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A Cloud Computing Solution for Patient's Data Collection in Health Care Institutions

Carlos Oberdan Rolim, Fernando Luiz Koch, Carlos Becker Westphall,
Jorge Werner, Armando Fracalossi, Giovanni Schmitt Salvador
Network and Management Laboratory - LRG
Federal University of Santa Catarina
Florianopolis - SC - Brazil
{ober, westphal, jorge, armando, giovanni}@lrg.ufsc.br; fkoch@acm.org

Abstract—**Existing processes for patients' vital data collection require a great deal of labor work to collect, input and analyze the information. These processes are usually slow and error-prone, introducing a latency that prevents real-time data accessibility. This scenario restrains the clinical diagnostics and monitoring capabilities. We propose a solution to automate this process by using "sensors" attached to existing medical equipments that are inter-connected to exchange service. The proposal is based on the concepts of utility computing and wireless sensor networks. The information becomes available in the "cloud" from where it can be processed by expert systems and/or distributed to medical staff. The proof-of-concept design applies commodity computing integrated to legacy medical devices, ensuring cost-effectiveness and simple integration.**

Keywords-utility computing, sensor networks, telemedicine, cloud computing

I. INTRODUCTION

Telemedicine allows remote diagnoses and monitoring of patients [1]. It guarantees agility, safety, and reliability in modern health-care institutions. There are several challenges associated to automation in this sort of environment [2], *viz*: heterogeneity of devices, protocols, and programming interfaces; the requirement for flexible, impact-free deployment; the requirement for easy to configure, easy to manage, scalable and, if possible, self-adjusting systems, and others.

We focus on the problem of patients' vital data collection, distribution, and processing. We suggest that current solutions based on manual note taking are slow, time consuming, and labor resource intensive. Besides, it imposes an obstacle to real-time data access that curbs the ability of clinical diagnostics and monitoring.

We present a solution to automate this process from bedside data collection to information distribution and remote access by medical staff. Our solution is based on concepts of wireless sensor networks and utility computing. "Sensors" are attached to existing medical equipments that are inter-connected to exchange services; these are integrated to the institution's computing network infrastructure. The information becomes available in the "cloud", from where it can be processed by expert systems and/or distributed to medical staff for analysis. We argue that these technologies provide desirable features for automation in telemedicine environment addressing the challenges listed above.

Our contribution is two-folded in social and scientific fields. In social we demonstrate an innovative and low cost solution to improve the quality of medical assistance delivery and; in scientific field we address the challenges of how to integrate sensors connected to legacy medical devices which cloud computing services to collect, process and delivery patient's vital data.

This work is organized as follows. In the next section we present our motivation. Section 3 introduces the related works. Section 4 presents our proposal and describes the proof-of-concept design. Section 5 shows the conclusions and future works.

II. MOTIVATION

Figure 1 depicts how the process works based on manual notes [3]. The interactions are described below.

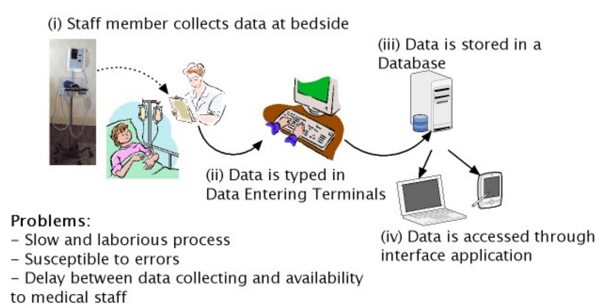

Figure 1. Current scenario.

(i) A staff member collects patient's data at bedside, writing it down to a paper spreadsheet;

(ii) The notes are typed in a data entering terminals;

(iii) The data is transmitted to a database server that organizes, indexes, and make it accessible through a database interface; and

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(iv) At this point, medical staff can access this information through an interface application.

It is clear that there is latency between (i) data gathering and (iv) information accessibility. This is undesirable and prevents real-time monitoring of vital patients' data, restricting the clinician's monitoring capabilities. Moreover, this process is error prone, as there is a possibility of incorrectly input.

We proposed that this scenario presents an opportunity to deliver an integrated telemedicine service that automates the process side-to-side; that is, from data collecting to information deliver. We suggest the following high-level requirements for the solution:

1. It must *implement the methods to collect, process and distribute patient's vital data*, from bedside to remote accessibility.
2. It must be *open, flexible and extensible*; that is, it must support heterogeneous equipments in different numbers that can be added to system on *ad hoc* basis.
3. It must be *secure*; that is, the system must guarantee the integrity and confidentiality of medical data.
4. It must be *manageable*; that is, it must provide control over the myriad of computing devices connected to the environment.
5. It must be *reliable*; that is it must guarantee system availability despite of fluctuations of operational conditions and punctual issues.
6. It must be *scalable*, to support the deployment in large health –care environments and the integration of different institutions.
7. It must be *optimized* for computing resources; that is, the application must run in inexpensive, low-profile computing devices.

To that end, we exploit concepts from diverse cut-edge technologies. First, the solution is based on the idea of utility computing [4] as a "service provisioning model that provides adaptive, flexible and simple access to computing resources, enabling a pay-per-use model for computing similar to traditional utilities such as water or electricity". This model provides inherent support to ideas of outsourcing and on-demand availability of resources, which is desirable for creating composed services in dynamic environments. In our case, it provides support to *ad hoc* integration of diverse medical devices, distributed processing, and open accessibility.

We focused on a specialized sub-set of utility computing, named "cloud computing [5][6]. One can visualize this environment as a "cloud" where sensors connected to legacy medical devices are plugged in and begin to operate, i.e. to collect and transmit data; computer resources available in this cloud are configured to receive, store, process, and distribute the information. Different than multi-layered engineered computing environments, resources can be plugged in and out the cloud and configured for the different aspects of the operation at *ad hoc* basis, sharing the common infrastructures for communication, management, and security.

To provide support to existent sensors in environment we considered aspects of wireless sensor networks (WSN) [7] [8]. Wireless networks facilitate the collection and distribution of information to and from mobile devices. The structure created by wireless sensor nodes is flexible, low cost and can leverage the combination of local sensors to collect data with remote processing power to analyze and deploy information as a utility computing. This setup allows the deployment of dynamic and collaborative applications. This technology provides the solution to interconnect heterogeneous devices over an open area and without "wired structures".

Although we acknowledge that our solution is not a WSN *per se*, we re-used concepts from this field of research such as:

- methods for resource management, including indexing, discovery and monitoring;
- methods for ubiquitous communication between mobile computing and stationary computing devices;
- methods for implementing security, including confidentiality of the transferred data, authentication, authorization, and;
- programming interfaces for mobile computing and stationary computing devices.

The integration of these technologies provides the infrastructure to implement the target solution. Some of the solutions provided by this infrastructure are: device location and indexing; scalability via "on demand" resource provisioning; mechanisms for resource management; and data communication mechanisms, and security mechanisms (although security is not strong considered in scope of current proposal).

III. RELATED WORKS

There is several related works that envision similar solutions. We analyze these works in two categories: (i) solutions for telemedicine and automated data gathering; and (ii) solutions for data gathering on wireless sensor networks.

On the first group, the work in [9] proposes a solution to monitor cardiovascular disease using personal digital assistant (PDA) and applying Grid Computing as technology enabler. Medical staff can access use application in software as a service (SaaS) basis. The resulting solution provides some requirements of our work; however, it focuses on a different solution thus not covering how vital data is acquired, i.e. requirement (1) in the previous section.

UbiMon [10] proposes a platform for patients' monitoring. It applies sensors implanted in patients' bodies to get vital data. This platform uses nodes to carry out the acquisition, processing, and storage tasks. Nonetheless, it does not provide a flexible, scalable and 'on demand' way to handle collected data, thus failing to requirement (2).

Finally, the work in [11] provides an overview of the utilization of pervasive computing to healthcare solutions. The concepts presented in that paper helped us defining the requirements and high-level architecture. Nonetheless, the paper is not focused on concrete solutions, leaving it open to other works to build on the introduced ideas.

For the second group, i.e., "solutions for data gathering on wireless sensor networks", the work in [12] introduces a monitoring system for multiple vital signs based on mobile devices and remote connectivity. It uses wearable sensor to collect vital signals. However, this work focus on individual support cases, failing to support large scale environments as we are seeking in this work, i.e. requirement (6).

In addition, the work in [13] introduces wearable biosensors (WBS) for cardiovascular monitoring. It addresses both technical and clinical issues of WBS; however, it is not oriented to distribution and integration of large scale institutions, thus failing with requirements (2), (4) and (6).

Moreover, the work in [14] proposes wireless sensor networks to patient's data gathering. As our work it allows medical specialists to monitor patients at any place via the web or mobile phones. This work utilizes microcontrollers to analyze collected data. However again, the solution is not oriented to distribution and large scale integration.

The work in [15] proposes a framework design based on cloud computing concepts, Microsoft technologies, existing middleware and image toolkits to process colorectal cancer images. Finally, the work in [16] proposes a solution based on wireless web access, where mobile devices uses processing power of cloud to parser HTML components of a web page. This work shows how cloud computing is an alternative for processing intensive solutions.

Based on the examination above, we concluded that none of the analyzed solutions satisfy our requirements completely. Therefore, we identified the opportunity to contribute with a solution that integrates concepts of wireless sensor networks and cloud computing to create a platform to support automated data gathering in telemedicine environment. We outline our proposal in the next section.

IV. PROPOSAL

Our proposal is a system to automate the process of collecting patient's vital data *via* a network of sensors connected to legacy medical devices, and; deliver this information to the medical center's "cloud" for storage, processing, and distribution.

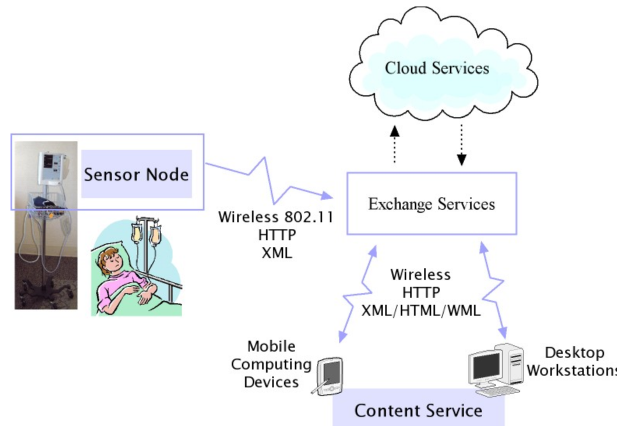

Figure 2. Proposed solution.

Figure 2 depicts the proposed architecture. At the patient's bedside, there are *sensor nodes* which are loaded with software to collects, encode, and transmit data through wireless communication channels to be stored. The *Exchange Service* acts like a broker between local and remote services. It is responsible to receive collect data from sensors and to dispatch it to appropriate storage service hosted on cloud. It also receives requests from content service to retrieve data from the *Cloud Service*, whose functionality is two folded: (1) it is responsible to provide services to store collected data; and (2) it provides a platform for development, testing and deployment of applications needed by medical staff. Mobile and stationary devices interacts with applications using *Content Service.* This service acts like a "door" where medical staff devices can access all available information.

There are several practical advantages in this implementation, such as:

- it provides always-on, real-time data collecting;
- it eliminates manual collecting work and possibility of typing errors; and
- it facilitated the deployment process, as wireless networking means no need for cabling or other physical setup.

The proposed architecture covers the several elements in current systems, such as:

- Sensors attached to legacy medical devices replace the necessity of (i) manual data gathering and (ii) data entering on medical system.

- Computer resources available in the cloud are responsible to (iii) organize, index, and make the data accessible, and; distribute the data to (iv) medical staff.

At this level of abstraction, there is no need to specify "what" elements are available in the cloud (logical design) or to care for performance and scalability (physical design). It suffices to say that the "cloud" provides the standard interfaces for application integration. In the next sub-section, we detail our proof-of-concept design.

A. *Proof-of-Concept Design*

Figure 3 depicts the proposed solution.

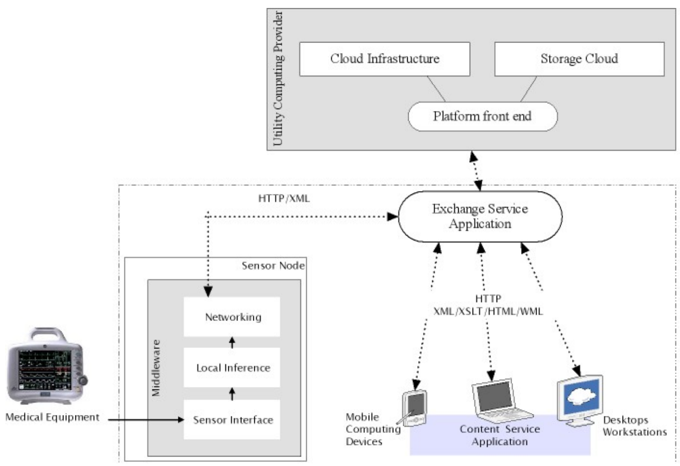

Figure 3. Proof-of-concept design

It is based on simple components deployed to commodity computing devices. In our case, we utilized commercially available wireless routers that allow the replacement of the operating software by Linux solution – we used the LinkSys WRT54 router -; and a simple application that collects the data from a serial port (attached to the medical device), transforms and load this information the exchange server. We suggest that the same functionality can be replicated in different hardware/software combinations.

The elements and interactions are described below:

- *Sensor module* contains the elements to extract, transform and load the data from the attached hardware; the software provides a standard set of control interfaces easily configurable for different medical equipments; the data is transmitted over the wireless network to "cloud services".
- *Exchange Service Application* contains a number of service functionalities to organize overall related patients' data; it acts as a broker between locally attached devices and remote services; it has two main functionalities: (i) it works as an access point;, and; (ii) it allows sensors to store data locally for pre-processing – e.g. for aggregation or simple analysis before the transmission to the main system.
- *Content Service Application* is a common interface used to show information to medical staff; it talks to the exchange service application to request pre-processed data.
- *Utility Computing Provider* is responsible to provides logical and physical infrastructure for storage, processing and content delivery services.

We are working on a proof-of-concept implementation. The test-bed is already available through an application that is capable of interface with the medical equipment; collect the data correctly, translate the data *in situ*. In addition, the modules responsible to store and process collected data are also implemented, running on virtual machines managed by Open Nebula [17]. We are also considering ANEKA as the middleware for cloud computing [18] in Microsoft Windows networks, which is abundantly available in health institutions.

We have the first results form our limited prototype implementation. They demonstrate that the solution provides good performance, support simplified delivery to health institutions, and clearly improves patient's data accessibility by medical staff. With some improvements, especially in index and store collected data, we believe that prototype can be used in controlled environment to monitor non-critical patients. Another point observed form preliminary result is the overhead in communication level caused probably by XML usage. We need to investigate this situation to improve scalability of overall system. These results are encouraging and make obvious the add-value proposition of the solution.

V. Conclusions and Future Works

In short, our solution delivers an integrated telemedicine service that automates the process from data collecting to information deliver as a computing utility. There are several practical advantages in this implementation, such as: it provides always-on, real-time data collecting; it eliminates manual collecting work and possibility of typing errors, and; it eases the deployment process, as wireless networking means no need for cabling or other physical setup.

From the software engineering perspective, the proposed design promotes re-usability through the use of a standard services implemented and deployed by using a Platform as a Service (PaaS). In addition, it leverages others health-care institutions to use services through a Software as a Service (SaaS) model without investments on hardware or software licenses.

Moreover, we suggest that this project contributes to scientific and social fields. On the *scientific field*, the project generates new knowledge and applications for utility computing, cloud computing, sensor networks and mobile computing. These areas are being extensively explored by the academic community and the developments from this project will address some of the outstanding questions. There are many lines of research involved in this development, such as: information systems, system modeling, networking, mobile service development, service management, computational security and quality of service (QoS).

In addition, there is a contribution to the *social field*, as the proposed service helps to improve the quality of medical assistance delivery, especially in needy communities. It is difficult to gather medical staff with varying expertise in a single place, and it is even more challenging to enable medical assistance to remote patients located in remote communities. In addition, expert medical staff has restricted time and cannot monitor patients or collect additional data from patients at bedside. Thus, the proposal presents an innovative solution that addresses problems of integration, such as medical staff from one institution being able to monitor patients located at another. It also helps with releasing support staff workload that can use of saved time to focus on assistance. Finally, due to its pragmatic approach the project results in a cost-effective solution to address the requirements for modernization of health-care system in developing countries.

As future works, we intend to validate the proposal in a real world setup to assess the benefits of the solution in large scale scenarios. In addition, we intent to implement several services enhancements of security and management with interaction of thirty-party infrastructure service provider.

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