Virtual Sensors in Remote Healthcare Delivery: Some Case Studies

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Keywords: E-Health, Sensor-cloud, Virtual Sensors, Remote Health.

Abstract: Delivery of healthcare services to the people living in remote places is a challenging task. A *remote healthcare* framework has been proposed in our earlier work based on sensor-cloud technologies. This paper explains the scenarios for deployment of such a framework in a remote healthcare delivery system. In our sensor-coud environment we propose to create virtual sensors and offer them on-demand to the health-care service providers for use in their services. In this paper, we discuss the purpose of using virtual sensors in healthcare domain and demonstrate how additional responsibilities that cannot be handled by physical sensor devices, can be delegated to virtual sensors in order to improve the efficiency of the system. Results of preliminary deployment of virtual sensors in two scenarios are discussed within limited scope and their advantages and related issues are put forward for future implementation of the sensor-cloud infrastructure.

1 INTRODUCTION

Providing basic healthcare services in rural areas in developing countries is a challenge. Primarily, this is because doctors are not available in the same proportion in the rural areas as they are available in urban areas. Some studies in India indicate that there are about four times as many trained doctors per ten thousand population in urban areas as compared to the rural areas. This includes doctors in the public sector (in primary healthcare centres set up by Government) as well as in the private hospitals and nursing homes and privately practicing doctors. Clinical testing facilities are also unavailable in these areas.

Although, the situation can only be reversed through government initiatives and some changes in the societal structure, we propose to increase the reachability of rural people to healthcare services with the use of modern information and communication technologies. In particular, our solution is based on integration of cloud computing and sensor technologies and deployment of a sensor-cloud environment. However, while building the sensor-cloud environment, we propose to create virtual sensors and offer them on-demand to the health-care service providers for use in their services. This paper presents few scenarios where instead of directly collecting data from physical sensors and transmitting those to the cloud environment, use of virtual sensors will be effective and in some cases a necessary requirement. Such scenarios for using virtual sensors in healthcare domain are discussed in Section 2. A scheme for remote delivery of healthcare services on top of sensor-cloud environment is discussed in Section 3. We also demonstrate the use of some virtual sensors in the kiosk-based system and discuss their advantages and related issues. Section 4 discusses use of virtual sensors in the proposed kiosk-based scheme and finally Section 5 concludes.

2 DEVELOPING A SENSOR-CLOUD ENVIRONMENT

Cloud computing brings a change in the users' vision towards the computing world. Restrictions put by the limited resources in a dedicated server are overcome when computing and storage resources, software and information are provided over a network as an utility with an analogy with electricity or water supply. According to NIST (Mell and Grance, 2011), cloud computing enables "ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction".

On the other hand, advancements in sensing tech-

Mukherjee, N., Bhunia, S. and Bose, S.
Virtual Sensors in Remote Healthcare Delivery: Some Case Studies.
DOI: 10.5220/0005823204840489
In *Proceedings of the 9th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2016) - Volume 5: HEALTHINF*, pages 484-489
ISBN: 978-989-758-170-0

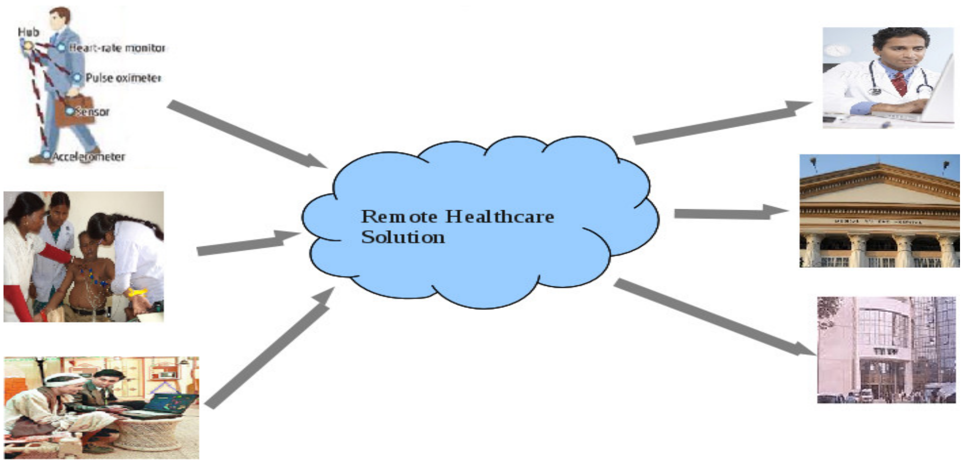


Figure 1: Remote Healthcare: Use cases.

nologies, and possibility of connecting numerous spatially distributed sensing devices wirelessly in a multi-hop network create enormous scope for implementing various applications which were never envisaged earlier. However, instead of using sensor nodes only for data transmission to cloud, we propose to create a layer of abstraction of sensor nodes through virtualization. Thus, with virtualization, it is possible to delegate additional reponsisibilities to the virtualized sensing devices and offer access to these devices on demand basis and in shared and pervasive manner. Virtualized sensors can also be reserved for a time period. In other words, virtual sensors enable us to offer *SENsing-As-A-Service* with extra capabilities in comparison with what can be offered by physical devices and also providing ways to overcome the limitations of physical sensing devices. A sensor-cloud framework with sensor virtualization and the issues related to the development of the framework have been discussed in (Mukherjee et al., 2014). In this section our endeavor is to present some rationale for use of virtual sensors in healthcare domain.

Virtual Sensors: A virtualization layer of the sensor nodes can be created for several purposes. As mentioned earlier, the tiny sensing devices have limited capabilities in terms of computing resources, storage and energy. Thus, creating virtual abstractions of physical sensors in cloud environment and thereby enabling them to use additional resources, it is possible to enhance the capabilities of these sensing devices. Furthermore, in case of healthcare applications, we envisage other requirements which can be fulfilled by virtualizing sensor resources. A virtual sensor accumulates the data from one or more physical sensor nodes and analyzes and processes the data to make a decision. Based on the complexity of the decision making algorithm and whether it runs at the infrastructure level (IAAS) or at the platform level (PAAS), different names are given to the respective virtual sensors. In our earlier work (Bose et al., 2015), we have already defined eight types of virtual sensors. In this paper, we describe applications of some of the virtual sensors in healthcare domain.

1. Number of sensing units are deployed on a patient's body to sense various clinical parameters, such as blood pressure, body temperature and oxygen level (or oxygen saturation) in the blood. All these parameters are related to one single patient and an application should be able to access these parameters as a single data unit. A single virtual sensor is created to accumulate the sensed data from different sensing units and represent them as a single data unit. Such a virtual sensor is named as an *accumulator*.

2. A virtual sensor may sense the blood pressure of a patient and when the sensed data goes beyond a threshold value, the virtual sensor generates an alert. Such a virtual sensor gets data from a single sensor node and can be implemented at the sensor network level. This virtual sensor is named as a *qualifier*.

3. A *context qualifier* virtual sensor is similar to a qualifier virtual sensor, but instead of considering data from a single sensor, it obtains data from multiple sensors and applies a decision algorithm. Such a virtual sensor may be implemented at body sensor network level. An example of a context qualifier virtual sensor is as follows: "When body temperature sensor reads high value and skin conductance sensor reads normal (patient is not sweating), the values indicate that the patient has fever". A range of values is defined for describing the terms like high, normal and low.

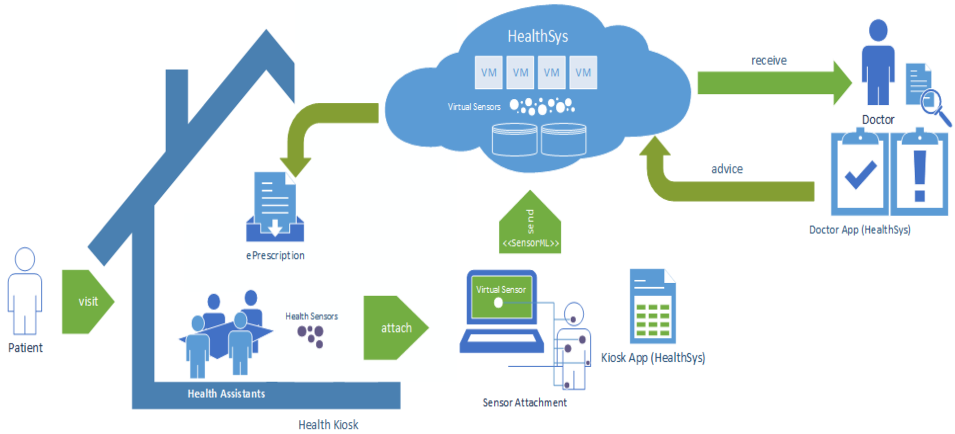


Figure 2: Kiosk-based remote healthcare delivery.

We can also use fuzzy rules in such cases (Bhunia et al., 2014).

4. A virtual sensor may be implemented with a predictor algorithm to predict possible sensed values based on time series data analysis on previously sensed data when actual physical sensor goes down. For example, a heart rate monitoring sensor may be attached with the patient's body for continuous monitoring and the patient may be on move (traveling in a train). The monitoring data can be regularly uploaded to the cloud environment and used by the care giver for taking care of any unusual situation. Due to connectivity problem or any other reason data may not be available at every instant. The predictor algorithm is implemented at the platform level (PaaS) and can be used to predict the intermediate values. The predicted values can later be compared / corrected with the actual values which are locally stored and uploaded later to the cloud environment. We name such a sensor a *predictor*.

5. A virtual sensor may be equipped with some contextual computation abilities that analyzes the sensed traffic from a set of sensors. The computational procedure transforms sensed data to a more understandable information. For example, an image analysis algorithm may be executed on the data obtained from a group of physical sensors collecting images from a patient's body. The virtual sensor is then represented in an integrated form which contains the data obtained from the set of physical sensors, the algorithm and necessary computation and storage resources. We name this virtual sensor a *compute* virtual sensor. This sensor is also implemented at the platform level (PAAS).

In addition to the above sensors, some other virtual sensors with various capabilities have been described in (Bose et al., 2015). However, these virtual sensors are more applicable in case of applications other than healthcare applications (such as environment monitoring).

It is clear from the above description that when a user application requests for a virtual machine in our sensor cloud environment, it not only requests for usual virtualized resources like CPU, memory and storage, it can also request for virtual sensors, as necessary on the basis of the patients' requirements. APIs are provided for requesting virtual sensors and they are provided on demand basis.

3 A SCHEME FOR REMOTE HEALTHCARE DELIVERY

The sensor-cloud environment described above is being implemented for a remote healthcare delivery system. Three use cases are considered for implementation of such a system (Figure 1). These use cases are described below:

- **Kiosk-based Healthcare Delivery:** In rural areas, where doctors are not available, a health kiosk can be set up. The kiosk should be equipped with e-health sensor kit and operated by a team of health assistants. The health assistants must be trained to use health sensors, gather data from patients' bodies using the sensors and transmit data to the cloud through an e-health application. The e-health application will run on a virtual machine with capabilities as requested by the application itself including necessary virtual sensors. Doctors may be located in urban areas. Our sensor cloud-based application allows the doctors to visualize the patients' data remotely. When a patient comes to a kiosk, the health assistants collect data, upload data to the cloud. Doctors, after remote analysis of data, make diagnosis, suggest medication and further investigation. All investigations and tests may not be possible in the health kiosks (such as X-ray) and in such cases the patients are advised to visit external laboratories (although such situation arises only in a few number of cases). A patient visits the kiosk more than once until the treatment related to a complaint is over or the patient is referred to a secondary healthcare centre. The entire scheme is described in Figure 2.

In the above scenario, virtual sensors can be deployed in cloud environment and can be used to represent patients' clinical data in an integrated form to the doctors.

- **Continuous Monitoring of Patients on Move:** A single sensor (such as heartbeat monitor) or a body sensor network can be put on a patient's body. The patient will carry out normal activities. The patient can be in motion as and when necessary. Therefore, it is required to have seamless connectivity when the patient moves through different networks, including cellular network, Wifi etc. While transmitting data from various sensors through a common channel, there may be interferences. Handling such interferences is another issue. When the sensor data exceeds some threshold values, it may also be required to generate alert messages. Virtual sensors may be created to deal with the above issues.
- **Offline Data Collection:** Health assistants may move from dood-to-door and collect health-related data from several households. At certain instances, these data may be uploaded to cloud environment for analysis. The data, as well as analysis results may be used by caregivers (doctors or health assistants), healthcare units (hospitals), or by the government organisations (health departments). While the caregivers and the healthcare units require the data for monitoring purposes, health departments may use the analysis results for controlling any epidemic or introducing new schemes for reducing the disease burden in the state. Enhanced capabilities of virtual sensors may run algortihms for data analysis and present data in different formats to the users based on their requirements.

Patients' data contains five parts: (i) demographic data, (ii) past medical history of the patient, (iii) the complaint of the patient, (iv) data collected by virtual sensors deployed at the kiosk or on the patient's body and (v) data collected by tests and investigations. The last part, that is the data collected by tests and investigations are filled up on the basis of doctors' advice and are possibly filled up during the subsequent visits of the patient. Data are stored using sensorML format. A description of the data model is given in (Sen and Mukherjee, 2014).

4 USE OF VIRTUAL SENSORS IN REMOTE HEALTHCARE DELIVERY

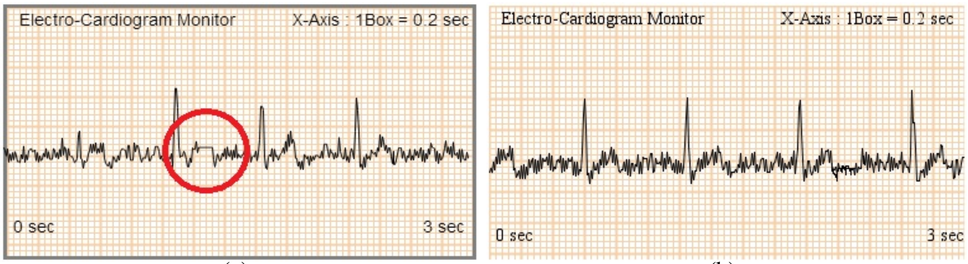
In this section, we discuss the use of virtual sensors in our remote healthcare delivery application Healthsys. In this paper, we will consider two particular scenarios of deploying virtual sensors.

Case 1: Various physical sensors are put on the patient's body and a virtual sensor is deployed on a gateway which is a laptop or an android-based smart phone placed in the kiosk. The virtual sensor accepts data from all the physical sensors, interleaves them and forwards the combined data for the use by an application or a service.

Benefit: Parameters like electrocardiogram (e.g. ECG) and other graph based parameters require higher sampling rate, but have small data size per sample. But parameters involving images and audio (e.g. respiratory sounds) require low sampling rate, but large data size per sample. The required sampling rate must be maintained for each sensor. Also, the data is sent through a common channel. Therefore, a data interleaving technique needs to be incorporated so that each sensor gets a share of the available bandwidth enabling each of them to maintain sampling rate, data length and delay. If interleaving cannot be done suitably (a sensor data may need to be split between the samples of other sensors), then there may be overlapping between the sensor data and interpretation of the data may be deformed as shown in Figure 3(a).

Implementation: A virtual sensor is deployed at the infrastructure level that accepts data from different physical sensors, interleaves the data in such a way that none of the samples from any physical sensor is missed and data are delivered in time.

For example, ECG data requires high sample rate, but data size is low. On the other hand, body temperature data requires low sample rate and the data



(a) (b)

Figure 3: (a) ECG without using interleaving with other sensed data, (b) ECG with interleaving with other sensed data.

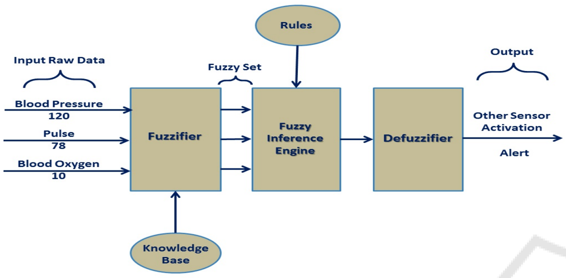


Figure 4: Framework for Fuzzy-based Data Collection.

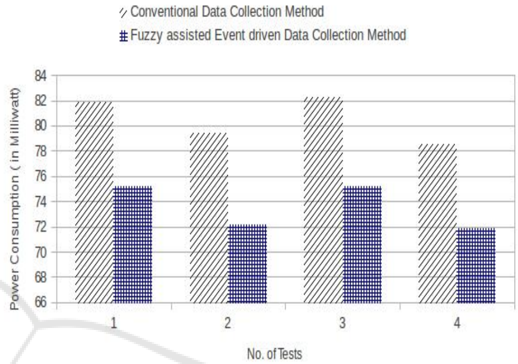


Figure 5: Reduced energy consumption in fuzzy-based method.

size is large. Therefore, multiple ECG samples can be interleaved with a sample of body temperature data and can be transmitted through a common channel.

An example of the interleaving technique in a specific scenario has been discussed in detail in (Dhar et al., 2014) and some experimental results are given. Figure 3 compares two ECG results without and with the use of interleaving techniques.

Case 2: A virtual sensor accepts data from one or more physical sensors and applies fuzzy rules to generate an alert or to activate another physical sensor. Figure 4 shows a framework for fuzzy assisted data collection in healthcare domain.

Example: An example of a fuzzy rule can be as follows: "When body temperature is low, and skin conductance sensor reads high (patient is sweating), it is indicated that the patient is in shock. Shock may arise from fear or heart problems or psychological issues. As one of the symptoms of heart attack is severe shock of the patient, our system activates the heart rate monitor when the above two conditions are true." (Bhunia et al., 2014).

Benefit: This virtual sensor avoids unnecessary data collection from multiple physical sensors and saves energy consumption at the physical level. An implementation of the fuzzy rule-based system has been discussed in (Bhunia et al., 2014). Figure 5 describes the reduction in energy consumption with this implementation.

5 RELATED WORK

Delivering healthcare services remotely is being in focus of the medical practitioners, as well as scientists. Advantages of offering medical diagnosis and monitoring services based on mobile health systems and the challenges have been discussed in (Mohammadzadeh and Safdari, 2014). In (Henderson et al., 2014), it has been argued that nurse practitioners can use technology through a telehealth service that can improve quality and overcome geographic barriers to health care access. They have also shown that technology can improve patients access to health care in a cost-effective manner. Few critical questions have been raised in (Puddu et al., 2014) in relation to remote healthcare systems and the pertinent technologies implied in transferring surveillance and care to the patients. The reviewed some use case scenarios and attempted to integrate different points of views of physicians, patients, academicians, health service organizations, industries, and the end users.

In spite of the above research works and studies on remote healthcare delivery, application of sensor-cloud and sensor virtualization have not received much focus in healthcare domain. Sensor virtualization for underwater event detection has been discussed in (Wang et al., 2014) in which the base station collects measurements from multiple sensor nodes, and makes a decision based on the sensors reports. enables the collection of data streams from multiple heterogeneous geographically dispersed data sources, as well as their semantic unification and streaming with a cloud infrastructure. It has been proposed in (Petrolo et al., 2014) to enable collection of data streams from multiple heterogeneous geographically dispersed data sources and their semantic unification and streaming with a cloud infrastructure for a smart city solution.

Our research studies the purposes of using virtual sensors for healthcare services and focuses on introduction of a layer of abstraction to implement virtual sensors. Use of virtual sensors have been demonstrated in two scenarios. Currently, we are focusing on other types of virtual sensors and their implementation.

6 CONCLUSION

This paper focuses on remote healthcare delivery on top of a sensor-cloud framework. The paper particularly discusses virtualization of sensors and their applications in healthcare domain. A remote primary healthcare delivery application has been dicussed and its implementation using virtual sensors has been conceptualized. We are currently developing an architecture for implementation of virtual sensors and APIs for their uses in healthcare services.

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