

Smart Items, Fog and Cloud Computing as Enablers of Servitization in Healthcare

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Abstract: In this article we argue that smart items and cloud computing can be powerful enablers of servitization as business trend. This is exemplified by an application scenario in healthcare that was developed in the context of the OpSIT-Project in Germany. We present a three-level architecture for a smart healthcare infrastructure. The approach is based on a service-oriented architecture and extends established architectural approaches developed previously at our group. More specifically, it integrates a role model, a layered cloud computing architecture, as well as a fog-computing-informed paradigm in order to provide a viable architecture for healthcare and elderly-care applications. The integration of established paradigms is beneficial with respect to providing adequate quality of service and governance (e.g., data privacy and compliance). It has been verified by expert interviews with healthcare specialists and IT professionals. To further demonstrate the validity of this architectural model, we provide an example use-case as a template for any kind of smart sensor-based healthcare infrastructure. *Copyright © 2015 IFSA Publishing, S. L.*

Keywords: Sensors, Smart items, Cloud computing, Fog computing, Cyber-physical systems, Healthcare, Servitization.

1. Introduction

Healthcare can benefit greatly from a targeted application of the cloud computing paradigm as shown in [1].

The usage of smart items like collaborative radio frequency identification (RFID) solutions that have already shown a positive impact, such as continuous quality improvement [2]. Furthermore, patients can privately maintain it which is supportive to medical adherence. A report issued by world health

organization (WHO) states that there is a majority of patients who do not adhere with their medical prescriptions as they are supposed to which results in delay or failure in the treatment of the diseases [3]. In such scenarios smart healthcare items can support the monitoring of patient adherence and allow for better treatments by providing solutions to such challenges like smart pill boxes, which come up with features like opening at accurate time and recording of pill intake time. Furthermore, smart healthcare items like physiological parameter monitors can automatically

record the health parameters and update it to the cloud, which become available for patient and the healthcare staff who can make comparison with record history and can take corrective decisions based on that.

While the economic opportunities of cloud computing in healthcare are quite promising and often subjects of recent research [4], optimization of smart items infrastructure for healthcare processes is underrepresented in research [5]. There exist approaches that define composability for such embedded architecture [6] with a specific focus on dependability in distributed environments [7]. In this regard the approach of architectural translucency [8-9] aims to offer standardized ways of controlling such architectural properties via an architecture-wide view while using standardized measures such as replication [10-11]. Applications range from position sensing [12] to project portfolio management [13] and consider applications in the healthcare domain specifically [14-15].

The diversity of sensors applications combined with an increase of data flow (to and from the cloud) in terms of volume, velocity or variety i.e. Big Data [16], have amounted a challenge from the prospective of data computing, storage, and transmission. This challenge is appreciated more by network operators [17]. To coup with such demands CISCO [18] has led a vision to pushing some computing capacity toward the edges of the network, this concept is also known as *Fog Computing* [18]. Fog computing will provide service localization and heretical structure leading to inherent advantages and performance improvement. The integration of smart items, Fog and Cloud computing altogether will require a framework where the Fog Devices play the intermediate role at the edge of the network.

The project “Optimaler Einsatz von Smart-Items-Technologien in der Stationären Pflege”, Germany (OpSIT) builds on these existing works and is conducting literature research, workshops, and expert interviews with healthcare specialists as well as IT professionals to model reference processes for practice-oriented cloud applications in the healthcare domain. Fig. 1 shows an overview of the working mechanism of the project. In smart environment, smart sensors are responsible for monitoring different vital signs of human health, and upload and update it to the respective cloud server where the data become available and accessible for individuals who are involved in the treatment process or directly related to the patient.

This article is an extended version of a conference proceedings paper presented at SENSORCOMM 2014 [19]. It aims to introduce an architectural approach for smart items in healthcare environments that is being developed as part of the research objectives of the OpSIT project. In Section 2, we introduce the benefits of sensors in healthcare. Subsequently, we elaborate how sensors are used in cloud computing environments (Section 3). In addition, in Section 3 we introduce fog computing as

a possible computing paradigm in this context. As a consequence, in Section 4, we define eHealth in the context of cloud computing. Section 5 presents our architecture model, including an application example and how it can be modified for individual purposes. Managerial implications are presented in Section 6 for smart homecare and in Section 7 for smart stationary care. Section 8 provides a conclusion and an outlook on planned future activities.

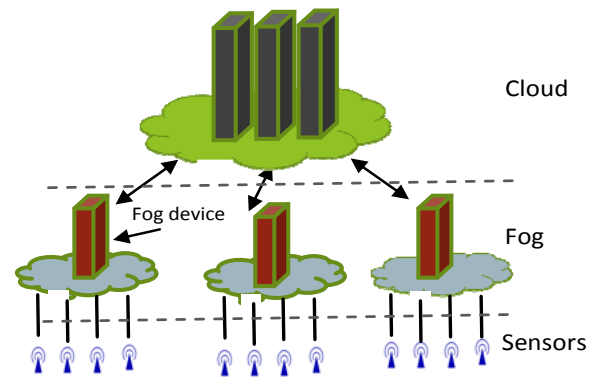


Fig. 1. Fog computing.

2. Sensors and Smart Items in Healthcare

The use of smart items has successfully been practiced in the hospitals and other healthcare institutes. Nowadays, sensors are embedded in a variety of instruments for use at home, elderly houses, clinics, and hospitals and providing a critical evaluation of physiological, physical and mental state of the patients. Most of the diagnosis will not be possible nor affordable without using even simple sensors, such as thermometer, blood glucose monitors, electrocardiography, electroencephalography etc.

These sensors are composed of transducers and capable of detecting electrical, thermal, optical, chemical, genetic and other signals with physiological origin. Signal processing algorithms can help to calculate, forecast and measure different features of human health based on input from these sensors. Measuring the vital state of a patient is also important for devices like pacemakers and insulin pumps [2].

The dimensions which are helping in advancing computer technologies in healthcare can be structured as follows:

a) Sensing: Involvement of new, effective and cheap technologies with the ability to diagnose and provide immediate results and solutions to the healthcare and public sectors on promising basis. For example, a non-contact electrocardiogram can be helpful in detecting symptoms like heart diseases [20].

b) Cost: Several years ago, most available sensors were quite expensive and often not affordable for small clinics. But now, the revolution in this industry and the availability of cheap sensors, such as RFID,

made it possible for clinics to invest in these technologies thus making personalized treatment possible.

c) Size: The form factor of sensors is quite handy and they are easy to integrate in clothes and pockets thus facilitating their portability. These devices are available in different shapes and types like blood pressure monitors, pulse reading wrist watches, blood glucose monitors, etc.

d) Data: Data collected by sensors generates increasing volumes, and require proper evaluation by experts in a timely manner. A feasible solution in this regard is to transfer it to the cloud, which is a flexible and straightforward way for handling so-called "big data" [16].

e) Cloud services: The three fundamental cloud services models which are available to any type of businesses [21] are also available to healthcare to support the industry in their information systems management [1, 22]:

- IaaS: Enables the healthcare service provider to rent the fundamental cloud resources like storing, processing, and networking.

- PaaS: Helps the healthcare service providers to deploy their own or rented applications, software, libraries and tools on cloud infrastructure.

- SaaS: Configured software running on cloud infrastructure is available where healthcare institutes can subscribe under the management of the cloud contractor.

3. Fog and Cloud Computing

A large variety of definitions for cloud computing exists, but there is no single universal upon agreed definition. Authors and experts define cloud according to their own understandings. The most commonly used definition comes from NIST (National institutes of standard and technology) *"Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service providers interaction"* e.g., networks, servers, storage, applications, and services that can be rapidly provisioned and released with minimal management efforts or service providers interaction [23].

Here, the word "cloud" refers to the two essential concepts:

- Abstraction: The specifics of the technology are not disclosed to the users and developers. Unspecified physical systems are used to run the applications, location of the data is often undisclosed, further it allows to delegate the administration of the infrastructure while maintaining ubiquitous access of the users.

- Virtualization: It is a pool of resource sharing. Centralized storage capability offers storage provisioning and can be done when required. The cost model is similar to utility model. Moreover it

offers multi tenancy, while providing dynamic resource allocation.

When considering cloud computing and fog computing in healthcare, it becomes very obvious that – similar to other industries, healthcare can also greatly benefit from the introduction of such approaches. Internally it can ease the burden of the infrastructure and number of people associated with it [4] and allows the institutes to focus on their core competencies. Synergistically cloud computing and smart items are helping patients, clinics and insurance providers to access the health records of the patient whenever needed. As a result, the development in smart healthcare technologies such as mobile healthcare, wireless sensors and cloud computing lessen the requirement for visiting medical facilities and consultation, which can be remotely fulfilled and significantly reduce the manpower requirements, while providing quality treatment to the patient by making remote treatment and consultancy possible and achievable [20]. However, the implementation of such technologies implicates different challenges such as security and privacy issues, technological restrictions, or management and governance challenges [24].

On one side, it's highly important to understand the evolving business processes occurring in healthcare environments before developing a cloud and smart items infrastructure. On the other side the technical possibilities and requirements needs to be understood to create an architectural approach for smart healthcare.

Wireless sensors can easily be deployed in any environment and with the help of cloud computing, the information can be gathered and saved from these sensors at any time. Smart devices are evolving at a rapid pace in health monitoring, while meeting the needs and demands of assisted living and healthcare providers. This system focuses on the different features for a mobile healthcare system.

The active smart systems with the help of mobile devices collect physiological signals such as body temperature, pulse rate, etc. Once the data collection is completed, it will be transmitted through WiFi or another compatible system network, which will be stored, synchronized, and shared instantaneously on a server. Health symptoms can be diagnosed continuously and immediately. The collected health data can be consolidated and accessed with a cloud service so that health professionals can analyze the information and continue patient treatment on the conclusion of the collected data.

Fog computing is an emerging trend that extends the cloud computing paradigm to the edge of the network thus providing a unifying paradigm for cloud infrastructures and smart-items infrastructures. It enables a new breed of applications and services and – in the same time - challenges some established worldviews in IT [18].

Fig. 1 shows fog computing paradigm. In fog computing, the fog devices are deployed in localities where they serve sensors in its vicinity. In the

meanwhile, the backbends of the Fog devices are connected to the cloud, and hence a fog device on a local level, perceived by the sensors as service point and from a global prospective, the Fog device is the lowest level of computing hierarchy. Therefore, in addition to computing and storage functions, the fog device (or platform) has another two functions, which are sensing and networking. Sensing function refers to either direct sensing or signaling aimed at establishing links with sensors. As for the networking function, it is not specified yet whether the Fog device is connected to a switch or a router. Moreover, the group of fog devices can be connected on peer to peer fashion using dedicated links to serve specific structural purposes.

The advantages of fog computing paradigm are many; the most important advantages from the perspective of user (or sensor) is reducing latency, location awareness, support of users (or sensors) mobility [17-18]. In addition to that, the hierarchal structure of the system can enforce security measures necessary in some applications [25]. On the other hand, the disturbed nature of the system may come at the expense of amounted cost of hardware and what is usually associated to the distributed systems of different security risks such as the man-in-the-middle-attack [26].

In the previous sections, we have introduced the potential use of sensor devices in healthcare where multiple sensors with different functions are integrated to provide assistance in healthcare processes, with such application, Fog computing paradigm can be essential part of the system to provide improved performance. Prior to accessing the cloud, the sensing devices are connected to localized fog devices that cater for their needs such as computing and storage. Fog devices can in turn provide local management for the sensors and handle mobility. Interconnectivity with enhanced Quality of Service (QoS) is also sought of this computing paradigm as latency toned down due to proximity between the Fog device and sensors. The fog devices provide computing redundancy and backup in case the link to the cloud is faulty. In addition to that access control can provide better management measures for the flow of data to and from the cloud.

4. Servitization and eHealth

Servitization is the trend of convergence between product-based industries (e.g., manufacturing) [27] and the service sector where sensors, connectivity and cloud computing serve as the main enablers [28].

Healthcare can be defined as the maintenance of physical and mental well-being, supported by available medical services while eHealth is the maintenance of physical and mental well-being while employing computer technology resulting in improved and better quality of services [29].

The combination of servitization and sensors using the cloud and fog computing paradigms can

serve as an underlying model for novel provision models in healthcare. Another important precondition is the implementation of proper governance models for these infrastructures. Due to the specifics of the processed data – detailed information about health status, vital parameters and their historical trends - healthcare applications are particularly challenging with respect to data privacy and information security.

Cloud Governance denotes the idea of applying corporate governance concepts to the world of cloud computing [22]. This can be of particular relevance for healthcare, due to the complex requirements regarding data privacy and information security [24]. Furthermore, aspects of performance evaluation [30] or ensuring the reliability of systems, e.g., through replication [10-11] can be of significant relevance from a governing point of view.

5. Architectural Model

An overview of the proposed architectural model is shown in Fig. 2. It employs a service-oriented-architecture [9] while interaction among the nodes is enabled by wired and wireless communication channels between them.

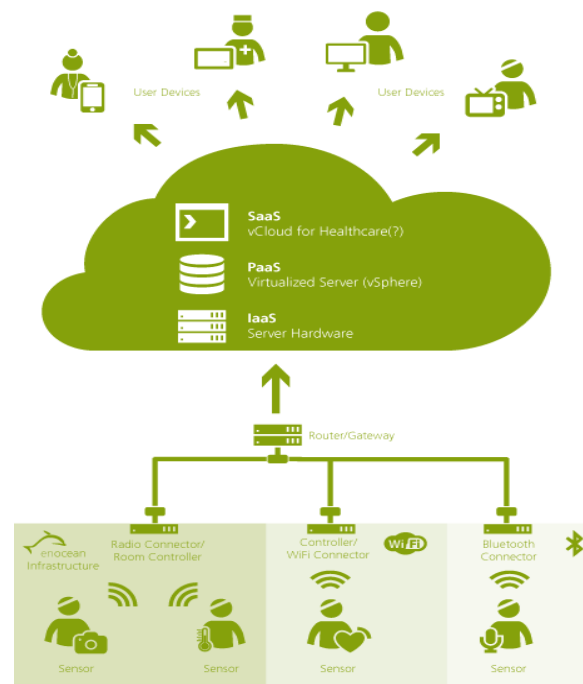


Fig. 2. Architectural Overview.

5.1. Communication Aspects

Interaction among the devices is empowered by proper communication channels between them. In the past, sensors' connectivity was often isolated within a proprietary medical device and it was nontrivial to connect with. Contrary to that, modern day sensors are capable of connecting with a large number of standard interfaces, such as wired, RS 232, USB and

Ethernet as well as wireless ones, including Bluetooth, ZigBee, UWB for short distance and WiFi, radio frequency, or ZigBee for longer range [2, 12, 31].

Some devices come with the capability of connecting directly to Smartphones and computers allowing sensors to save data in the non-volatile memory and make them available for later usage.

5.2. Process-oriented View

It is a recursive process, where the respective sensors remain active and observe even minor changes in the pattern of human body which human

cannot easily observe. As shown in Fig. 3, this process is divided in three different levels. In each level, devices are responsible to perform the assigned tasks and forwarding the data to the further level, or triggering directly an output process. The entire process accomplish in a short period of time (in nanoseconds) making it very fast while helping human to have good control over their health and take corrective measures and steps as soon as possible.

In general, Fig. 3 shows the process flow modeled with Business Process Modeling Notation (BPMN) based on the working mechanism of smart sensors architecture from the OpSIT project.

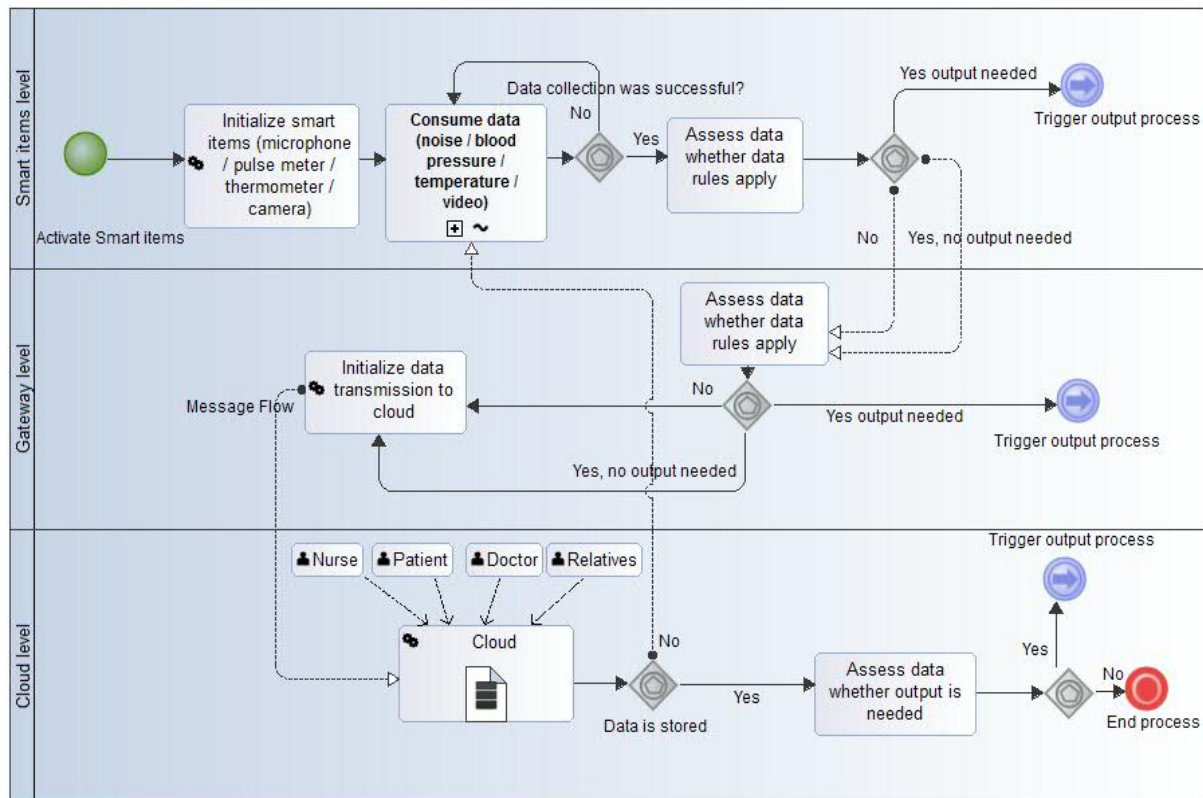


Fig. 3. The BPMN Model of the underlying application scenario.

As BPMN is an established way to analyze and design operational process flows regarding multiple kinds of resources [32] it is utilized in the presented architecture which aims to enhance current healthcare processes. Moreover, the architecture model can be seen as a process flow template for any specific use-case, importing it and revising its tasks with modeling software such as Modelio.

As a very basic example use-case, we consider a blood pressure measurement process in home care. To analyze the traditional process, it is important to keep in mind three different levels matching with the levels presented in our approach. Hence, the “smart items level” can be entitled in the traditional process as “measuring device level” where a patient uses the blood pressure gauge that directly outputs

the data on a display. The “gateway level” can be compared with a “short-term storage level” where the patient will be manually note down the value shown on the display. The “cloud level” illustrates permanent access and evaluation of the data, while its equivalent in the traditional process may be called “evaluation level”, when the doctor receives the patients’ data in order to evaluate whether medical intervention is necessary or not. This simple comparison points out the disruption within the traditional process flow. Obviously, every level in the traditional process ends with an output task and is not directly connected to the next level. Analyzing this problem is made possible by considering the proposed BPMN model even at the stage of modeling the status quo process.

5.3. Mapping Processes to Sensors Via a Service-oriented Approach

A service-oriented architecture (SOA) allows for a mapping of IT capabilities with business process requirements using the concept of services [9]. In a SOA the business processes are modelled using notations such as event-triggered process chains (EPC) [33] or BPMN [34]. This not only allows for a better visualization of process steps but also provides a formal and strict mathematical model of the process that can be automatically checked for correctness, completeness, and whether it is logically executable.

In the functional area the mapping to IT capabilities requires the further particularization of process steps to autonomous services which in turn can be provided by different elements of the underlying IT infrastructure, e.g. in the form of web services [8]. This can even happen in a dynamic way where the appropriate service is selected from multiple available alternatives based on the respective degree of coverage of the functional requirements of the business process by the corresponding web services.

Furthermore, this paradigm allows for more advanced approaches with respect to the mapping of QoS [35] by a structured formal representation of nonfunctional properties (NFPs) and their sub sequential enforcement [37] thus providing the possibility for assurance of certain QoS levels [34]. Such service-level-assurance approaches are particularly well-suited for healthcare-related scenarios [37].

6. Smart Care and Smart Home

Mobile networks give rapid access to the patient data provided by the servers of the healthcare cloud computing environment.

Smart healthcare items benefits are broad range and dual natured (benefiting healthcare providers as well as the patients). These are the physically interconnected hardware performing their tasks seamlessly through a network. For healthcare providers, it is valuable for several reasons:

At first, it reduces the number of labor due to the replacement of human based monitoring. Moreover, it reduces the chance of human error.

Secondly, wearable sensors are capable of sensing even very small changes in vital signs and recording it, which a human can't easily observe, such as pulse and blood oxygen level.

Thirdly, on-time measurement can help in saving lives while collected health data of the patient stored in the cloud can support in decision making process whenever needed as enabling the doctor in making well informed decisions. And last but not least human physicians will be able to get valuable assistance from decision support systems.

Patients can benefit in several ways. They can get quality healthcare treatment at home within their own private environment while living close to their family members while feeling more comfortable and relaxed resulting in less mental stress. Other significant factors involved are dignity and convenience which are highly supported while the patient gets treatment at home.

7. Smart Care in Hospitals

Most of the smart items available in the healthcare sector can be utilized in stationary care scenarios as well. Due to cost pressure, hospitals as well as intensive care units or other patient care facilities, are facing challenges like less financial resources. As a result, reduction of labor cost becomes the critical criterion for the implementation of smart items infrastructure in a stationary setting.

According to a study conducted by the European Commission, the large majority (81 %) of the hospitals within the EU are connected to the internet and two third (66 %) of all surveyed hospitals have an in-house wireless infrastructure, an increase of twelve percents points within two years. Moreover, most of the used IT services are managed in-house which means that qualified IT staff is generally available [38]. Consequently, the basic infrastructure for smart items implementation is already provided in the majority of hospitals. The ongoing challenge is the integration of IT professionals and medical experts to realize smart items solutions supporting healthcare processes in a proper way.

8. Conclusions

Cloud computing based smart healthcare solutions and stationary items can play a vital role in improving the quality of health services in near future by remarkably supporting care staff in fulfilling their tasks and providing for a better quality of service.

Wireless communication channels between sensors, gateways and other devices enables continuous data transfer to the cloud and making it available for doctors, care staff and patient to access the health status and maintain the records time to time. Hence, synergistic combinations among smart healthcare solutions and cloud help the doctors and other care staff in making highly informed decision and produce better output with quality of care service provided.

Understanding healthcare processes and modeling them for IT application is an inevitable task to create practice-oriented cloud solutions with the aim of providing high quality smart healthcare services. The approach presented in this paper can be used as a basic design for further developments.

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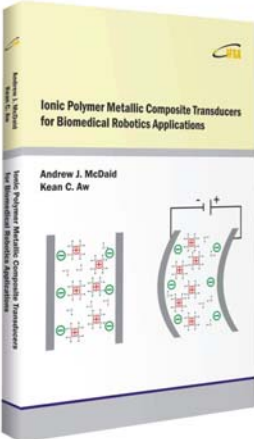
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