A Cloud-based Intelligent Remote Patient Monitoring Architecture

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Abstract—The increase in population and the need for high standard of welfare and healthcare are today's challenges for emerging technologies in healthcare. The monitoring of patient health status and medical variables is essential in physicians' diagnostic processes. We propose a new approach for intelligent remote patient monitoring (RPM). We recommend a system architecture that involves all major groups in any healthcare services. The proposed solution will be entirely cloud-based, enabling hospitals to achieve a more cost-effective management, higher speed for their medical processes, and increased quality of medical services. The main objective of the system is to monitor the health status of patients and generate alerts when undesired medical conditions are predicted.

Keywords—Intelligent Remote Patient Monitoring (IRPM), Telemedicine, Cloud Computing, Vital Signs Measurements, System Architecture

I. INTRODUCTION

Cloud computing has been dubbed the ‘next big thing’ in healthcare IT and can bring tremendous benefits to healthcare organizations. Cloud computing has the potential to consolidate patient data by centralizing and organizing methods, and that will help healthcare organizations make better decisions and reduce operational costs.

RPM uses devices such as sensors or actuators attached to the human body to collect patient data and send it to a hospital or a health agency for interpretation. In our solution, data will be sent to the cloud computing service provider. RPM services can be used to supplement the use of visiting nurses.

RPM services in this cloud computing solution will enhance the quality of the healthcare services. Cloud computing embraces new opportunities of transforming healthcare delivery into a more reliable and sustainable manner. The improvement of the monitoring of discharged patients’ health-related quality of life will reduce the cost of treatment and detect illness early.

An Intelligent Remote patient monitoring (IRPM) is a smart way to utilize patient data by applying a set of machine learning-based techniques that will enable the system to generate highly automated health-related recommendations. We will narrow the scope of IRPM to vital signs and medical variables which will help detect, predict, and prevent some of the diseases related to general health. Vital signs are measurements of the body's most basic functions that give clues to possible diseases and show progress toward recovery. The main vital signs are body temperature, pulse rate, respiration rate, and blood pressure. Normal vital signs change with age, sex, weight, exercise capability, and overall health.

To add the intelligent layer to our system, we will involve machine learning techniques. Machine learning is a method of data analysis that automates analytical model building. It identifies patterns and makes decisions with minimal human intervention. We call the process of learning training and the output that this process produces is called a model. A model can provide new data and it can reason about this new information based on what it has previously learned. Machine learning has three main types of models: classification, clustering and regression.

In brief, the solution is designed to allow patients or potential patients to collect vital signs or any physiological signals through medical devices or sensors and send the data to a centralized cloud-based system. The system will store the data. After that, the system will do some data analysis and data mining to generate reports to be used by the system participant groups.

The research is significant because it will find an automated way to collect patients’ data such as medical conditions and store them in a centralized system. Remote Patient Monitoring in a cloud computing platform reduces the need for hospital admission by discovering a small health issue before it becomes a significant one. It will improve the quality and efficiency of health care delivery. For example, existing processes for patients’ vital data collection require a great deal of labor to collect, input and analyze the information. These processes take time and are subject to errors. They cause a latency that makes real-time data accessibility impossible. The system will help reduce hospital’s emergency room ER waiting time. Also, it will help patients avoid staying in hospitals for a long time.

IRPM systems can benefit businesses. IRPM deployment attempts to bring change and benefit to a health organization by using the system to achieve some of the goals and models. For example, IRPM will allow more access to care by delivering care in rural areas that suffer from lack of access to health care due to geography or limited resources. Moreover, IRPM will save cost by creating a new healthcare delivery method that
allows the sharing of resources between hospitals by using a cloud-based platform. Furthermore, IRPM will allow healthcare providers to expand their market by servicing more patients. Also, IRPM will help create a chronic care model for people in a specific area who suffer from a common disease such as heart disease with a high costs. The system is significant for healthcare providers because it will increase the profit by opening a new business and saving hospital operation cost and time. It will enhance the job of home care service too. For insurance companies, the system can improve quality of life and make people healthy, which will save the cost of treatment.

Healthcare manufacturers must think differently. They must provide IP-enabled products that can send data to a destination address. Products should be easy to use, easy to carry, and has a long battery time. Non-healthcare manufactures can participate by including some health applications.

The limitations of running RPM services in the cloud are unavoidable. The poor or lost communication, especially in rural areas, will affect the quality of the service. One restriction is the compatibility with the system; if the RPM device cannot communicate then there is no way to exchange data. The system stores specific patient data. So, the system must follow HIPAA (Health Insurance Portability and Accountability Act) regulations to protect individuals’ personal health information. Not all RPM services can be delivered by a cloud. IP-based-devices should support wired or wireless network. Stand-alone and closed-products cannot communicate.

The risk of running RPM services in the cloud is inevitable. RPM services might generate false data, which will affect the system functions. One risk is losing the identity, which happens when the devices are used by different people. An RPM system should run on a secure and reliable cloud computing platform. It includes all appliances needed like firewall, intrusion detection and prevention, and authentication systems. The system should account for confidentiality policy, traceability and privacy of the data stored in a cloud. Since it is patient data, the system should meet HIPAA requirements or any other required standards. The system also needs to do a service level agreement SLA.

The proposed system architecture is in a shared platform. It is designed to run on a cloud computing environment. Cloud computing has many features. It reduces the cost of healthcare service implementation. It provides rapid service and infrastructure availability. Resource pooling is one cloud computing feature that allows multiple customers to access the resources at the same time. Also, cloud computing frees the customer to select services of their choice from the service catalog.

To answer what happens next to a patient, we might need experienced physicians to respond. However, clinical prediction models can answer too. Applying machine learning techniques will help predict illness from vital sign variables and that is the key difference between our proposed intelligent remote patient monitor system and traditional remote patient monitor systems.

II. BACKGROUND

We now explore telemedicine, cloud computing and machine learning in the healthcare industry. We will go through some telemedicine barriers and explain current solutions that are working widely in the healthcare industry. We will then give an overview of past and current research and development work in RPMs. Afterward, We will define cloud computing and list some cloud computing advantages, issues, challenges and limitations. Finally, We will present machine learning and its applications in healthcare.

A. Telemedicine

Telemedicine solutions have successfully enhanced the quality and accessibility of medical care by allowing distant providers to evaluate, diagnose, treat, and provide follow-up care to patients. Telemedicine uses telecommunications technology as a medium for the provision of medical services to overcome geographical barriers and to increase access to healthcare services.

1) Telemedicine Overview

The rapid developments in technology are enabling healthcare organizations to see new methods of providing healthcare. Telemedicine is a crucial initiative for healthcare organizations today. Telemedicine is needed to optimize and support more types of health services for all ages. It makes healthcare more affordable for the poor and the elderly. Telemedicine can be used to provide preventive care in addition to emergency treatment. It is a useful way to provide remote rehabilitation monitoring and chronic disease relief. However, telemedicine deployment is facing a lot of barriers at different levels [1].

Healthcare organizations are working to implement telemedicine solutions for several reasons including reducing costs, improving patient services, providing improved access to specialists, access to care, educating patients, and expanding the geographic footprint of the organization. Telemedicine’s common elements include providing clinical support, overcoming geographical barriers, involving the use of various types of ICT, and improving health services.

The massive improvement and high utilization of technology by the general population have been the biggest drivers of telemedicine over the past decade, which will open room for healthcare providers to extend and innovate a new way of delivering healthcare services worldwide by enhancing access, quality, efficiency, and cost-effectiveness [2].

2) Barriers to Telemedicine

There are several barriers for implementing telemedicine. According to the Global Observatory for eHealth, the top four potential barriers facing countries in their implementation of telemedicine services are cost, legislation, culture and infrastructure [2].

The cost of implementing telemedicine is high, especially the setup cost. However, cost can be lowered by using cloud computing. The services price will decrease because the system is designed to be customized and opened for general users. Legal issues are a major obstacle. However, after considering and
complying with standard regulations like HIPAA, the issues related to patient privacy and confidentiality will be mitigated. The third barrier is culture from both healthcare organization and patient sides. They resist adopting healthcare services that differ from traditional ways. However, we envision a solution that will not require a big change in healthcare service delivery. The system will add a support layer that will improve the quality of health services. Poor infrastructure has an impact on the quality of telemedicine services, e.g., insufficient communication networks and low Internet speed. We propose an architecture based on cloud computing that is more scalable, reliable, and flexible. Also, we will present ideas that will reduce the risk for patient data loss because of commination interruption.

3) Current Telemedicine Solutions

There are some services that telemedicine is capable of supporting today. The primary services currently used worldwide include the following:

- **Teleradiology:**

  This is the use of telecommunication to transmit digital radiological images like X-rays across geographical locations for interpretation and consultation [3]. One of the main benefits of using teleradiology is financial because it will bring the images to the qualified radiologist rather than vice versa. Teleradiology services can be implemented on top of cloud services where we can get the benefit of cloud services and the quality of radiology services. It will facilitate the sharing of clinical information, medical imaging studies and patient diagnostics [4].

- **Telepathology:**

  This is the use of telecommunication to transmit digitized pathological results (e.g., microscopic images of cells) for the purpose of interpretation and consultation. Pathology plays an essential role in identifying the characteristics as well as a cause of a disease in the medical field. Together with current technological advances in medicine, pathology continues to play a role in providing information to medical professionals as well as researchers for further investigation in the form of telepathology. Telepathology is a way of using images in an electronic format rather than the view from a glass slide [5].

- **Teledermatology:**

  This is the use of telecommunication to transmit medical information concerning skin conditions for the purpose of interpretation and consultation.

- **Telepsychiatry:**

  This is the use of telecommunication for psychiatric evaluations and consultation via video and telephony. The use of telepsychiatry provides increased access to mental health services.

In our opinion, IRPM or telemonitoring deserves to be the top telemedicine solutions in the market. It will improve the quality of delivering other telemedicine solutions.

4) Remote Patient Monitoring Services

Much research has explored patient monitoring systems but, to the best of our knowledge, little research has been done in developing and deploying RPMs that can be shared by several entities such as patients, hospitals, insurance companies, and government agencies, etc. In this section, we will give an overview of past and current research and development work on RPMs.

Several researchers have examined the potential for RPMs to improve the quality of healthcare services. For example, the authors in [6] present a preliminary performance study of mobile cloud to demonstrate its potential in performing continuous health monitoring in daily life and achieving higher diagnostic accuracy. In [7] the authors found that the use of remote monitoring is a promising approach that has the potential to reduce morbidity and increase patient satisfaction in non-homebound heart failure patients.

There is active research on utilizing cloud computing platforms in RPMs. For example, in [6], the authors present a preliminary performance study of mobile cloud to demonstrate its potential in performing continuous health monitoring in daily life and achieving higher diagnostic accuracy. Furthermore, the work in [8] proposed a platform that integrates mobile application technologies and cloud computing to provide secure, robust, scalable and distributed backend for hosting health services that cost-effectively improve life quality. In [9], the authors present a new hybrid framework based on mobile multimedia cloud that is scalable and efficient and provides a cost-effective monitoring solution for noncommunicable disease patients. They propose a novel evaluation model based on Analytical Hierarchy Process (AHP). They found that healthcare and cloud computing are such a natural fit for monitoring patients with chronic diseases. The authors in [10] propose a probability-based bandwidth model in a telehealth cloud system. They design an effective cloud-based telehealth system that will help cloud brokers allocate the most efficient computing nodes and links.

Numerous studies have examined the benefits of wireless sensor networks (WSNs) to collect patient data. For example, the authors of [11] show how to accurately track indoor positions, recognize physical activities and monitor vital signs in real time. However, it is an overview research without intelligent components. In [12], the authors deliver an integrated telemedicine service that automates the processes of patients' vital data collection. They used a wireless sensor network and they sent the data to a cloud computing solution. The implementation provides always-on, real-time data collection. That will help eliminate manual collection and the possibility of typing errors in traditional systems. Moreover, the authors in [13] propose an integrated model based on an IoT architecture and cloud computing telehealth center to integrate software, hardware, and healthcare systems. They present an analytics module as a solution to control an ideal diagnostic about some diseases. Specific features are then compared with the recently deployed conventional models in telemedicine.

B. Cloud Computing in Healthcare

Cloud computing is a computing model based on distributed computing, process automation, and virtualization technologies.
Cloud computing is the basic environment and platform of future healthcare. It provides quick, secure, reliable, cheap service and allows the user to access the service at any time from different devices [14].

1) Cloud Computing Characteristic and Advantages

Cloud computing can help innovate and deploy applications quickly on a small budget [15]. Cloud computing provides cheap services. Clients should not worry about maintenance and management problems of IT resources [14]. Cloud computing end users can access cloud resources directly through smart devices. Moreover, cloud computing can work as a distributed system. IRPMs can be deployed on decentralized servers and allow patient data transmission through Internet access. Cloud computing can extend the IT resources dynamically based on the need.

According to the National Institute of Standards and Technology (NIST), “cloud computing essential characteristics are on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service” [16]. We propose an architecture that targets the broad network access to maximize the communication capability and availability. IRPM service can be measured and utilized efficiently on the top of cloud computing environments. IT resources of IRPM include storage, processing, memory, and network bandwidth. These can be elastically provisioned and released based on system usage.

2) Issues, Challenges and Limitations

Despite the benefits that cloud computing offers, there are numerous issues and challenges for organizations embracing this new paradigm. The major challenges are security, data management, governance, control, reliability, availability, and business continuity [17] [14].

Moreover, there are numerous issues and challenges for adopting telemedicine in cloud computing:

- Considering critical success factors (save time, accuracy, large scale).
- Building strategic thinking.
- Security and privacy issues.
- Privacy risks involve a lack of control over the collection, use, and sharing of data.
- Applying and complying with HIPAA privacy and security regulations.
- Lack of trust in the use of telemedicine.
- Unauthorized access to data during collection, transmission, or storage.
- Network security and cryptography needed.
- Globalized telemedicine services issue.

Each point above deserves to be a research topic but we’ll focus on building the system architecture.

C. Machine Learning in the Healthcare Industry

Machine learning is helpful in the healthcare industry. Classification is the most prominent machine learning technique since it corresponds to a task that frequently occurs in everyday life such as classifying medical patients as suffering from a certain illness or risk of a acquiring it. A popular classification model usually applied in medical problems is neural networks, support vector machines, or decision trees. Classification models can help predict illness with the restriction that the value to be predicted is a discrete class. However, there are situations in which the goal is to provide a numerical prediction which is known as regression. The second type of machine learning is called clustering which consists of examining the available data to find groups of examples that are similar in some way [18].

Classification problems are widely used in medicine in order to detect or diagnose a disease or even to determine its severity. Classification techniques have been used not only to support the diagnosis of different diseases but also to analyze clinical information in the form of text or reports. When the goal is to provide numeral prediction regression techniques are used instead of discrete classes [18]. Deep learning is a particular case of machine learning algorithms which is artificial neural networks.

Several researchers have included intelligence to RPM. For example, the authors of [19] introduce DeepCare, an end-to-end deep dynamic neural network that reads medical records, stores previous illness history, infers current illness states and predicts future medical outcomes. They claim that the results are competitive against current state-of-the-arts treatment. They argue that DeepCare opens up a new principled approach to predictive medicine. However, in [20], the authors found that Recurrent Neural Networks (RNNs), particularly those using Long Short-Term Memory (LSTM) hidden units, are powerful and are becoming increasingly popular models for learning from sequence data. They effectively model different length sequences and capture long-range dependencies. They present the first study to empirically evaluate the ability of LSTMs to recognize patterns in multivariate time series of clinical measurements. Our approach aims at applying machine learning in an architecture that allows global users (sick or not).

The authors of [21] present semi-supervised sequence learning for cardiovascular risk prediction by using multi-task LSTM. They claim that their work is a first step in showing how health conditions can be detected using techniques first developed in natural language processing and computer vision. Furthermore, the work in [22] proposed a generic framework to predict septic shock based on LSTM which is capable of memorizing temporal dependencies over a long period. The experimental results demonstrate the superiority of the proposed framework and the effectiveness of LSTM compared with multiple baselines. Our proposed architecture aims at monitoring the general health based on vital signs and medical variables and that will answer some questions about what happened to the patient before he/she gets admitted to a hospital and after the discharge.
In addition, some research studied the mortality prediction in Intensive Care Unit (ICU). For example, the authors of [23] compare sliding window predictors with recurrent predictors to classify patient state-of-health from ICU multivariate time series. They report slightly improved performance for the Recurrent Neural Network (RNN) for three out of four targets. Moreover, in [24], the authors propose a novel ICU mortality prediction algorithm combining bidirectional LSTM model with supervised learning. They train and evaluate the LSTM model using a real-world dataset containing 4,000 ICU patients. Experimental results show that their proposed method can significantly outperform many baseline methods. However, our goal is to reduce hospital admission and waiting time by monitoring people (sick or not).

III. INTELLIGENT REMOTE MONITORING ARCHITECTURE

We now present the intelligent remote monitoring architecture. The architecture shows the main four groups who will use the system. We highlight the most challenging part of the system which is the data collection from RPM devices. We also list some specific healthcare application and its solutions by using machine learning techniques.

A. IRPM System Architecture

The proposed system in Figure 1 interprets information from different RPM devices. RPM devices are used to diagnose, monitor, and treat medical variables. The variables will not be treated individually and they will be available for professionals who can interpret information. For example, Age, Weight, and Height are quantitative variables and Race, Gender, and Smoking are categorical variables. So, the professional can see all variable in a single screen even though the data were collected from different RPM devices. The RPM devices must be compatible with the system and follow some standard to enable integration.

The proposed system will be used by four major groups:

**Patients:** There are patients who suffer from chronic conditions that require continuous monitoring and tracking of the history of health measurements. We can extend this group to include a potential patient who likes to get the benefits of the system. Patients can select the type of service. They can select which vital sign measurements to be included. Moreover, patients have view access to the system to monitor themselves and to get system alerts and recommendations. Furthermore, patients should read and accept a service level agreement (SLA) for security and privacy purpose.

**Hospitals:** Hospital physicians, nurses and clinicians can get to the system inside or outside the hospital through a system portable page or by integrating the system to the hospital electronic health record (EHR). The system will add features to the hospital EHR system. The system is recommended to be integrated to EHR by using Health Level Seven (HL7). Based on the system result, a hospital can make an action to treat the patient such as a call for a visit, home care, or referral to another clinic or hospital.

**Insurance Companies:** They will handle the medical insurance plans and coverages.

**Controller:** An organization that sets up, develops, operates, and maintains the system. It can be a profit or a non-profit organization. It coordinates the type of service between the other three groups involved in the system. Moreover, it can apply data analysis and generate some statistics based on the collected data. Furthermore, it can generate alerts based on unusual data and enable the system to generate highly automated health-related recommendations for a single patient, hospital, or organization.

![Fig 1. Proposed Intelligent Remote Patient Monitoring (IRPM) Architecture.](image)

B. Data Collection Challenges

Cloud computing has the ability to store the system data in a highly available environment but the most challenging part of the system is collecting data from RPM devices. There is no guarantee that RPM devices will be connected with the system without interruption or data loss but there are some ideas that reduce the percentage of service downtime and data loss.

**Idea One:** One solution is to save the data inside the RPM devices and work in an off-line mode. Once the connectivity becomes stable, RPM devices will upload the data to the system. Data archiving will help save the data but storage may be limited. On option is to only save significant data. A second option is doing data overwriting.

**Idea Two:** This idea allows different types of communication like wired, wireless, or satellite VSAT technology. This idea will challenge medical devices manufacturers to include these types of communication on their RPM devices.

**Idea Three:** The authors of [25] recommend using fog computing between cloud computing and RPM devices but, this idea will add one more layer and that will add more potential for failure. It will require products to be installed in heterogeneous technologies on heterogeneous platforms.

**Idea Four:** Simplify the RPM devices function to make it user friendly. This will encourage the concept of patient
centeredness. The work in [26] found that cloud computing supports patient centeredness, a promising future direction for health IT. The medical staff are the primary users of health IT applications and these applications are heavily physician-centered. However, the authors in [26] found evidence that imply a high potential of cloud computing to realize patient centeredness. They noted that cloud computing innovatively involves patient family members to realize patient centeredness.

Idea Five: Support manual operations. Manual operations are not recommended but it can be a solution in critical situations. The system’s Web interface is originally designed to be read only for patients but, to achieve the goal of this idea, we need to allow patients to enter data after considering security, legal and regulatory concerns.

C. Machine Learning Examples in Healthcare

The main inputs of the system are authentication ID, vital sign measurements, and medical variables. We focus only on the main vital sign measurements (body temperature, pulse rate, respiration rate, and blood pressure) and medical variables both quantitative (e.g., age, weight, and height) and categorical (e.g., race, gender, and smoking). We will add blood glucose since it is also important.

The main outputs of the system are recommendations for a single patient or an organization, reports (daily, weekly, monthly, or yearly), and alerts to both patients and hospitals. The objectives of data analysis are significant. We can use data analysis to detect, predict, or prevent illness.

Examples of Detection Applications:

- Find a pattern by using the clustering model. In this case, we would like to find if there were any distinctive patterns, e.g., if there is an unexpected result coming from a specific area like epidemic.
- Positive or negative illness result by classification models. We would like to train the model using a set of labeled data to determine if it is either one thing or another.
- Health significant change. In this case, the objective is to detect whether there is a sudden change in one or more vital signs measurements. We will try to find the best machine learning technique that could achieve this objective.
- Pain/No pain, especially for children by doing vital signs assessment. Vital signs provide a lot of insight into our overall health which can be affected by pain in several ways. For example, a normal response to pain is an increase in heart rate, breathing rate and blood pressure. We can indicate a pain with severe and harming conditions if the vital signs measurements are abnormal.
- Body mass index (BMI) by measuring height and weight in order to calculate the body mass index. The model will help get weight under control by doing a measure of body fat based on height and weight. According to the World Health Organization (WHO), the normal BMI should be between 18.5 and 24.9 kg/m². Anything over 25 is considered overweight and 30 or more is deemed to be obese.
- Emotion status. For example, determine if the patient is calm or under pressure, active or passive.

Examples of Prediction and Prevention Applications:

- Morbidity prediction. To predict a potential illness and condition (Diabetes, Hypertension, Obese, and Fever).
- Recovery prediction. It is close to morbidity prediction. It will predict if there is a possibility of health improvement.

We plan to use the LSTM variation of RNNs which enables the accurate modeling of long- and short-term dependencies. Also, we will use some other machine learning techniques to support the application. We will also focus on data preprocessing, training methods, algorithms, and validation.

IV. Conclusion

The ratio of doctor to patient is very low and the population keeps increasing which will require a smart and reliable solution. Some significant impacts are coming from cloud-based IRPM systems in healthcare environments. For example, the collected data can be used to do data mining. It will support decision makers to take an action especially if there is an unexpected result coming from a specific area like epidemic or high radiation rate in the human body. People can watch themselves by knowing the health status and take health recommendations generated by the system. The system is designed to provide cheap, customized health services.

The system should integrate into the standard care process. The system will help reduce hospital’s emergency room waiting time. Also, it will help patient avoid staying in hospitals for long periods of time. IRPM cloud-based architectures help in performing continuous health monitoring in daily life and achieving higher diagnostic accuracy and high-quality life.

Our focus is currently on developing the prototype to validate the proposed machine learning part which will enable the proposed IRPM to generate highly automated health-related recommendations to (healthy or sick) users.

REFERENCES


