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Intelligent hybrid remote patient-monitoring model with cloud-based framework for knowledge discovery☆

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ABSTRACT

This paper proposes an intelligent hybrid context-aware model for patients under supervision at home that adopts a hybrid architecture with both local and cloud-based components. The cloud-based portion of the model facilitates storing and processing the big data generated by ambient assisted living systems that are used to monitor patients suffering from chronic diseases in their homes, particularly the elderly. The local portion of the model monitors patients in the event of internet disconnections or any other failure in the cloud system. The proposed model utilises context-aware techniques by monitoring physiological signals, ambient conditions, and patient activities simultaneously to derive the real-time health status of the patient. Experimental results demonstrate the effectiveness of our proposed model for monitoring patients and accurately detecting emergencies in imbalanced datasets through a case study on patients suffering from blood-pressure disorders.

1. Introduction

Machine learning has many applications in the medical field, such as ambient assisted living (AAL) systems that are responsible for supporting patients who are suffering from chronic diseases [1]. AAL is defined by its use of all concepts, methods, products, services, and medical assistance systems that enable elderly patients to live independently for as long as possible, as safely as possible. The average human lifespan has increased by five years between 2000 and 2016 to reach 71.4 years (73.8 years for females and 69.1 years for males) [2]. The direct consequences of this increase in average lifespan are a lack of caregivers to serve an increasing number of elderly patients and an increase in healthcare budgets. These problems are more severe in developing countries with high populations than in other countries because of low health budgets, poor healthcare infrastructure, and a lack of well-trained medical staff.

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In the last decade, wearable and implantable biomedical sensors have attracted significant interest because of the need to monitor vital signs, activities, or any health parameters in real time, without obstructing the movement of a patient or restricting their freedom. Wireless sensor network (WSN) technologies are the primary drivers of the rapid development in ubiquitous sensing, which enables sensors and actuators to interact seamlessly with the ambient environment and share collected information between various platforms. Internet of things (IoT) sensors have achieved breakthroughs using various technologies, such as radio-frequency identification (RFID), near field communication (NFC), and non-invasive sensors to transform the internet into a fully integrated platform [3,4].

Patient vital signs vary based on activities, temperature, humidity, smoking, sleeping patterns, and many other factors [5]. For example, when a patient's heart rate (HR) increases significantly during sleep, it is considered to be an abnormal case. In contrast, it is considered to be normal if the patient is performing exercises. Additional factors, such as patient age, gender, daily personal habits, or personal differences for the same medical issues, may affect their vital signs [6]. All of these factors emphasise the importance of context awareness, which is defined as the ability to comprehend the situational context of collected data and provide customised personal service based on patient health status [7]. The aggregation of data generated by AAL systems with high levels of abstraction during predefined time windows into a single contextual state can provide detailed information regarding the health conditions of the patient and reveal insights regarding fluctuations in the values of patient vital signs using machine learning [8].

Big data is a buzzword in current research. The characteristics of big data are described by the 'Four Vs' model (volume, variety, velocity, and veracity) according to IBM's formal definition. Data must satisfy at least one of these characteristics to be called big data [9]. The continuous monitoring of patients using AAL systems is a source of big data because monitoring duration varies from hours to years with a sampling rate may be on the order of milliseconds. Therefore, any architecture that utilises IoT sensors for continuous patient monitoring depends on cloud-based components to provide scalable data repositories and resilient computation processes for big data [10].

Traditional health care assistant (HCA) systems depend on standalone applications on a local server or handheld device, which are always customised for a specific patient suffering from a particular disease based on a set of generic rules [11]. These systems do not have flexible generic architectures to facilitate the monitoring of different patients suffering from various diseases. Therefore, some studies have proposed context-aware AAL systems for processing big data to extract knowledge regarding patient health status in real time [12].

Recently proposed cloud-based architectures depend entirely on the cloud for classifying patient health status. This means the patient is at risk when the internet connection is interrupted or a problem occurs in the cloud system [13,14]. Additionally, the performance of these models has been evaluated over imbalanced datasets using only accuracy as a metric, which yields misleading results. Furthermore, previous studies did not adopt sampling methods designed to process imbalanced datasets.

The primary motivations for this work are:

- The need to integrate generic and personalised medical rules, which are designed by medical experts to be exploited during the implementation of intelligent personal medical assistants that are aware of the individual differences between patients, which helps to minimise false alarms.
- The need for developing an intelligent hybrid model that utilises two modes to classify patient health status if the connection to the cloud is lost or the internet is disconnected. A hybrid model benefits from the advantages of both local and cloud-based architectures, while avoiding their disadvantages.
- The need for building a model that addresses the shortcomings in previous models in terms of handling imbalanced datasets.

Considering these points when developing the proposed intelligent hybrid context-aware model for patients under supervision at home (IHCAM-PUSH) helped to produce a fast, accurate, and fault tolerant-model.

The remainder of this paper is organised as follows. Section 2 summarises the background of remote patient monitoring (RPM) models and imbalanced datasets. The architecture of the proposed IHCAM-PUSH is discussed in detail in Section 3. Section 4 presents the proposed hybrid classification model (HCM). Section 5 provides a case study on monitoring patients with blood pressure (BP) disorders using IHCAM-PUSH. Section 6 presents experimental results and Section 7 discusses our final conclusions.

2. Background

AAL is an RPM model that helps physicians, nurses, and caregivers to monitor elderly patients remotely using digital technologies. RPM gathers physiological signals, ambient data, associated activities, etc. in a remote location, such as a patient's home, then transfers this data to a central healthcare provider (e.g., a smart hospital) for investigation and assessment to determine preventive actions. The inclusion of non-invasive wearable sensors in healthcare management strategies facilitates the gathering of patient physiological signals and other ambient data to be shared among different platforms to make accurate decisions regarding patient health [15].

In the last decade, there have been many studies on patient-monitoring models using mobile devices, but these models have encountered many obstacles, such as their inability to handle big datasets and a reliance on general medical rules. Models that rely on generic medical rules and ignore the ambient circumstances of vital sign readings are prone to failure