An Agent-Based System for Medication Adherence Monitoring and Patient Care

Research-in-Progress

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Abstract

Modern information technology along with wireless sensors and wireless body area network (WBAN) has many applications in patient care, telemedicine and health care. We have developed an intelligent agent based mobile application for the monitoring and care of patients. The service includes continuous monitoring of body sensor values, monitoring adherence to taking medicines, controlling medicine dispensing devices, wirelessly sending data to an intelligent and secure server, condition based medical treatment by sending information to the appropriate caregiver (e.g. doctor, nurse or ambulance) and creating the effect of a doctor being always available for the patient. A network of body and medication adherence monitoring sensors, facilitates intelligent mobile agents to collect the sensor values and update the patient database. Finally, we describe an architecture solution (front end and back end) with various services and relevant technologies for implementation with intelligent glucometer and medicine dispenser equipped with RFID.

Keywords

Patient Monitoring Services, Body Area Network, Service System Architecture, Medical Adherence Monitoring

Introduction

The merging of wireless technologies with nanotechnology based sensors, advanced implants and low power consuming processors has led to WBAN (wireless body area network). WBAN could be the appropriate technology (i) for continuous monitoring of various body sensor values, like heartbeat, glucose level, temperature and other indicators, (ii) wirelessly sending this data to an intelligent and secure server, (iii) facilitating condition based medical treatment, and (iv) making the medical practitioner "always available" for the in-hospital, ambulatory care or physician office patients. Mobile smart phones and iPad like devices make the continuous monitoring and visual display of various sensor values, facilitating the comparison with previous data from the patients.

Our aim is to provide care to patients by monitoring and identifying the emergency conditions early and automatically, notifying the doctors with monitored values, and predicting emerging health problems so that timely corrective action may be taken with the help of the remote hospital/doctors. Some of the benefits are:

- Continuously monitor the vital conditions of patients in the hospital and out of hospital patients

- Reduce hospital re-admissions

- Co-ordination of care at home, and in the hospital

- Check medication rate, time, dosage, adherence of taking medicines
- Monitor medicine dispensing devices
- Automatic capture of body sensor values including BP, sugar level, oxygen level using non-invasive sensors
- Automatically transmit through Internet without patient effort

Two aspects of medical intervention which may be enhanced by contemporary technology, "patient care" and "medication adherence" monitoring, are the focal points of this exploration. "Patient Care" monitoring relates to those aspects of the medical encounter and the patient-doctor relationship (Goold and Lipkin 1999) (the "keystone" of modern medical care), on which the physician relies in the efficient treatment of the patient and which are currently performed by either the patient, physician, non-physician specialists and technicians, or by isolated technology. These include physical examination (which may involve visual, palpation, percussion and auscultation examinations and measurement of height and weight), use of instruments to measure vital signs (thermometer, blood pressure monitor, stethoscope, ophthalmoscope, speculum, otoscope and an echoscope), followed by a detailed examination of various parts of the body. The World Health Organization (WHO) estimates "more than half of the medicines (prescription drugs, over-the-counter drugs and other over-the-counter products such as vitamins, minerals, herbs and dietary supplements) are prescribed, dispensed or sold inappropriately, and that half of all patients fail to take them correctly. The incorrect use may take the form of overuse, underuse, or misuse of prescription or non-prescription medicines. Common problems include the use of too many medicines including antibiotics and injections, inappropriate self-medication, incomplete communication of the remedies being consumed, and use of medications not in accordance to clinical guidelines (WHO 2014).

Establishing the Need and Existing Solutions

Patient-Care Monitoring

As mentioned above, the doctor patient relationship forms the "keystone" of modern medical care (Falan and Han 2011; Han and Falan 2012; Falan and Han 2013). Hence it is not surprising that the doctor patient relationship is one of the most researched areas in medicine. Goold and Lipkin (1999) stated that this special relationship has "received philosophical, sociological, and literary attention since Hippocrates, and is the subject of more than 8000 articles, monographs, chapters, and books in the modern medical literature." They further add that the medical encounter between practitioner and patient (including the "medical interview") may be distilled into three functions and 14 structural elements. The three functions are gathering information, developing and maintaining a therapeutic relationship, and communicating information.

When the medical encounter is rich and conforms to sound protocols, the patient is stimulated to ask questions, participate in the care, and thus do better biologically, in quality of life and have higher satisfaction (Kaplan 1997). However, being a physician has always been a busy job and time is a major factor constraining the doctor-patient relationship. It has been argued that while an optimal consultation should last upwards of twenty minutes, modern medical practice forces such encounters to less than eight minutes on average (Chen 2013).

Medical Adherence Monitoring

More than 3 billion prescriptions for over 60,000 drug products are dispensed annually in the United States. 75% of physician office visits resulted in the prescription of drugs (CDC 2010). Hospital inpatients receive about 120 million courses of drug therapy. The number of drugs ordered or provided during hospital outpatient department visits was 285 million. Half of adult Americans receive prescription drugs on a regular basis.

It is estimated that in 2012, United States consumers spent an additional amount of $53 billion dollars on consumer health-care products (OTC medicines, vitamins and dietary supplements, herbal and traditional products, etc.), a 23% increase over 2007. During the same period, the corresponding estimate for global

consumption of consumer health-care products was $198 billion dollars (32% increases over 2007). It is estimated that for every prescription drug consumed, patients consume at least one OTC drug and one herbal or traditional medicine.

Statistics on prescription drug usage indicate that 48% of the US population in 2010 (149 million) consumed at least one prescription drug in the past 30 days, 21.7%, or 67 million, consumed 3 or more prescription drugs in the past 30 days, while 10.6%, or 33 million, consumed five or more pills in a 30 day period. The corresponding use percentages by gender and age are presented in Table 1 (CDC 2012). Given the plurality of prescription and consumer health-care products consumed, and the potential harmful consequences of misuse or abuse of drugs, medical adherence monitoring would go a long way in optimizing medical care.

Category	% of population with five or more prescription drugs in past 30 days	Total Population (2010)	Number of People with five or more prescription drugs in past 30 days
Both Sexes	10.6	308745538	32727027
Male	9.1	151781326	13812101
Female	12.1	156964212	18992670
Under 18 years	0.8	74181467	593452
18-44 years	3.1	112806642	3497006
45-64 years	16.8	81489445	13690227
65 years and Over	39.7	40267984	15986390
Male			
Under 18 years	0.8	37945136	303561
18-44 years	2.1	56729723	1191324
45- 64 years	14.4	39743507	5723065
65 years and Over	39.5	17362960	6858369
Female			
Under 18 years	0.7	36236331	253654
18-44 years	4.0	56076919	2243077
45-64 years	19.1	41745938	7973474
65 years and over	39.8	22905024	9116200

Source: CDC/NCRS, National health and nutrition examination survey. Health, United States 2012

Table 1. Prescription Drug use in the past 30 days in USA (2007-2010) (CDC 2012).

Mobile Agents

The "intelligent agent" based software performs some of the above operations in a mobile environment. Mobile-agents are used in mobile commerce and e-commerce. An agent is a software module that will move to various nodes/devices for delivering and acquiring data. The main advantage of using mobile agents is reduced communication bandwidth and latency compared to the legacy client/server application. The mobile agent will move to various patients to collect data, update the patients' records in the server, compare with previous records, report abnormal conditions, seek out the doctor in the hospital floor, deliver the messages if urgent to the appropriate specialist on-duty or to the patient's physician.

WBAN systems that monitor vital signs promise ubiquitous, yet affordable health monitoring. We believe that WBAN systems will allow a dramatic shift in the way people think about and manage their health – in the same fashion the Internet has changed the way people communicate with each other and search for information. This shift toward more proactive preventative healthcare will not only improve quality of life, but will also reduce healthcare costs to patients.

Typical Existing Systems

Mendes and Silva (1999) discussed the design and architecture of a mobile multi-agent based information platform – MADIP – to support the intensive and distributed nature of wide-area (e.g., national or metropolitan) monitoring environment. According to the authors, MADIP is composed of hosts running the agent platform and hosts running supporting services such as a directory agent and a naming agent. The directory agent provides supervisory control over services that other agents provide in the environment. It serves as 'yellow pages' in which agents have been registered. Agents may query the directory agent to explore the types of services that can be acquired in the environment. The registration with the directory agent is mandatory for all agents to provide services that other agents need for collaboration in MADIP (Mendes and Silva 1999).

Doukas, Pliakas and Maglogianni (2010) have written extensively on Mobile healthcare systems. Mobile healthcare systems focus towards achieving two specific goals: the availability of e-health applications and medical information anywhere and anytime and the invisibility of computing. Mobile pervasive healthcare technologies can support a wide range of applications and services including mobile telemedicine, patient monitoring, location-based medical services, emergency response and management, personalized monitoring and pervasive access to healthcare information, providing great benefits to both patients and medical personnel (Doukas et al. 2010).

As a new approach, Varshney (2003) worked on the implementation of a mobile system that enabled electronic healthcare data storage, update and retrieval using Cloud computing. According to the author, the mobile application was developed using Google's Android operating system and provided management of patient health records with medical images.

Kahn, Yang, and Kahn (2010) have discussed Mobile health (or M-health) in their paper "Mobile health needs and opportunities in developing countries." According to them, M-health is the use of portable electronic devices for mobile voice or data communication over a cellular or other wireless network of base stations to provide health information. They also discussed the importance of M-health for the following reasons:

- The long latency period for chronic diseases often requires early, broad based community health interventions.

- Reducing chronic disease often requires rejecting behaviors associated with greater wealth (for example, tobacco, diets high in fat and sugar, and low physical activity) and thus relinquishing perceived status value.

- Treatment of chronic diseases typically uses complex interventions involving ongoing interactions with multiple components of the health system. This requires skilled health professionals and coordinated and continuous care.

- Chronic diseases often require chronic medication, introducing issues of access, cost, and quality of pharmaceuticals and adherence to treatment regimens. Self-care is often required by people with chronic diseases. Health systems must equip patients to deliver self-care (Kahn et al. 2010).

Proposed Service System Solution

Patient care and medication adherence requires several services. On the client side, wireless sensor networks can be used to collect data related to vital signs, medication dispensing etc. and the data is sent to the server side. This data is analyzed on a continual basis and coupled with other patient information, preliminary diagnoses can be made which can be reviewed by the physician and additional recommendations can be made as needed. A variety of services may be needed in order to automate this process. Some of the essential services are: data acquisition services, intelligent dashboard services,

medication monitoring services, domain knowledge interface services, preliminary diagnostic services, EMR system interface services, and physician recommendation services. In this paper we develop a design for the patient care and medication adherence service management system that has direct impact on the patient and supports their medication taking process as well as their overall wellbeing. Typically, a service system consists of two stages to support the entire process; namely, the "front stage" and the "back stage." The front stage deals with customer related touch points and facilitates the gathering of relevant data through appropriate interfaces. The back stage deals with processing of this data and making decisions based on different types of analyses. In the case of patient care monitoring system, the back stage involves proactively monitoring the patient data and providing reminders and additional suggestions the physician might recommend as the situation warrants.

Figure 1 depicts the overall architecture of the proposed solution. It shows the various services that are part of the front stage and the back stage. The following two sub sections briefly describe the front stage and the back stage of the proposed solution. In particular, the processes, the required data, and the communication between various entities are discussed below.
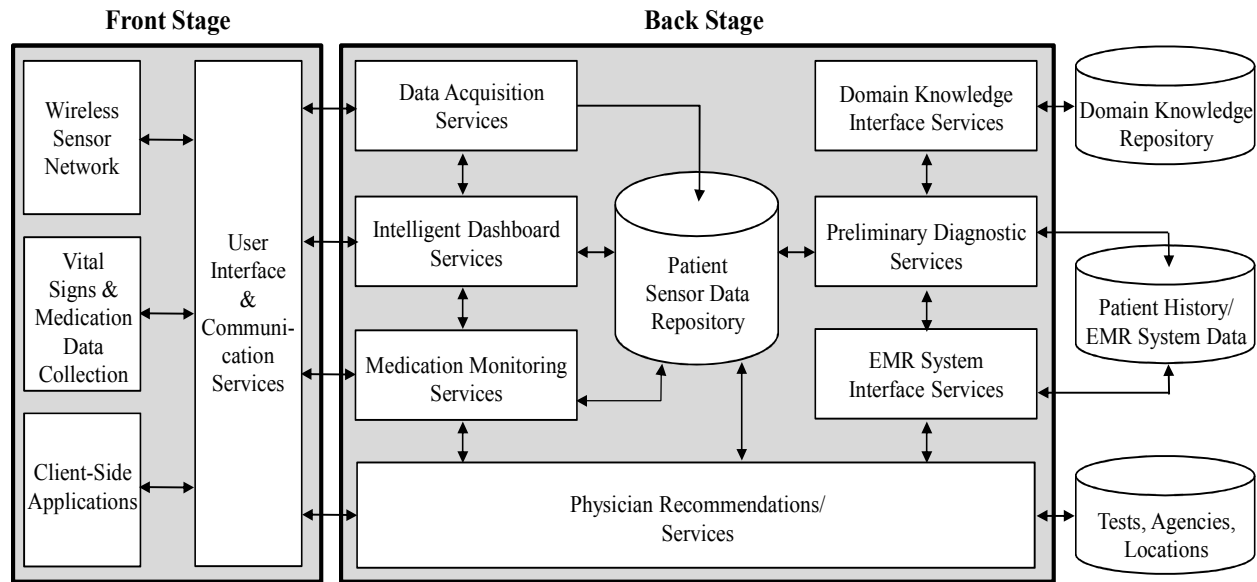

Figure 1. Service System Architecture for Patient Care and Monitoring

Front Stage

The front stage is customer facing and focuses on the necessary processes required to facilitate the patient collect the required data such as the vital signs, medication intake etc. and provide it to the server side in an automated manner. Depending upon the level of monitoring required, the front stage may include wireless sensor networks, mechanisms for gathering vital signs and medication related data and other special client-side applications. The front stage includes wireless sensor network for collecting data, the User Interface and Communication Services needed to interface to the backstage, client-side application for communication by patient with the physician and other health care providers, vital-signs and medication data collection for collecting the data at regular intervals and communicating this to the backstage.

Back Stage

The back stage deals with setting up the necessary infrastructure for information sharing as well as the different services needed to support patient care and medication adherence monitoring. The back stage consists of services related to data gathering and monitoring, and diagnostic services. It also consists of a central repository where the patient sensor data is stored. The various services that are part of the back stage are shown in Figure 1. The back stage incorporates a number of services that would improve the communication between the patient and the health care providers. It also facilitate access to the right data

as needed in order to proactively monitor and respond to abnormalities in a timely manner so that the patient can receive quality care from his or her health care provider. Some of the services in the back stage are data acquisition services, intelligent dashboard services, medication monitoring services, domain knowledge interface services, preliminary diagnostic services, EMR system interface services, and physician recommendation services. The medication monitoring services are described below in detail.

Medication Monitoring Services

This component monitors the medication intake data provided by the front stage component and ensures that appropriate medications are taken by the patient. If there is any discrepancy between the incoming data and the prescribed medication amounts, this component generates an alert and communicates it to the relevant stake holders. For example, in case of elderly patients, if they forget to take their medications at the prescribed times, this component will generate an alert and remind the patients to take their medications. At the very least, it will get the attention of appropriate people to resolve the situation in case of missing data.

Relevant Technologies for Implementation

Wireless Body area network and Mobile agent

The WBAN (Johny and Anpalagan 2014) with wireless sensors like blood glucose monitor, blood pressure monitor, medication dispenser device sensor, medication adherence monitor of patients are connected through the internet to hospital server and databases. Agent applications are also needed to display the messages or graphs on the iPhone/iPod like devices. The mobile agent will feed the collected data to an intelligent analyzer (IA). The IA compares the current sensor value against a threshold set for the patient and also with previous values to look at the trend. For example, if the blood oxygen value of the patient is decreasing at a high rate, it predicts the approaching emergency. IA also aids condition based healthcare. For example, IA will alert the physician on duty by sending information to his/her mobile device with graphs, charts and previous values. This would avert a medical crisis for the patient and help improve savings in the management of chronic diseases.

Commercially available blood glucose monitors (Yanez 2013) do not have wireless capability and interface for intelligent mobile agents or periodic interval monitoring capability. We developed such sensors/monitors and connect them to the WBAN network.

Radio Frequency ID tags (RFID) on medications with properly placed antennas can identify whether the medicines were taken and record the time at which they were taken. RFID tags also points to information for each medicine, dosage for the patient and other relevant data. The Corporate Machine (TCM), an RFID systems provider (TCM 2014) has introduced RFID-enabled products designed to help health-care providers track pharmaceuticals and monitor when drugs are administered, to make sure correct doses are administered. This system uses a nurse to perform the medicine dispensing and to dispense the medicine to the correct patient.

We have developed our own RFID based medication monitor to evaluate adherence to medication at the patient's home. This device will have wireless capability and will interface with intelligent mobile agent. Figure 2 shows a simple device for this application. By using the RFID tag and reader, the microprocessor connected to the tray will identify which tablet is taken and at what time. The weight sensor will help identify the number of tablets taken. The intelligent mobile agent will collect the data from the microprocessor. The patients will be asked to place the medicine containers in the tray (as shown in Figure 2), and to take their medications daily from each container as prescribed by their physician. The monitor is able to record the time patients remove and place the medicine bottles in the tray, and if the patients took the medicine or not that day. The monitor will be able to report the changes in each bottle's weight after it is placed back in the tray. The patients will be blinded to the fact that the monitor is able to detect changes in the weight of the medications containers; this will decrease the risk of bias and the risk of the patients changing their usual medications taking behavior during the monitoring period.

Figure 2. Special Tray for Medicine Dispensing Monitoring

Study of Medicine Adherence

Poor adherence to medicines is a common problem in patients with chronic diseases especially when they live alone (Shuz 2011; Cutler and Everett 2010; McDonald et al. 2002; Glalato 2012). Our monitoring system can be used to understand patients behaviors related to taking chronic medications. Women with gestational diabetes need to monitor their blood sugar 4 times daily, and frequently they report these results to their physicians at least once per week. If their sugar levels are also not monitored and reported accurately the risk of pregnancy complications increase significantly. Our system will help in monitoring daily blood sugars and report the sensor values to the physician. Figure 3 shows a typical screen shot of a Physicians access to Health System via mobile with secure login.

Our mobile agent based system is currently being implemented using JADE and JADE-LEAP add-on. JADE (Java Agent Development Environment) (Bellifemine et al, 2006) is a full agent middleware platform. The JADE platform is composed of agents and containers that they "live" in. The agent platform contains two default agents, Agent Management System (AMS) and Directory Facilitator (DF). The prior is responsible for the management of agents and the latter used to discover and manage the services that an agent offers through its yellow page functionality. The agent containers can be distributed over the network. A special main container coordinates and acts as the bootstrap for the JADE platform and all other containers must register with this main container. Along with JADE-LEAP, we implemented the system in Android 4.2 platform phones. Android is a software stack for mobile devices that includes an operating system, middleware and key applications. Google developed Android to be in Java based open handset suitable for use on mobile devices such as cellular phones and other wireless devices (Android 2014). It has mechanisms and allows the JADE container to be split into a front-end running on a mobile device and a backend running on the wired network. The JADE-LEAP add-on allows connection to other JADE agents. This is necessary due to the fact that Android mobile devices have limited resources. Moreover, this implementation used MYSQL 5.5 for data storage. MYSQL is the most popular Open Source SQL database management system. As shown in Figure 3, our initial system is being developed in Android emulators using JAVA as the underlying language. In order to gain entry to the mobile system, a user must provide credentials in login screen to be authenticated against a user database.

In our system, there is a main container which hosts the Health Monitor System and there are several Sensor agents stored in Split containers in different locations that are linked to the main container. JADE allows message-based asynchronous communication between these agents. The benefit of this is that there is no temporal dependency between the sender and receiver as the receiver might not be available when the sender issues the message (Bellifemine et al. 2007). In order for the agents to communicate in JADE, when the agent is first created, they are stored in containers where they "live"; it must then register with the main container. Upon registering, an agent is given a unique identifier called Agent Identifier (AID); this distinguishes one agent from another. Once an agent knows another agent's AID then it sends messages directly to the agent. As stated earlier, JADE provides directory services which allow agents to

discover each other based on services which allows agents to discover each other based on services that they provide. When the agent first registers with the main container, it publishes the services that it offers. It is this mechanism that our implementation uses in order for Sensor agents to discover Health System Monitor Agents and vice versa. As shown in Figure 3, the Mobile system collects data from different sensors. For example, the Glucometer collects data proactively and any deviation from the control limits will be automatically identified or notified. Similarly, as shown in Figure 4, Medicine Dispensing Monitor will give alerts whenever user doesn't take medicine.

The information received from the sensor is stored in the data hub. The data hub is a device that allows the sensor data to be stored for immediate or late release of the data to a medical network. Here the data hub is an Android phone; it acts as a mediator for the communication between the patient's special sensor based tray and physician's medical networks such as phones and computers. As and when the patient is consuming medicine, sensors in the tray are measuring the quantity and sending data to mobile agent. The mobile agent captures the data and uploads it to a Cloud server. Physicians whosoever in the Medical network, can access their patient's records. For example, if a physician wants to check patient 2's medicine consumption level, he can login to Medication Adherence Monitor system (Figure 3) and then choose Patient 2 on top of the screen then Patient2's weekly report will be generated as shown in Figure 4. Here, the medical network is the most crucial tier as it receives all of the information about the patient's medical status, which is then assessed by physicians. The medical network is usually operated by a hospital, clinic or a telemedicine center. The gathered data can be sent to the medical network over a local area network, wide area network or a cellular network. The design of the application provides configuration parameters where the frequency of the data collection, how the data is transmitted, and where the data is stored can be changed easily by changing the value of the appropriate parameters. Thus, data can be collected every day, once in two days, every week etc. by the mobile agent and stored in the Server Back Stage data base. The Physician can access this data and take necessary action. The monitoring services can also send a reminder to the patient if the medicine dosage is missed or in-correct and also inform the physician about this situation.

A clear and verifiable contribution of the research is a design artifact and an overall architecture of a system for patient care and monitoring, particularly, medication adherence. This research follows the design science research requirements (Hevner et al. 2004). The prototype is currently under development and one aspect of our future work will involve the evaluation of the prototype to demonstrate the efficacy of the design artifact. A controlled experiment will be conducted to investigate the usability of the system, its effectiveness in terms of the medication intake data collection, checking the data for conformity and identifying missing medication intake and informing the patient and appropriate healthcare providers.
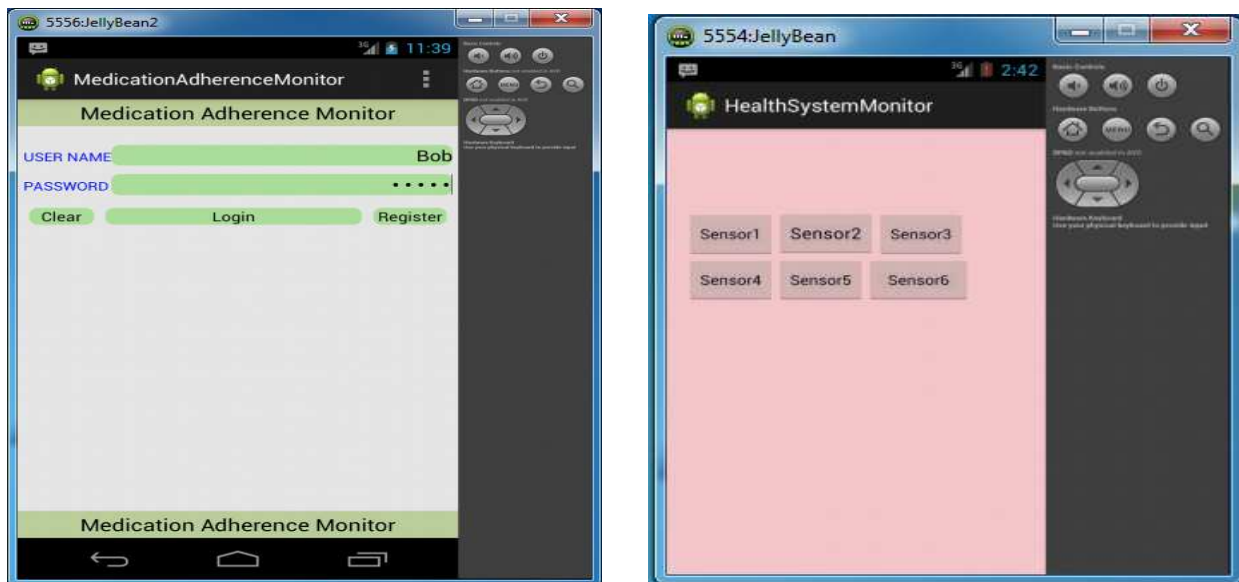

Figure 3. Typical screen shot of a Physicians access to Health System via mobile device with secure login.
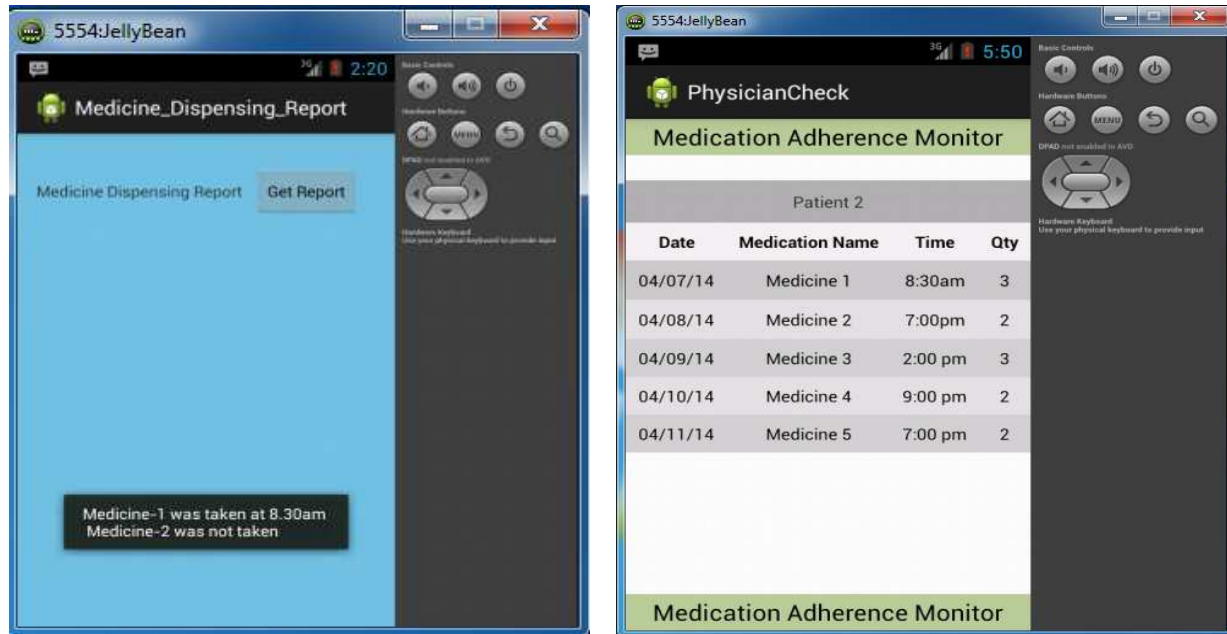
Figure 4. Typical screen shot of a Physicians access to Medicine Dispensing Monitor via mobile device

Discussion and Conclusion

We have mentioned the benefits of our system in the introduction section on objective/goal. Our proposed service architecture has front end and backstage components. The front end focuses on collection of various patient data while the back end incorporates a number of services related to patient data base, intelligent analysis, and communication with physicians. Our proposed technology implementation includes body area network, Data flow in the system, intelligent glucometer, and medicine dispensing monitor with RFID. This research will have a good impact on patients with chronic illness and expectant mothers with gestational diabetes. In addition to continuous monitoring, this approach provides predictive care at a relatively low cost. The outcome of this research will give us enough results to apply for future detailed research on developing wireless body area network with secure communication, and application in medication adherence and study on a large number of patients.

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