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Internet of Health Things: Toward intelligent vital signs monitoring in hospital wards

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ABSTRACT

Background: Large amounts of patient data are routinely manually collected in hospitals by using standalone medical devices, including vital signs. Such data is sometimes stored in spreadsheets, not forming part of patients' electronic health records, and is therefore difficult for caregivers to combine and analyze. One possible solution to overcome these limitations is the interconnection of medical devices via the Internet using a distributed platform, namely the Internet of Things. This approach allows data from different sources to be combined in order to better diagnose patient health status and identify possible anticipatory actions.
Methods: This work introduces the concept of the Internet of Health Things (IoHT), focusing on surveying the different approaches that could be applied to gather and combine data on vital signs in hospitals. Common heuristic approaches are considered, such as weighted early warning scoring systems, and the possibility of employing intelligent algorithms is analyzed.
Results: As a result, this article proposes possible directions for combining patient data in hospital wards to improve efficiency, allow the optimization of resources, and minimize patient health deterioration.
Conclusion: It is concluded that a patient-centered approach is critical, and that the IoHT paradigm will continue to provide more optimal solutions for patient management in hospital wards.

1. Introduction

Patients are routinely assessed during hospitalization by measuring their vital signs. These observations are crucial to preventing health deterioration, potentially minimizing morbidity and mortality, abridging hospitalization time, and reducing costs [1,2]. The process of collecting vital signs in hospital wards varies, and different approaches are used worldwide. In some cases, data is only manually collected, and stored in spreadsheets that are discarded after the patient is discharged. Other typical approaches include collecting vital signs using tablets, personal digital assistants (PDA), or other similar equipment, storing the information in an electronic health record (EHR) for the patient [2]. In some cases (e.g., in the United Kingdom), this data could be used to evaluate patient health status using heuristic approaches, such as the early warning or modified early warning scoring (EWS/MEWS) approaches [3].

With the advent of the Internet of Things (IoT), in which objects can communicate and process data [4], the collection of vital signs could be partially or fully automatized, diminishing the burden imposed on nurses for constantly gathering and storing this information. Furthermore, IoT uses a distributed platform to process and store data, typically employing cloud computing [5]. The use of this platform introduces the possibility of developing machine learning algorithms [6,7] to infer the risk of patient health deterioration, and to optimize resources in hospitals by predicting future patient requirements.

This review introduces the concept of the Internet of Health Things (IoHT), in which objects exchange and process data to monitor a patient's health status. On top of this architecture, we argue for the need to employ machine learning techniques to correlate this data, transforming it into useful information and predicting future issues, trends, and requirements. The concept of IoHT is closely related to the idea of utilizing information and communication technology (ICT) in the

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healthcare area, usually called electronic health (eHealth) [8] or mobile health (mHealth) [9]. It is also related to the notion of using mobile devices in health services, and ubiquitous health (uHealth), allowing the use of ubiquitous and mobile computing [10] to monitor patient health anywhere at any time [11]. The concept of uHealth represents a paradigm shift from a reactive to a predictive and personalized healthcare system [12].

The main scientific contribution of this article is to describe the possibilities of the IoHT within the scope of monitoring vital signs in hospital wards. The current approaches for collecting and analyzing vital signs are surveyed, and then possible automatic and intelligent solutions to anticipate risks of patient health deterioration are discussed.

The article is organized into six sections. Section 2 covers the state-of-the-art in terms of patient care in hospitals. Section 3 details the ideas behind the IoHT concept, and possible approaches to collecting vital signs in hospitals wards. Section 4 focuses on machine learning techniques for transforming the collected data into useful information. Section 5 discusses the main challenges, and presents future directions. Finally, Section 6 presents the conclusions.

2. Patient-centered care in hospitals

Patient-centered care (PCC) is one of the most important indicators of the quality of care provided in hospitals [13,14]. There are many ways in which PCC can be evaluated, including adjustments to special requirements of patients, the sharing of patient health information, and accessibility to care and services. From an ICT point of view, PCC refers to any medical information system centered on patient-related data (i.e., their EHR). This differs from the traditional approach of many enterprise resource planning systems, which are mainly focused on optimizing the general process and workflow [15].

PCC can be described in three aspects: (1) the vital signs monitored in hospital wards, (2) the use of vital signs to evaluate the risks of patient health deterioration, and (3) the vital signs that can be combined with other preexisting data.

2.1. Vital signs monitoring

Since the beginning of the 20th century, nurses have performed patient surveillance in hospitals by measuring the same vital signs [16]. These typically consist of blood pressure, temperature, heart rate, and respiratory rate, with the recent addition of oxygen saturation [17]. The guidelines from the National Institute for Health and Clinical Excellence (NICE) recommend the observation of six vital signs as a minimum, including oxygen saturation in addition to the five others used in the original score. Furthermore, they suggest that in specific circumstances additional parameters should be considered, including urine output, level of pain, or another biochemical analysis [18]. However, the exact types of vital signs collected vary according to different protocols and methods applied in hospitals [19], representing a topic that is subject to continuous debate [17].

Motivated by the complexity resulting from an increasing patient survival rate and longer life expectancy [20], Elliott and Coventry proposed eight vital signs, recommending three additional measures that should be part of the assessment: level of pain, level of consciousness, and urine output [17]. Table 1 presents the definitions, normal ranges, and influencing factors of the eight main vital signs that could potentially be monitored for surveilling patient health in hospitals.

Other open questions concern the optimal frequency for vital signs monitoring, and how it should be measured and registered. In fact, not all the vital signs presented in Table 1 can be collected automatically. For example, evaluating the level of pain is highly subjective and depends on following specific guidelines. In this context, the WILDA approach verifies five key components to pain evaluation, including words to describe pain, intensity (0–10 scale), location, duration, aggravation, and alleviating factors [25]. Although use of the WILDA protocol implies the interaction between caregivers and patients, some form of electronic registration of the data could also be implemented. For instance, data could be entered into a tablet computer or smartphone to be recorded as part of the patient EHR. Another vital sign that depends on the interaction between patient and caregivers is the evaluation of level of consciousness. This is typically performed using the Glasgow Coma Scale (CGS), which includes the assessment of eye opening, and verbal and motor responses [23]. For each of these evaluations, a numerical value is assigned according to the patient's responses to stimuli. These values could also be registered electronically, for further visualization of the patient's neurological status. In the case of monitoring urine output, there are also devices that allow this to be automatically and continuously recorded if the patient is using a catheter. However, in many cases urine output is still measured using a manual urinometer, or estimated [26].

2.2. Risk evaluation of patients

One of the key priorities for PCC in hospitals is the monitoring of vital signs at regular intervals, with the frequency increasing when abnormalities are detected. This information is used to assess a patient's risk of health deterioration based on graded response strategies [18]. These strategies include tracking and triggering systems, employing many vital signs to define the frequency of observation, the parameters to be measured, and the time point at which a response should be triggered. Table 2 lists the typical risk evaluation strategies currently used in hospitals.

The first group of strategies is based on monitoring single parameters. Among the proposals, the Medical Emergency Team (MET) calling criteria [30] is the most commonly employed, and is representative of this category. MET is based on possible changes in specific vital signs defined as abnormal physiological variables [27], which includes threatened airway, respiratory arrests, cardiac arrests, sudden changes in the level of consciousness, and seizures.

In the second group, the requirement is the presence of one or more abnormal vital signs. One of the most representative strategies in this group is the Patient-at-Risk Team (PART) calling criteria [28]. The PART protocol consists of a combination of predefined thresholds for vital signs, including respiratory rate, systolic pressure, heart hate, level of consciousness, oxygen saturation, and urine output [31].

The third group of risk evaluation strategies consists of attributing scores to vital signs in order to identify early signs of health deterioration. The pioneer metric of aggregate scoring is the Early Warning Score (EWS) [29]. EWS has been widely employed by most hospitals in United Kingdom, and it is recommended by NICE [2,32]. The idea behind EWS is to closely monitor patient health status by evaluating several parameters at different frequencies according to the calculated values. To integrate the EWS into the patient EHR, vital sign data needs to be registered, either manually or automatically, and the score calculated and visualized over time. These latter steps could also be performed either automatically or by using paper-based EWS systems. The original EWS score was based on five vital signs, comprising systolic blood pressure, body temperature, heart rate, respiratory rate, and level of consciousness [33]. Based on comparing these observed vital signs with normal ranges, a single composite score is generated. Deviations from normal ranges produce a score for each vital sign (i.e., 0–6 for systolic blood pressure, 0-3 for the other parameters), and the sum of these scores is used to calculate the overall EWS [29]. Many variations from the original EWS are currently in use. For example, the Modified Early Warning Score (MEWS) includes urine output as a sixth vital sign, and relative deviation from a patient's normal blood pressure [34]. The VitalPac EWS (ViEWS) is a proprietary system based on a PDA that helps to gather the vital signs at the bedside and to calculate the appropriate score [35,2]. Another variation is the Worthing Physiological

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