

## A Smart System Connecting e-Health Sensors and the Cloud

Mohammad S. Jassas, Abdullah A. Qasem, Qusay H. Mahmoud

Department of Electrical, Computer and Software Engineering  
University of Ontario Institute of Technology  
Oshawa, ON, L1H 7K4 Canada

**Abstract**—This paper presents the design and implementation of an e-health smart networked system. The system is aimed to prevent delays in the arrival of patients' medical information to the healthcare providers, particularly in accident and emergency situations, to stop manual data entering, and to increase beds capacity in hospitals, especially during public events where a large number of people are meeting in one place. The architecture for this system is based on medical sensors which measure patients physical parameters by using wireless sensor networks (WSNs). These sensors transfer data from patients' bodies over the wireless network to the cloud environment. Therefore, patients will have a high quality services because the e-health smart system supports medical staff by providing real-time data gathering, eliminating manual data collection, enabling the monitoring of huge numbers of patients.

**Keywords**—cloud computing; data mining; Wireless Sensor Networks; Raspberry Pi; Amazon Web Service; Amazon Elastic Compute;

### I. INTRODUCTION

Wireless Sensor Networks (WSNs) have facilitated the way for development of various aspects of sensing. WSNs have been applied in different applications such as military applications, climate monitoring applications, underwater networks applications, and structural health monitoring applications. WSN are facing many challenges such as limited computing power, memory capacity and data transmission capabilities. Thus, using cloud computing would be an appropriate solution to improve sensors efficiency.

Cloud Computing is a general expression for any technological services provide through the Internet [1]. Cloud computing provides compatible and on-demand network access for numerous computing resources such as networks, systems, applications, and services. Moreover, cloud computing are using modern and flexible methods to provide, manage, and pay for information technology services with minimal management effort and cost. Cloud computing technology has several advantages such as flexibility, highly auto-mated, low cost, fast services providing, and a huge storage capacity. The Cloud's features enable customers to build, test, and deploy their applications on virtual servers using different infrastructures and multiple operating systems. Cloud service providers offer three different types of services in order to obtain their customers more flexibility, which are Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS). SaaS provides remotely access to software applications and their functions as a Web-based service. (PaaS) offers application frameworks and operating systems, obtains to minimize the development

efforts, and provides many applications in the cloud for users without installing any framework or software on their machines. (IaaS) offers a pool of cloud computing resources, including hardware, servers, networking components, and a massive storage space [2]. According to the National Institute of Standards and Technology (NIST), there are four models of deploying cloud computing which are Private, Public, Community, and Hybrid Cloud [3]. Finally, cloud computing offers unlimited data storage. Therefore, the organizations and users who are using the cloud do not need to be concerned about the size of their files.

Amazon Web Service (AWS) is one of the famous cloud providers which provides infrastructure as a service with different types of services such as, Amazon Elastic Compute Cloud (EC2). Amazon EC2 is a cloud service that designed to make web-scale computing easier for developers and to provide flexible compute capacity in the cloud [4].

In this paper, we focus on the idea of integration between wireless sensor network and cloud computing. After health sensors that are connected to patients' bodies collect and transmit data to the cloud, services which are available in this cloud are responsible for receiving, storing, processing, and distributing this data. We suppose that this solution offers an appropriate scenario to provide a comprehensive telemedicine service which automates the processes from collecting patients data to delivering compatible medical decisions based on patients' current conditions and their historical medical data.

The contributions of this paper are:

- A framework for integrating WSN and cloud computing.
- A prototype implementation using e-health sensors and the Raspberry Pi.
- Applying data mining technique to extract an appropriate decision based on patient's condition and historical data.

To this end, the rest of the paper is organized as follows. The system motivation is mentioned in Section II. Section III illustrates the related works. The proposed solution is taken into consideration in Section IV. Section V illustrates a privacy and security issues. We have discussed the future works in the concluding section.

### II. MOTIVATION

Providing healthcare services is very important for people specially who have chronic diseases. Those people need continuous healthcare which cannot be provided outside hospitals. There are a variety of technologies around us, so to

get benefits from connecting such technologies to build a new e-health system platform could help to achieve high quality health care services. There are many reasons which motivate us to build this platform: (1) making healthcare more accessible for people who do not have access to healthcare providers in their communities; (2) making healthcare easier for people who do not have access to public transportation in order to go to hospitals; (3) increasing bed capacity in hospitals, especially during public events where a large number of people are meeting in one place; (4) giving medical staff more time to be attentive to patients who need more care; (5) preventing delays in the arrival of patients' medical information to the healthcare providers, particularly in accident and emergency situations; and (6) reducing manual data entry for patients' data which prevents real-time monitoring and restricts medical staff to monitor their patients efficiently.

### III. RELATED WORK

Lounis et al. [5] offer a novel design for gathering and accessing a huge amount of data generated by WSNs. The main objective of their architecture is to overcome the challenges of dealing with a huge amount of data and makes sharing of information easier for healthcare professionals. The paper focuses on data management in WSNs, specifically sensors' data gathered that have been generated from medical sensors which introduce many challenges for the existing architectures.

Rolim et al. [6] focused on developing patients' data gathering technique. This paper presents a novel framework to solve the problems of taking notes manually which is a slow process. Besides, they cause lateness for accessing real-time data and that restricts the capability of clinical monitoring and diagnostics. Thus, authors proposed a system to automate collecting patients' information process using wireless sensor networks which are connected to medical equipment, and then transferring this data to the healthcare provider centers in the cloud to store, process, and analyze patients' data. However, this paper does not take security risk in consideration, practically in the architecture of proposed solution.

Fortino et al. [7] state that the integration of cloud computing and wireless sensor networks can provide scalable powerful data storage, and improvement of processing infrastructure and analysis of body sensor data. This paper presents the management and monitoring of sensor infrastructure. In addition, this study also considers some components in the architecture of cloud computing such as data management and using APIs for communication between sensor data streams and the cloud. The authors implement their system by using an application of the google App Engine (GAE) which is one of the cloud computing providers for hosting and developing web applications in the cloud.

Hwang et al. [8] presents an interesting business model for cloud computing based on the concept of performing the encryption and decryption technique, and a cloud provider must ensure that the information has been stored in encrypted

format. Moreover, after the computation operations are completed, all data must be deleted. This study discusses many points related to encrypting data in the cloud. However, this paper did not discuss the security part during uploading and downloading operations in terms of securing the channel between the client and cloud provider.

### IV. PROPOSED SOLUTION

The architecture of the proposed solution is based on the integration between medical sensors which are responsible for collecting patients physical parameters and the cloud environment to provide a smart health system.

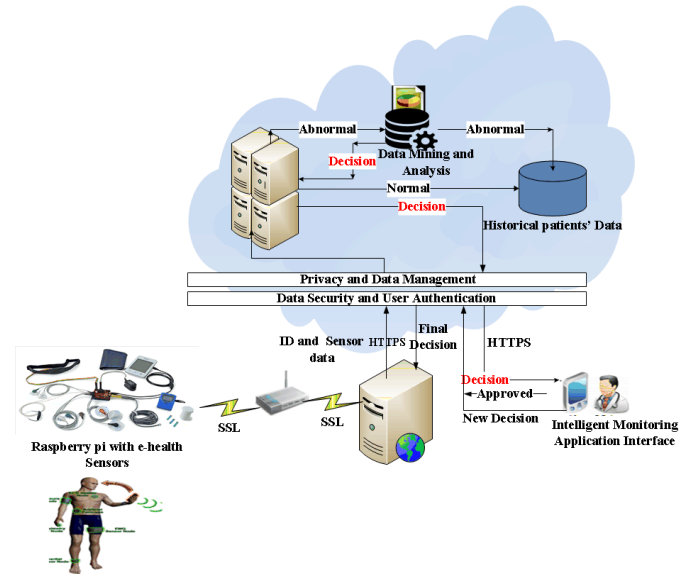


Figure 1: Proposed System Architecture

As shown in Figure 1, the wireless health sensors are connected to a Raspberry Pi. This Raspberry Pi is responsible for collecting data from sensors and transmitting this data through wireless communication channels to platform services hosted on the cloud. This platform has many services: (1) storage service, which is responsible for storing sensors' data; (2) data mining service, which is responsible for providing a medical decisions based on patients historical medical data; and (3) managing service for updating, reviewing and testing patients' data which is needed by medical staff. Medical staff and patients can utilize the application from different mobile and stationary devices connected to the Internet.

Security and privacy are the significant factors related to the cloud environment. The cloud computing environment provides numerous computing resources that are shared. Therefore, sharing hardware resources and storage data areas in the cloud are at risk from insider and/or outsider attacks. In order to achieve data security and privacy in our system, we apply two techniques, which are:

- 1) Socket Secure Layer (SSL), which is a popular technique for establishing an encrypted channel between a web server and the Raspberry Pi to transmit patients' data to the cloud application through secure channels.

- 2) Data will be stored in the cloud in encrypted format, using the AES (Advanced Encryption Standard) algorithm. The decision making process is depicted in Figure 2.

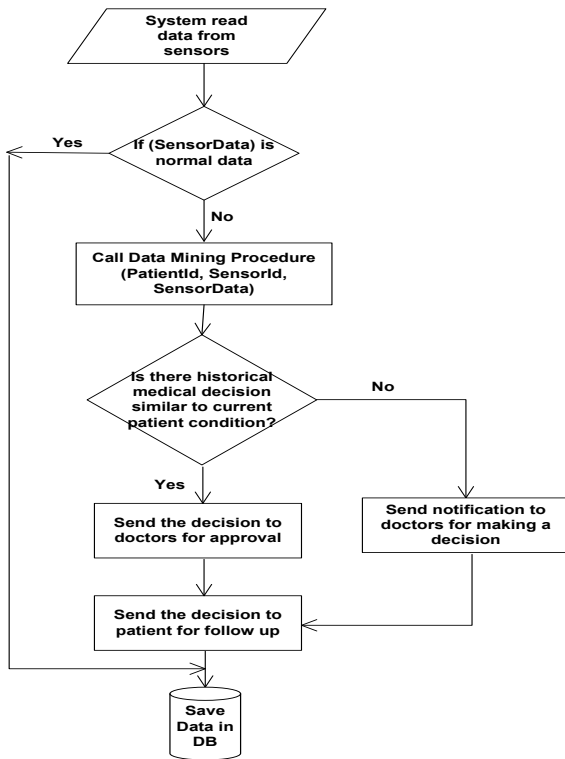


Figure 2: Decision making process

#### A. Data Collection

Patients' physical parameters are measured using medical sensors that are connected to a raspberry pi. The raspberry pi is responsible for collecting data from the sensors and transferring it, over SSL, to the cloud environment. The sensors transmit real time data to the application in the cloud continuously based on the delay time which is set in their configuration program.

#### B. Decision Making

Figure 2 depicts the system decision making algorithm. We use data mining techniques in order to build our algorithm. The data mining procedures are responsible to create appropriate medical decisions based on three parameters which are patient id, sensor type, and sensor current data. When the application receives the data from the sensors, the algorithm will check if the sensor data is normal or abnormal, based on the normal ranges of laboratory medical tests and patient's medical policy which are define in the system. In health-related fields, normal range of laboratory medical tests usually describe the variations of measurements or values in healthy individuals. Reference ranges are usually determined by taking either the lowest and the highest values (range) of results obtained on a normal population [9]. Every patient has a medical policy profile in the system based on the sensor type to assist the system to create compatible medical decisions. For example, some patients have chronic diseases, so medical staff should

consider some changes in the normal ranges of laboratory medical tests. Medical staff can set a specific policy for every patient based on the patient's condition as shown in the following examples:

Example 1:

*If Patient id = "1000001" & SPO2 < "70" & TEMP > "37.5" = "Set Status is Abnormal" & Making Decision & (send notification to the doctor).*

Example 2:

*If Patient id = "1000002" & SPO2 < "60" & TEMP > "38.5" = "Set Status is Abnormal" & Making Decision & (Send notification to Emergency Medical Services (EMS)).*

If the data is normal, the algorithm will store this data in sensors information tables in the database to populate patients' historical data. Otherwise, the algorithm will create a medical decision based on a patient historical medical data. If the patient does not have any historical medical data for the same condition, the system will make a medical decision based on historical statistical data of patients who have a similar health condition. The system is responsible to encrypt the data before storing it in the cloud. Different types of encryption algorithms have been developed to provide cloud users with data security. The objective of these algorithms is to protect the system against malicious users, and secure information against advanced threats. In our implementation we are using the Advanced Encryption Standard (AES) symmetric algorithm.

#### C. Decision Approver

After the system makes the decisions, they will be sent to the medical staff who are responsible for the patient's healthcare for approval. There are different ways to notify medical staff including, SMS and email. They can use a web browser from any device to review and update decisions as needed. Once they have reviewed the patients' historical information, medical staff can decide if the current decisions which are created from the system are appropriate for the patient's condition or they need to change and update them. After the medical staff approve the decisions, the system will notify the patient with the necessary instructions for dealing with that situation or condition.

There are several advantages for the proposed system, including:

- 1) Providing real-time data gathering.
- 2) Eliminating manual data collection process, which sometime includes data entry errors.
- 3) Enabling the monitoring of huge numbers of patients who are depending on limited numbers of medical staff.
- 4) Ensuring that bed occupancy in hospitals is only for patients who need them.

## V. PROTOTYPE

We have used commercial wireless health sensors that are connected with e-Health Sensor Shield [10] that allows Raspberry Pi developers to perform biometric and medical applications to measure patient's physical parameters. In our implementation, we used two types of sensors which are pulse and oxygen in blood sensor (SPO2), and body temperature

sensor. The Raspberry Pi is a Linux-based microcomputer that connects with a computer monitor or TV, and uses a keyboard and mouse. It includes 2 USB ports, HDMI and Ethernet port, SD card slot, memory, video/audio outputs, and power source [11]. We used C++ to implement the application (on the raspberry pi) for reading the data from the sensors and sending it to the cloud. We utilized TCP sockets to establish a connection between the Pi and the application in the cloud. The server program was written in C#.

In the cloud, we selected Amazon Web Services (AWS). AWS is one of the widely used cloud providers which provides infrastructure as a service known as Amazon Elastic Compute Cloud (EC2). Amazon EC2 is a web service that is designed to make web-scale computing easier for developers and to provide flexible compute capacity in the cloud. For the EC2 instance, we installed Windows server 2008 as an operating system. To build the application on this instance we used C# language, and Microsoft SQL server database to achieve e-health smart system which is responsible for receiving, managing, and processing patients' data, then store this data in the database.

## VI. SIMULATION AND IMPLEMENTATION RESULTS

We have tested our prototype using one body temperature sensor, Pulse and oxygen functions because we wanted to minimize the cost of the experiment. As a test sample, we have used seven hypothetical patients, and we have noticed that all of them have the same body temperature which is around 37 Celsius, so we worked on adding some training data to achieve our goal for allowing the system to make decisions based on the changing body temperature.

As shown in Table 1 we collected body temperatures for one patient in different times from June 12, 2014 until June 18, 2014. Thus, medical staff can monitor the patient easily during the day as shown in Figure 3. The medical staff also can make decisions based on the patient's condition if they notice that the patient has an emergency.

Sensor Id	Patient Id	Insert date	Sensor Data
TEMP	1000001	June 12, 2014	37.2
TEMP	1000001	June 13, 2014	38
TEMP	1000001	June 14, 2014	39.5
TEMP	1000001	June 15, 2014	37
TEMP	1000001	June 16, 2014	40
TEMP	1000001	June 17, 2014	38
TEMP	1000001	June 18, 2014	37

Table 1: Body temperature monitor for one patient

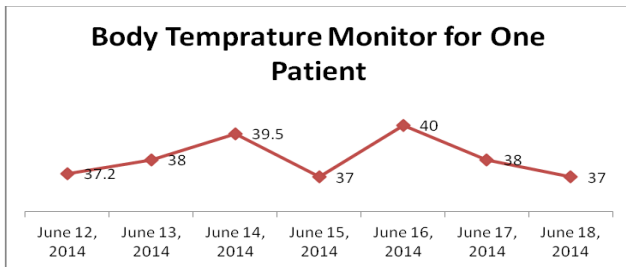


Figure 3: Body temperature monitor for one patient

Patient Id	Name	Insert date	Sensor Data
1000002	S1	12:07:00 PM	39.2
1000003	S2	12:08:00 PM	37
1000004	S3	12:09:00 PM	38
1000005	S4	12:10:00 PM	37.2
1000008	S5	12:11:00 PM	38.3
1000007	S6	12:12:00 PM	37.5
1000009	S7	12:13:00 PM	37.8

Table 2: Body temperature monitoring for seven patients

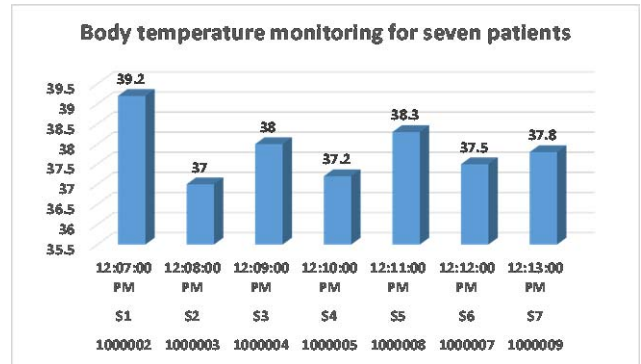


Figure 4: Body temperature monitor for seven patients

As shown in Table 2 we collected body temperatures data from seven patients. The objective of collecting this data is to compare the effectiveness of using body temperature sensors against the traditional way of measuring the body's temperature manually. We noticed that every patient needs about one minute to read his body's temperature which is a very short time compared with the traditional technique. We also applied a delay technique because we wish to obtain a high accuracy of body temperature because the body temperature sensor we have experimented with takes time to generate the correct body temperature. Therefore, we noticed that 30 seconds delay for collecting body temperature will assist in obtaining a high accuracy.

Patient #	Gender	Age	Decision Description	Sensor Id	Sensor Data
1000001	M	30	You should visit the clinic soon	TEMP	39.9
1000004	M	32	You should take Tylenol, 3 times a day	TEMP	38
1000005	F	19	Please Enter your Decision. There is not historical Data	TEMP	36

Table 3: System decisions

Table 3 shows that the decisions created by the system. Every time the application receives data from the sensor, it checks if this data is normal or not. This examination is based on the normal ranges of laboratory medical tests [9] and patient's medical policies. If this data is abnormal, the system

will send this data (patient id, sensor type, and sensor current data) to the data mining algorithm to create appropriate medical decision for the patient as shown in Table 3. These decisions will be sent to the medical staff who are responsible for the patient's file for approval.

## VII. CONCLUSIONS AND FUTURE WORKS

The integration between wireless sensor networks and cloud computing will create a new generation of technology in many aspects such as patient monitoring with minimal cost, reducing the number of occupied beds in hospitals, and improving medical staff performance. In addition, applying various data mining techniques help to extract and analyze patients' data. The system introduced in this paper provides decisions based on patients' historical data, real-time data gathering, and thus eliminating manual data collection.

For future work, we are planning to enhance the functionality of the system by adding more sensors and using it to collect data from a larger sample size of patients.

## REFERENCES

- 
- [1] Srinivasa, R. V., Nageswara, R., & Kumari, E. K. (2009). Cloud computing: An overview. *Journal of Theoretical and Applied Information Technology*, 9(1), 71-76.
  - [2] Buyya, R., Broberg, J., & Goscinski, A. M. (Eds.). (2010). *Cloud computing: Principles and paradigms* (Vol. 87). John Wiley & Sons.
  - [3] Mell, P., & Grance, T. (2011). The nist definition of cloud computing, recommendations of the national institute of standards and technology. *National Institute of Standards and Technology*, 800-145.
  - [4] AWS | Amazon Elastic Compute Cloud (EC2) - Scalable Cloud Hosting. (n.d.). Amazon Web Services, Inc. Retrieved June 22, 2014, from <http://aws.amazon.com/ec2/>
  - [5] Lounis, A., Hadjidj, A., Bouabdallah, A., & Challal, Y. (2012, July). Secure and scalable cloud-based architecture for e-health wireless sensor networks. In *Computer communications and networks (ICCCN), 2012 21st international conference on* (pp. 1-7). IEEE.
  - [6] Rolim, C. O., Koch, F. L., Westphall, C. B., Werner, J., Fracalossi, A., & Salvador, G. S. (2010, February). A cloud computing solution for patient's data collection in health care institutions. In *eHealth, Telemedicine, and Social Medicine, 2010. ETELEMED'10. Second International Conference on* (pp. 95-99). IEEE.
  - [7] Fortino, G.; Pathan, M.; Di Fatta, G., "BodyCloud: Integration of Cloud Computing and body sensor networks," *Cloud Computing Technology and Science (CloudCom), 2012 IEEE 4th International Conference on*, vol., no., pp.851,856, 3-6 Dec. 2012 doi: 10.1109/CloudCom.2012.6427537.
  - [8] Hwang, J. J., Chuang, H. K., Hsu, Y. C., & Wu, C. H. (2011, April). A business model for cloud computing based on a separate encryption and decryption service. In *Information Science and Applications (ICISA), 2011 International*.
  - [9] Lab Manual for UCSF Clinical Laboratories. (n.d.). Retrieved February 23, 2015, from <http://labmed.ucsf.edu/sfghlab/test/ReferenceRanges.html>
  - [10] E-Health Sensor Platform Complete Kit V2.0 for Arduino, Raspberry Pi. (2014, July 3). Retrieved from <http://www.cooking-hacks.com/ehealth-sensors-complete-kit-biometric-medical-arduino-raspberry-pi>
  - [11] Raspberry Pi: [www.raspberrypi.org](http://www.raspberrypi.org). Last accessed, July 27, 2014.