram of vital signs interpretation

In this section, the step-to-step procedure of activities by activity diagrams was stated. This flowchart diagram displays the implementation of affairs in this section. In basic UML2.0, the machine mode was replaced by another general semantic framework removing all these limitations. In addition, some industrial standards inspired the modeling of business processes [14,15]. We can see important activities of WSBS (proposed system) in figure 5.

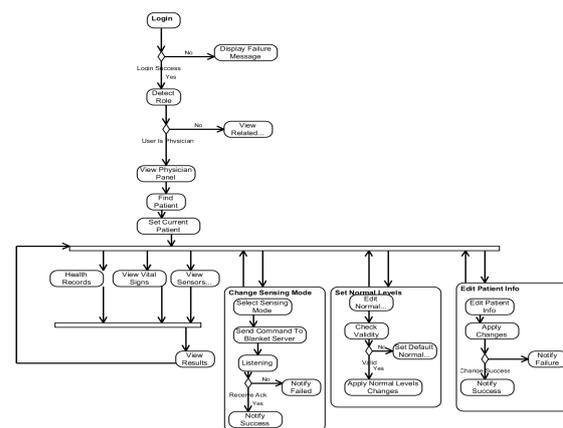


Figure 5. The activity diagram of patient monitoring

## Discussion

In this study, the designed architecture was discussed by using the ARID scenario-based method.

Unlike the other scenario-based evaluation methods, analyzing the complete architecture of a system, the ARID method focused on the partial design of different parts of the system. Thus, this method can be used for evaluating the incomplete architectures. ARID method aims at supplying the user's requirements [16]. In this study, two software experts and two ambulance physicians formed the review sessions. The above-mentioned scenarios expressed the services, which could be

provided by the system. Such scenarios were categorized based on the system services. The evaluation scenarios of the proposed system included logging into the system, monitoring the vital parameters, processing the vital signs, consulting, treating, and interacting between the physicians and the system.

In the scenario of logging into the system, the ambulance physician logs in the system software by entering his username and password. In case of any problem in entering the username, the physician's information will not be saved as the system user. If all identity and personnel information of the physician is correct, the username and password will be sent to his Email. The ambulance physician enters the system by entering his username and password. In case of need, the relevant physician can receive a training program about how to install sensors, activate and deactivate them, and change the number of sensors.

Then, the scenario of monitoring vital parameters by wearable smart blanket system was examined. Wearable smart blanket is a system, which is put on as a dress on the person and has fabric sleeves to fix the blanket on the patient. Such a blanket has medical sensors measuring the vital signs of the body along with the electrocardiogram and these vital signs include respiratory rhythms, body temperature, heart rate, blood pressure, and blood oxygen levels when the ambulance is moving. A sensor set is required to record any of the vital parameters. The size of each parameter is sometimes collected and transmitted wirelessly to a central node. The individual biological signals are recorded and sent to a portable unit. Depending on the monitoring command (active or inactive), the sensor set starts to receive signals from the patient's body. All recorded vital parameters are sent to the patient's portable unit providing the local storage and preprocessing the signals and signs. All preprocessed information is transmitted wirelessly to the physician assistant having a high level interpretation, processing (noise reduction), stream control coordination, and visualization of information. Reminder is one of the most effective control classes affecting the monitoring, counseling and treatment of patients. Such a class declares the reminder based on the request form of the physician. The physician can apply changes to

the reminder settings after entering his username and password and then can enter the patient's age and gender in the system to process the patient's vital signs based on his age and gender. Furthermore, the physician can record all his final and differential diagnosis on the system. The physician assistant system (system software) displays the vital signs and medical signals of the patient numerically and graphically. The ambulance physician sets the threshold for the entire patient's vital signs based on the patient's conditions; otherwise, all thresholds for the symptoms are compared with the defaults of the monitoring system. In order to continuously monitor the patient, the Smart Blanket system has the function of continuously recording the electrocardiogram signals, blood oxygen saturation, blood pressure, heart rate, and respiratory rate presenting the body temperature periodically (once every 15 min) to the current physician.

In the scenario of processing vital signs, the raw data are sent to the patient's portable unit, and pre-processing is applied to the information after recording vital signs of the body with sensors installed on smart blanket. All information is sent wirelessly to the system software. The ambulance physician enters the patient's gender and age in the software to accurately process and present normal and abnormal findings (e.g., heart rate based on age and gender). In addition, the ambulance physician sets the maximum and minimum vital signs in order to warn the system when it exceeds the threshold. The ambulance physician can activate or deactivate each sensor set and change the number of sensors (electrodes) to record the signs. The system software receives all information from the sensor set. Complex implementation algorithms interpret all vital signals. For example, the system software should be able to interpret electrocardiogram signals, display distances between waves, name the waves (wave detection), and identify and classify the heart rate in 60 seconds; the software can calculate the percentage of saturation of oxygen in the blood and displays it in numerical order. This software should display graphical rhythm disturbances and maximum and minimum respiratory rates over time. The system can calculate the blood pressure

indirectly from the ECG and PPG signals and display the pulse pressure. Furthermore, the physician's interactions with the system are as follows:

- *Setting the threshold for recording the vital signs:* the ambulance physician can change the threshold for each vital sign after entering the system, in case of worsening the patient's current condition, or he can the normal and abnormal findings of the patient based on the above-mentioned factors by entering the patient's age and gender.
- *Recording the patient-related diagnosis:* After recording and saving the vital signs and medical signals by the different sensors of wearable smart blanket, all relevant interpreted information is displayed to the ambulance physician. After examining the interpretations provided by system, the physician enters the patient's final and differential diagnosis in his temporary file and enters all medical decisions with the limits of clinical measures in the system.
- *Receiving the patient information from the electronic health record:* since the person in emergency conditions cannot say his national code, all medical information is displayed to the ambulance physician by the patient's fingerprint. All patient records, drug allergy, health information, and mental health information are shown to the physician, so that he can make his medical decisions based on the received information.
- *Requesting for a consultation:* if the ambulance physician requires consultation with the physicians of medical centers while transferring to the hospital, he can request for a consultation with the relevant physicians. The ambulance physician can send the patient's vital information to the system in the center to provide a voice, video, text message and help the physician with the differential diagnosis of the patient and provide short-term treatments (during the patient's transfer) to the hospital. ARID scenario-based

evaluation shows that the designed architecture and considered relations in the proposed system provide the functions and scenarios desired by the users of the system. Therefore, it is possible to monitor better and more effectively the patient's vital signs and provides the bio-signals of the patient by using smart and blanket. This fact provides the quality health care, reduce the care costs, and increase the patient satisfaction with the received care.

In this regard, the present study aimed at modeling the wearable systems to control the vital signs of the patients in ambulance. In order to provide a suitable model for this system, the functional and non-functional requirements were examined. The wearable Smart Blanket system has the capabilities and design requirements allowing the continuous monitoring of vital signs of the patient such as heart rate, blood pressure, oxygen, blood, and so on. The smart wearable blanket collects data from the sensor on the blanket on the medical signals while such data are processed and interpreted by the intelligent system. The information obtained from the patient's conditions helps the ambulance physician to provide adequate intervention without delay. As a result, the patient's information is stored and transmitted continuously without losing any information and definitive communication. The proposed wearable smart blanket system allows the continuous patient monitoring in emergency situations. In addition, the above-mentioned system registers all the vital signs needed to control individuals and provides interpretive data for the ambulance team, compared to other wearable systems. The physician assistant system and the patient's portable system apply a high-level processing to vital human data. Based on the defined algorithms, some threshold levels were defined for each vital sign to provide emergency warnings for emergency physicians to be informed of the relapse of the individual. All sensors and electrodes installed on the proposed smart blanket are connected through the conductive yarn and sometimes wireless to the portable unit of the patient while the total energy consumption of the system is provided through this unit.

## Conclusion

Today, the role of emerging technologies in the field of health-treatment is a significant category and using such technologies for enhancing the quality of care and treatment has attracted the attention of personnel and specialists. Wearable systems are one of these technologies facilitating the monitor and control of patient's unstable status for the medical team such as physicians, nurses, and counselors. All systems for registering symptoms in the ambulance environment require direct intervention by the physician in the ambulance. Furthermore, recording the information is absolutely instantaneous and the only function of the set of systems available in the ambulance is related to recording some limited symptoms such as blood pressure, oxygen saturation, glucagon, and heart rate (in some cases, electrocardiogram recording). In addition, the above-mentioned systems have no ability of applying any kind of processing to vital signs. Therefore, the continuous monitoring of vital parameters by wearable smart blankets allows the early detection of emergency situations among the high-risk patients in ambulance. In this study, a fiber-based smart blanket system, along with a wearable smart blanket system was described. Based on the results, all requirements for designing and modeling were described in the

standard SRS document. Furthermore, a wearable system architecture was designed in the present study. In conclusion, the design of this system makes it possible to monitor and control patients in risky conditions and integrate vital signs in a higher quality. Analyzing the biological data enables the doctors to take early diagnosis and interventions more easily. Future studies are suggested to implement and create this system for emergency patients while the cultural planning, allocation of funds, macro policies, management support, increasing medical personnel's awareness about wearable technologies are among the most important factors to be addressed.

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## Conflict of interest

Authors declare no conflict of interest.

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