DETECTING MEDICATION CONSUMPTION PATTERNS IN ASSISTIVE ENVIRONMENTS

by

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To my family who made me who I am.

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ABSTRACT

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One of the issues in healthcare systems or medical information systems is the reduction of medical errors to ensure patient safety. Our approach is to develop a cyber physical system which applies different RFID tags to monitor medicine consumption and its impact in an assistive environment. This approach talks about detecting the medication intake pattern in an assistive environment and implements an application oriented experimental research which tracks the drug consumption pattern using RFID readers and tags, motion sensors, a wireless sensor mote and a weight sensor. In this approach, an energy efficient technique by using multiple sensor devices which aims in efficient information flow to achieve significant extension of the system lifetime is implemented.

In our approach, we use wireless sensor network environment to gather a person's behavior of daily pill usage in an apartment. Most people especially elderly are likely to have a sudden behavioral change due to their aging or existing health problems. Therefore, it is necessary to have an autonomous system that can monitor their activities in order to prevent emergent situation in advance. Our approach presents a sensor network environment that can recognize normal behavioral patterns of the patients who live in an apartment without assistance. We use a Web Based Caregiver Module to make the process of monitoring the medicine consumption simpler and easier.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Due to the increasing number of medication consumption in people more and more interests have been given in building an autonomous system that can monitor them to detect medical or behavioral emergent situation in advance. Usually, people do not wish to have an invasive system for monitoring their daily activities. In this approach, we use wireless sensor network environment to gather a person's behavior of everyday life in an apartment. Factors affecting the recent increase in utilization of medications include the growth of third-party insurance coverage for drugs; increased marketing efforts to promote new medications to prescribers and directly to consumers; and clinical guidelines recommending long-term treatment for chronic conditions such as high cholesterol, acid reflux disease, heart disease, diabetes, asthma and clinical depression.

It is estimated that half the people taking prescription medication fail to stick to the regimen laid out by their doctor. As a solution to that problem, we are building the SmartDrawer, a medicine cabinet system that can track the usage of medication and prompt the user to remind them to take their prescription. Benefits from such a system include increasing the quality of life for the patient, the ability to assist in the paperwork and other duties of a caregiver, and of course to verify information on drug consumption for research to study trends and effects.

1.2 Assistive Environments using WSN and RFID Technology

RFID is radio frequency identification, the way of placing a physical tag on an object, and being able to store an identity number than can be read without using a line of sight. RFID is an enabling technology that improves efficiency, prevents errors, saves costs and increases security. RFID technology removes tedious procedures and provides patients with more freedom and dignity [1]. In addition, RFID technology is now used in smart packaging that allows the creation of a tool that records when patients take medication, and how much they take. Such a smart tool can also provide prompts to help them comply with the doctors instructions. A survey lead by IDTechEx shows that people are using RFID technology in healthcare marketing and are willing to apply RFID in future. This report describes 10 year forecasts of the use of RFID applications in the healthcare and pharmaceutical sector [2].

Any assistive environment involves an area where people live and work and are helped by the embedded technology within their space. Examples of these include systems to help the elderly, such as monitoring, tracking, smart furniture, and reminder systems. One aspect of assistive environments is smart furniture and the software applications that support and analyze the collected data. An important aspect is tracking the intake of medication. Monitoring medication intake for a person who needs assistance has become an important research arena recently. Statistical report has shown that almost 55 percent of the elderly people in US fail to adhere to their daily medication routine. Among these, 26 percent of the errors are severe. As patients forget to comply with their prescription, they need constant care from doctors, nurses or other caregiver. Therefore, at home pervasive and assistive monitoring systems with minimal intrusion into a persons personal life can be very effective in this scenario.

The SmartDrawer should be able to track the location of a medicine bottle, and now that RFID tags are starting to be shipped with medication, this technology would be a good to adapt for the medicine tracking. For this project, the materials being investigated include a TRF7960 RFID Reader and a selection of tags for experimentation with the pill bottles. For software, C# and Java have been selected to create GUI tools that can also interface with both the hardware and MySQL database.

I have a working prototype that uses RFID technology to track the temporal placement of pill bottles in the smart drawer. This prototype leads to the design of new tools based on three user views. First is a patient view that monitors medicine intake and generated prompts and warnings. Another question to ask is how to use this technology in a user-friendly manner for the people who will be going to use it. The person taking the medication, the caregiver taking the medication, and the person maintaining the system will all have different user views on how the tool should function.

Sensor motes nowadays have multi-functions such as data processing, seamless data transmission, data storage, as well as sensing the physical world. When these sensors connect their networks so that they communicate with each other or relay sensed data to a base station, we call them Wireless Sensor Networks (WSNs). WSNs are generally used in areas where people cannot easily reach or where a long term monitoring task is required. Currently, traditional monitoring and reminder systems for patients drug taking deploy multiple sensors in order to achieve improved accuracy in their systems. The Smart Drawer is an application that helps patients in maintaining their medication intake as consistent as it is prescribed by a healthcare professional to them. Besides reminding a patient to take his or her pills on time, the system also logs all the activities of the patient for further analysis in case he or she fails to obey the prescription. [1] In our recent development, the Smart Drawer system has integrated additional sensors to detect the open or close state of the drawer. Moreover, the system has incorporated a precision balance to detect how many pills a patient has actually taken out of the bottle after removing it from the drawer. Therefore, efficient data integration techniques are needed in order to combine information from all these sensors.

Data Fusion is a technique which integrates information from multiple sources in order to achieve better accuracy and higher precision when identifying patterns. In the context of a pervasive environment, the application of multi sensor data fusion will improve the inferring capability of the system more than it could using single sensor alone. Perhaps, the most appropriate example for multi-sensor data fusion would be the one that is naturally performed by the human animal. A human uses the combination of touch, smell, taste, vision and hearing capability so that they can access their surrounding environment better in order to improve their chances of survival.

One of the issues of wireless sensor networks is to save energy in the system. If SunSPOTs send all the values as soon as they measure, we have advantages and disadvantages. Advantage includes that we can use all the raw data from SunSPOT, which may be useful to analyze the situation at the time the data were gathered. On the other hand, disadvantage includes that i) frequent transmission of data consumes energy, which runs out of battery soon, and ii) data storage would be occupied by massive raw data, which is not good for system performance. Therefore, we choose event-driven query method, in which SunSPOTs transmit their data when an event happens. SunSPOTs measure all the sensing functions, such as light and accelerometers, at the frequency of 66 Hz. In order not to use raw data as source of events, we have an event-driven module that has predetermined condition for event triggering. An event-driven module reports data to the base station whenever the current sensed value is over threshold value. Within the event-driven module, we have data filtering in light intensity sensing function so that the SunSPOT cannot report the unexpected value, which has abnormally higher value than the average of previous ten measurement.

Most research work done so far focused on searching frequent patterns from daily behavior of a person The work usually use association rule, which is one of the data mining techniques. In order to look forward having real time behavioral pattern recognition system, we focus on searching abnormal behavioral pattern from everyday behavioral patterns. Within the environment of our miniature one-bedroom apartment, we define events that are represented as on/o status of sensor devices, sunSPOTs. We then model the episodes that are series of events. We predetermine a person's exemplary behavioral patterns by especially considering moving from one place to the other or everyday common behavior such as going to bed, watching a TV, taking a bath, preparing breakfast, etc. One episode can have its variation depending on the length of intervals between events. Based on exemplary episodes, once a random behavior detected, we run a search algorithm, longest common subsequences (LCS), to determine the episode is normal or abnormal.

In this approach, we present a web based application of data fusion technique into a multi-sensor environment like Smart Drawer. Our system records the removal of each individual medicine bottle from the drawer as well as the time when the medicine is actually taken. We now define a way we can study the pattern of the medicine intake. By knowing the pattern of medicine intake we can track the most common problems in patients and can help us treat them better according to their medical history. We try to track prior and subsequent activities of a person before they remove a pill from the drawer in order to derive useful information about the persons behavior. A person may open or close the drawer several times but forgets to take the medicine from it. On the other hand, the person may remove the medicine out from the drawer but put back it again without consuming a pill. Therefore, our system identifies useful patterns from a persons activities over the time.

CHAPTER 2

RELATED WORK AND BACKGROUND

2.1 Related Work

Sensor motes nowadays have multi-functions such as data processing, data transmission seamlessly, data storage, as well as sensing physical world. If these sensors build their networks so that they can communicate each other or relay sensed data to a base station, we call them wireless sensor networks. Wireless sensor networks are generally used in areas where people cannot reach easily or where a long term monitoring task is required. Examples of traditional wireless sensor networks applications include civil structural monitoring [3], habitat monitoring [4], and environmental monitoring such as wildfires [5]. In this paper, we adopt this technique to detect human behavior in the assisted living environment. Most research work done so far focused on searching frequent patterns from daily behavior of a person [6, 7, 8]. The work usually uses an association rule, which is one of the data mining techniques. But in the assisted living environment system, the triggered action after the abnormal behavior detection is also important in that it can deal with an emergent situation properly. In this paper, we handle a framework for human behavioral detection by using wireless sensor networks so that it can reach caregivers by additional communication module. Sensors will send data to a base station whenever their current values satisfy a predetermined condition, which is the response of event driven query.

There is a growing body of research on Web usage. Much of this can be found in the Library and Information Science literature (e.g, [9],[7]). However, within this field as well as within Human Computer Interaction, research mainly falls into two camps.

On the one hand there are studies that rely primarily on questionnaire, rating scale or interview data. Many of these are large scale studies which ask users to make general statements about how often they do certain kinds of Web activities, how they feel about different aspects of the Web and so on (e.g, [10]). These aggregated statistics are then used to draw conclusions about social, cultural and demographic trends.

Within the environment of our miniature one-bedroom apartment, we define events that are determined by the status of sensor devices, sunSPOTs [11]. We then model the episodes that are series of events. We create a dictionary to hold person's behavioral patterns based on all the possible combination of sensors. We pre-determine a person's regular behavioral patterns by especially considering moving from one place to the other or everyday common behavior such as going to bed, sitting on a chair or sofa, opening or closing refrigerator, taking a shower, etc. Later, a person's current behavior is looked up in a dictionary whether it is similar to any one in dictionary or it should be regarded as abnormal behavior. We run a search algorithm, longest common subsequences (LCS) [12], to determine the episode is normal or abnormal. The experiments are done in our miniature apartment equipped with tens of sunspot nodes. The result shows that our framework for human behavioral detection by wireless sensor networks is suitable to be used as non-invasive monitoring system.

Radio Frequency Identification (RFID) is an emerging technology, being used not only at the airports for security but also in monitoring healthcare related issues. RFID technology has been around since World War II, but today this technology is being used to embed radio identification into the labels on packages, everything from radio tags on herd animals to blister packs containing pills [13]. As the RFID technology improves, there are cases of its use in hospitals, in tracking the progress of medication in the supply-chain, and of individual pharmaceutical containers having radio tags. Also, sensors can be added to furniture and other objects in the environment to find out information about human activity as well as providing services. Finally, various systems exist that act as reminder systems for living quarters, handling products, and taking medicine. RFID in healthcare is currently being used at hospitals for verifying the identity of patients. RFID technology is currently being used in hospitals for everything from tracking patients and infants, to making sure that the correct medication reaches the correct patient [14]. In order to streamline their auditing systems and for cutting down on costs, as well as being able to track the patient, hospitals are turning to RFID technology Using the RFID tags, the staff can verify the medication is received by the correct patient. The new tracking system also increases the accuracy of their billing over the older pen and paper system [15]. At hospitals, so many pills are issued per year that using RFID tags is expensive, but for critical items like IV bags, the RFID is extremely useful [16]. But RFID tags are now started being added to the medicine bottles in the supply chain by the pharmaceutical companies themselves [17]. Pharmaceutical companies have to take care, because they have to protect the safety of their products and their contracts by keeping track of their inventory. Companies like IBM have been deploying RFID tags with medication to prevent counterfeiting of medication in the drug supply [18], In order to block counterfeiting, major distributors of drugs are already putting RFID tags onto their bulk packaging [19, 20]. The supply-chain for medications is already being tracked using RFID on the large scale. As the technology has been refined over the last decade, RFID tags start entering more and more into the supply chains of goods and services, especially anything manufactured including medication. In some cases, medication is already being fitted with RFID tags to improve security and safety. Medications such as the painkiller OxyContin, have started shipping with RFID tags embedded in their labels[21]. While these RFID tags are meant to prevent counterfeiting, they could also be used for other tracking purposes. With RFID technology improving, one goal is to be able to read multiple targets from within a single shipping container.

Other medical items are also being tagged with RFID to track dosages, such as syringes used in radiology treatment that have been fitted with RFID tags to ensure the right dosages reach the right patients [22]. Another aspect of the SmartDrawer project is the fact that the furniture itself will need to be fitted with a sensor. Several other projects already exist that detect human activity about and around a sensor, or embed technology into everyday items to enhance the wireless environment. Various types of sensors can be embedded into furniture in order to track either inventory or even human activity. One such system, the CapShelf, involves the use of monitoring the capacitance within a storage area to detect the presence of a human hand [23]. Other places, technology can be added to features within a living space in order to provide information or even be a relay for other technologies. Mirrors, signs, and lamps can all be fitted with components to relay wireless internet connections such as the SmartFurniture project [24]. In other cases, pieces of furniture are directly connected with sensors to detect events. In the case of the SmartRoom project, a bureau was fitted with switch sensors to detect the opening and closing of a drawer. Given the position of the drawer, and a model of the human form, an estimate was made of the human subjects position and posture from the various events [25]. In such cases as these, technology has been embedded into furniture and objects to detect events, provide services, and detect the interaction between a human and the furniture.

A reminder system is a way of prompting a user that they need to perform a certain task. This could be a cook in a kitchen, a manager at a warehouse, or a caregiver in an assistive environment. The Wisely Aware RFID Dosage (WARD) system is an integrated method of combining RFID information to ensure patient safety. RFID information from the patient is combined with the database of the medication to guarantee that medicine that could harm the patient due to allergy or other conditions is not dispensed. The goal is to remove any confusion of what medication a patient should receive using RFID tags to track their medical records [26]. Another system that uses prompting to remind a patient to do their needed exercise and take their medication is the AutoMinder system. The AutoMinder is a robotic assistant program that uses artificial intelligence to connect the needs of the patient with their schedule, and to prompt them with reminders of exercise, appointments, and medication by interfacing the patients plan with various devices such as telephones and PDAs [27]. Another RFID system is the NAMA-RFID reminder system for keeping track of products. As inventory decreases due to the supply being tracked by RFID, then the user is prompted to remember to re-stock [28]. Such a similar event could be used to remind a user it is time to refill a prescription. Also, there are some other RFID applications are used in assistive environment. Such as Assistive Kitchen [29] from Technische Univ. in Germany, uses RFID tags on the objects in a kitchen, and later uses some mobile robot to sense the environment with RFID reader and also helps disabled people use such an assistive kitchen more efficiently. One of the more recent systems is called GlowCap, which is from Vitality, a startup company based in Cambridge, Massachusetts. Their reminder system targets the health and business problems with an Internet-connected bottlecap. The GlowCap uses a wireless connection to report how the subjects take the medicine, as well as plays a tune to remind the subject when it is time to take their medicine. This reminder system also keeps track of the doses day by day using a commercial database. But the disadvantage for GlowCap is that they use a battery powered wireless connection, and GlowCap will be disabled when the battery charge is too low. If such a system were to use a passive RFID tagging system instead, the energy consumption would not be an issue.

2.2 The Smart Drawer Project

As noted, many patients often fail to follow the medication taking procedure exactly as prescribed. Especially for older people that suffer memory loss, remembering to take the right combination of drugs at the right time intervals can be a challenging task. Failing to comply with the doctor prescriptions can lead to deterioration of the patient's health condition and in some cases severe implications may occur. That gives us the motivation to search for ways to assist the patients to avoid such situations by creating a system that will assist them maintain consistent medication taking patterns which will follow predefined rules with regard to what medicines should be taken and at what time points. In cases where the predefined directions are not followed the system should be able to record those deviations for later examination. This will not only help patients maintain their health stability but will also give feedback to the caregivers as to if possible health implications of patients are related to the actual medication that was prescribed to them or to failure of the patient to follow their directions. The latest technological advances and market trends enable us to propose a viable solution to the problem. We suggest the use of the effective and affordable RFID technology for the monitoring of the patient drug taking patterns. The idea is to create a smart drawer which will be able to keep an inventory of the medicine that is stored inside it and monitor and record the drug taking activities of the patient. By combining the appropriate hardware and software we can create an easy to use system which not only monitor the patient's drug taking activities but will alert him in cases where his behavior does not follow the predefined directions. Compared to other active Wireless Sensor Networks (WSNs), RFID tags do not need a battery, recharging, and so have no battery power loss problems. RFID tags are tiny in volume, and can be embedded into different objects.

Such a system can either be used as an autonomous tool or be incorporated in a larger Assistive Environment where medication patterns are correlated with other patient conditions monitored. For example, the body temperature or blood pressure can be monitored and correlated with the time that a specific medication was taken in order to examine the effect of the medication to the patient's health condition. The basic concepts behind the SmartDrawer are the ability to scan for identification, and to know when the drawer is open and shut, and to record those events with a time stamp into a database.

In the general case we anticipate that the system will have three main users: the patient, the caregiver and the maintainer. Each of them will be able to access a different view of the system with different functionalities and different user interfaces.

The main functionalities of the patient view will include an alert system to alert the patient when he is deviating from the prescribed directions, an interface from where the patient can access historical data regarding medicine he has already taken and interface to obtain directions and instructions regarding what drugs are to be taken next and in what way. Of course the interfaces to be used by the patient must be very intuitive and user friendly. A touch screen will probably be a good option for that case.

The caregiver view will offer functionalities for retrieving historical data about the patient's drug taking patterns as well as options to enter new or modify existing prescriptions. Ideally the System should give remote access to the caregivers so that they can update their directions without having to physically visit the patient's location.

The maintainer will be the administrator of the system and will have options for adding or removing functionalities, accessing the stored data and converting them in different formats for use by other applications. The maintainer can be either the caregivers themselves or a computer system expert in cases of more advanced operations.

2.3 Data Fusion in Web Based tracking tool

The top level of a Data Fusion model [30] contains a Human computer interface module, a module containing all sensors, a source pre-processing module named Data Cleaning and Filtering module [31]. The bottom layer contains a Database Management System that consists of two components named as Support Database module and Fusion Database module. The Sensor Module contains all the disparate sources of information connected to the Data Fusion system. For the purpose of Data Fusion, we are considering only the information from the RFID reader, SunSPOT device and a precision balance as part of the Smart Drawer project. Here, the RFID reader generates a continuous stream of tuples identifying the presence of a medicine bottle inside the drawer. The SunSPOT device generates data to represent the drawer opening/closing status at a particular moment. Finally, the precision balance generates data representing the total of the weights of medicine bottles in the drawer at a specific time.

The HCI (Human-Computer Interface) module contains high-level user interfaces for inserting prescriptions, monitoring drug intake and gathering statistics. In order to identify a patients activities such as drug-intake to be normal or abnormal, the system must know the normal medication pattern for the patient, which may be prescribed by an authorized person. We believe it is the responsibility of the caregivers, doctors or the families that they will provide accurate prescription information to the system. But, our system will at least provide a flexible interface to its users for adding these prescription data with a minimum of effort. HCI is also the mechanism through which the system can generate alerts or remind caregivers and patients in case a patient deviates from their prescribed medication pattern. Moreover, the system summarizes all the activities of a patient at different time via HCI so that doctors and caregivers can analyze that information to identify useful patterns.

The Data Cleaning and Filtering module is a very important component in data fusion. Basically, sensors generate a large volume of data; most of which might be irrelevant to the current context. Moreover, data generated from sensors contain both redundancy and error. Therefore, appropriate filtering techniques must be adopted in order to remove this redundant information. Reliable data cleaning techniques should also be applied to the data in order to correct any errors.

The next part of the Data Fusion model is the Data Aggregation module, which combines all the preprocessed data from different sources according to the domain specific logic. In the context of Smart Drawer application, we will aggregate the data in the form of (drawer open time, drawer close time, RFID event start time, RFID event end time, RFID tag, weight changes). Next, the Database Management System is a very important component for our Data Fusion model. It consists of a Support Database along with a Fusion Database. The Support Database contains information about doctors prescription for a patient, patients current medical condition as well as his or her personal information. It also contains medicine records, total number of bottles per medicine, total weight per bottle along with its associated RFID tag and expiry date as well. Our Fusion Database will contain all the aggregated information generated from the continuous interaction of patients with the sensors. The Database Management System will provide support functions to access the fused data as well as making queries of the data.

2.4 Background

Radio Frequency Identification (RFID) is an emerging technology, being used in monitoring including healthcare. In this approach we apply different types of RFID tags to monitor drug taking and its impact in an assistive environment. Compared to other active Wireless Sensor Networks (WSNs), RFID tags do not need a battery, recharging, and so have no battery power loss problems. RFID tags are tiny in volume, and can be embedded into different objects. This work is an extension of a paper that talks about an RFID-based application in an assistive environment called Smart Drawer, which tracks medicine taking for the elderly. We investigate the hardware involved to build such an application and we develop the software infrastructure to create a functional system to assist patients and caregivers with the medication procedures and also collect data for future use.

The power of the Web and its enabling infrastructure, the Internet, continues to change the way we work and live. As its use spreads inexorably across the globe, one cannot help but feel that its true potential is still yet to be realized. At the same time, indications are that experienced users interest in the Web for anything more than a small set of mundane purposes is waning [15]. Perhaps this is unsurprising given the significant lack of innovation in this area. What most users think of as the Web continues to be very much shaped and limited by the interface through which most of us use itnamely, through Web browsers. These have changed very little over the past eight years. Unleashing the power of this technology may therefore require changing the way we interact with the Web. Especially in the research and design community, signs are that new Web-based devices, services, tools and enriched infrastructures may be on the horizon. We are beginning to see new kinds of applications and devices connected to the Web, new methods of searching and extending Web information and new ways of accessing Web information, for example through physical objects and locations. At the same time, technological advances mean more devices are now internet-enabled, mobile phones being an obvious example. In our own laboratory, we too have been studying ways in which the power of the Web might be exploited in innovative ways. Central to this endeavor is taking a user driven approach rather than a technology-driven one. This means we aim to understand what new kinds of technological offerings users would value rather than simply asking what the technology could provide.

My approach is to begin to answer this question by looking at how the Web currently finds its place within peoples lives. In other words, this is to ask: What are the different kinds of activities that people use the Web for, and what are their characteristics? What sorts of activities does the Web naturally support well and where does it fall down? What is the context of use of the Web and what other kinds of tools and activities are carried out in conjunction with it? By exploring the answers to these questions, we hope to show that we can begin to look at new uses and new incarnations of Web-based devices and applications. At the very least, we hope to show that such an understanding of the range and nature of what people currently do with the Web provides a reality check for our notions and prejudices of what the Web is used for, and for judging whether the technologies we are currently developing make sense in light of this understanding.

The effects of drug dependence on social systems has helped shape the generally held view that drug dependence is primarily a social problem, not a health problem. In turn, medical approaches to prevention and treatment are lacking. We examined evidence that drug (including alcohol) dependence is a chronic medical illness. A literature review compared the diagnoses, heritability, etiology (genetic and environmental factors), path physiology, and response to treatments (adherence and relapse) of drug dependence vs. type 2 diabetes mellitus, hypertension, and asthma. Genetic heritability, personal choice, and environmental factors are comparably involved in the etiology and course of all of these disorders. Drug dependence produces significant and lasting changes in brain chemistry and function. Effective medications are available for treating nicotine, alcohol, and opiate dependence but not stimulant or marijuana dependence. Medication adherence and relapse rates are similar across these illnesses. Drug dependence generally has been treated as if it were an acute illness. Review results suggest that long-term care strategies of medication management and continued monitoring produce lasting benefits. Drug dependence should be insured, treated, and evaluated like other chronic illnesses. It is unfortunate that the majority of drug-dependent persons are merely treated with detoxification and little or no long-term follow-up care. This is not logical, but it is a fact of the current health-care system in the USA. Detoxification is actually performed by the patient's own metabolic processes. Thus, it can be accomplished voluntarily (although not necessarily safely) through sheer will power by ceasing drug use or accomplished involuntarily when an addict is incarcerated or placed in a treatment program where access to drugs is denied. The withdrawal syndrome from opiate addiction can be very uncomfortable, but it is not life-threatening unless the patient has pre-existing medical problems. The symptoms consist of sweating, muscle aches, cramps, nausea, diarrhoea, vomiting, lachrymation, rhinorrhoea, tremors, tachycardia and other signs of autonomic nervous system hyperactivity. The discomfort has been compared to a bad case of the flu. Several sorts of treatment of these symptoms are available. Withdrawal from sedatives, alcohol and stimulants will be considered below. Replacing the drug of dependence or using another drug in the same pharmacological category in gradually decreasing doses is a direct way to block withdrawal symptoms. As in all forms of detoxification, transfer from a short-acting drug such as heroin to a longer acting drug such as methadone provides a smooth transition to the drug-free state. By appropriate dosing, detoxification can be achieved with minimal discomfort. A recent innovation for opiate dependence involves using the partial agonist buprenorphine as a transition to the drug-free state. The patient can be switched from dependence on heroin or methadone to buprenorphine, which is then stopped with few or no withdrawal symptoms.

CHAPTER 3

APPROACH

In this chapter we explain our approach by describing the system architecture, the work flow of the web tool, the data fusion model, a state diagram followed by a sequence diagram and , the layout of the experimental setup.

3.1 Web Tool

3.1.1 Architecture of the Web Tool

This project implements a web based tool for detecting pill usage using an RFID reader system. Here we establish the connection by imposing some constraints on the hardware. This system is required to have a caregiver view, a maintenance view and a patient view. The caregiver view enables to view the details about the history of the patient's drug taking pattern. The maintainer's view will mainly involve the detection and analyzing the working of different sensor nodes at some defined time. The patient's view includes an alert system that will include a prompt to the patient when they have forgotten to take their medication.

In an assistive living environment, a patient may be required to take different types of pills each day. Our approach involves detecting the sequence of the medicine intake by creating a pattern which may help the patients and the caregiver in reminding them to take the medicine on time. It also becomes necessary to take the right number of pills which will be notified by a precision balance which is integrated with the Smart Drawer system.

The caregiver/doctor is required to authenticate themselves as being legitimate users of this web based Smart Drawer tool. On successful logon into the system, they can get all the details of their patients and check if they have taken the right medication at the right time. They can also add a new patient and their details at this point. The medication details are compared with the backend database. The caregiver or the doctor can verify if the patient had taken the right medication.

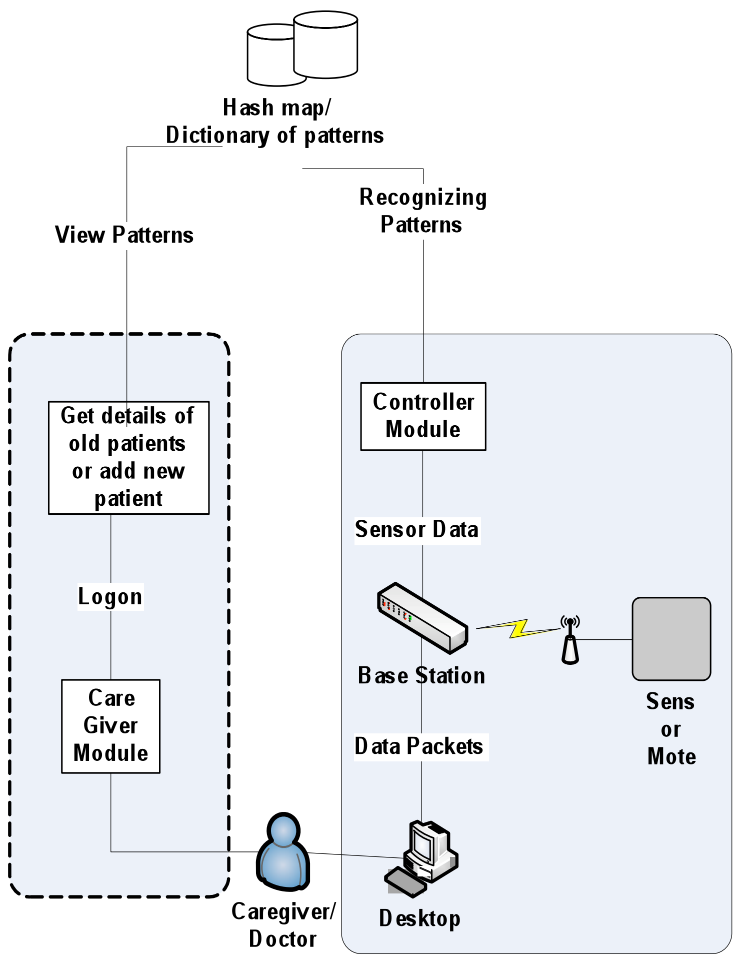

Figure 3.1. Web Tool Architecture.

The web tool architecture shown in Figure 3.1 can visually be divided into two parts for clarity and better understanding. The left portion of the figure deals with crucial web module design, the right portion is mainly the maintenance view. The Controller Module acquires the heterogeneous data from all the sensors operating in the Wireless Sensor Network Environment and determines the Pattern using an algorithm. The Controller Module also compares the pattern with the backend Database to recognize if the pattern making an event is a normal or an abnormal. The database contains a dictionary of behaviors which are defined to be normal events. By dictionary of behavior, we mean a data set which is composed of valid events. All valid events result in a successful activity of medicine consumption pattern.

3.1.2 Work Flow of the Web Tool

Figure 3.2 explains the work flow of the web tool. The care giver/user of this system for example the doctor or a nurse is expected to login in to the system as health related issues is an issue of personnel concern. The caregiver or the user can register himself/herself by providing valid information. On successful registration, the caregiver or the user can login in to the system using the unique username and password combination. On successful login, an HTTP request is sent to the server to update the backend system, requesting for all the patients data from the server who are being involved with the particular caregiver or the user. The caregiver can view all the clients he/she is responsible for and even track their behavior and pattern of their medication consumption. The caregiver can determine the most recent medication consumption of the patient and validate this data from the update server against the prescription database server for monitoring. The results from the server are sent as a response back to the care giver for future monitoring.

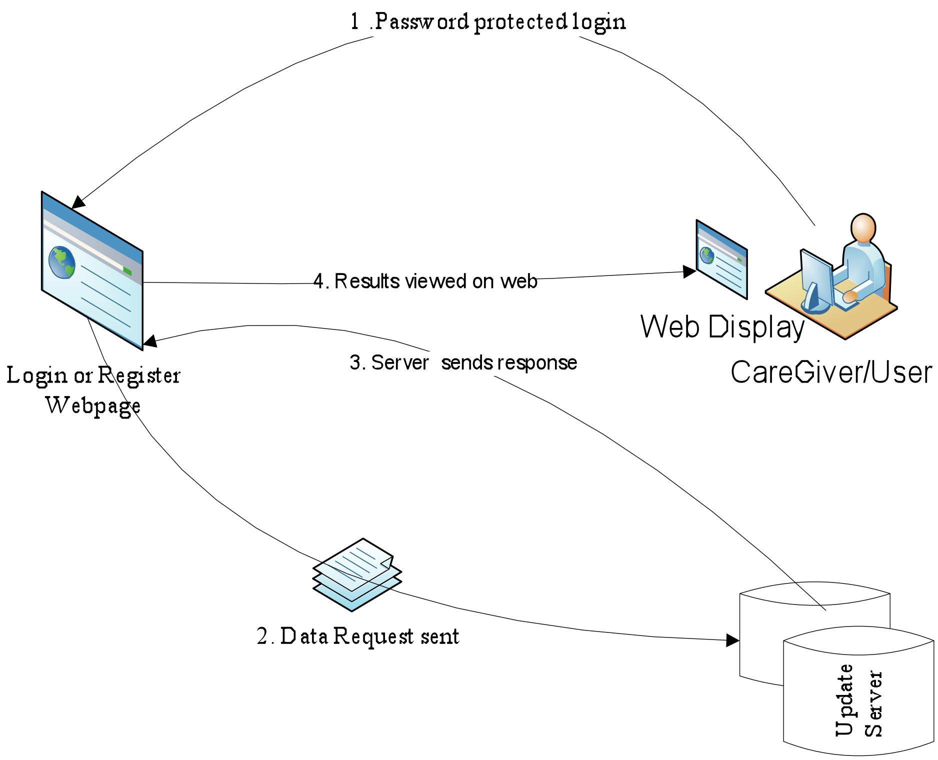

Figure 3.2. Web workflow.

3.2 Energy Efficiency

In order to combine the various sensors and events in the medicine intake system, a design has to be considered for the fusing of the data.

3.2.1 State Diagram

The setup for the drawer describes the types of sensors put into the environment. These sensors by themselves, however, must work together in order to create a sequence to find meaning and to conserve energy.

Figure 3.3 shows a system consisting of 5 states that correspond to the different types of sensors involved in the testbed. S1 represents the start state, representing a system where no motion is detected within the room with the medicine drawer.

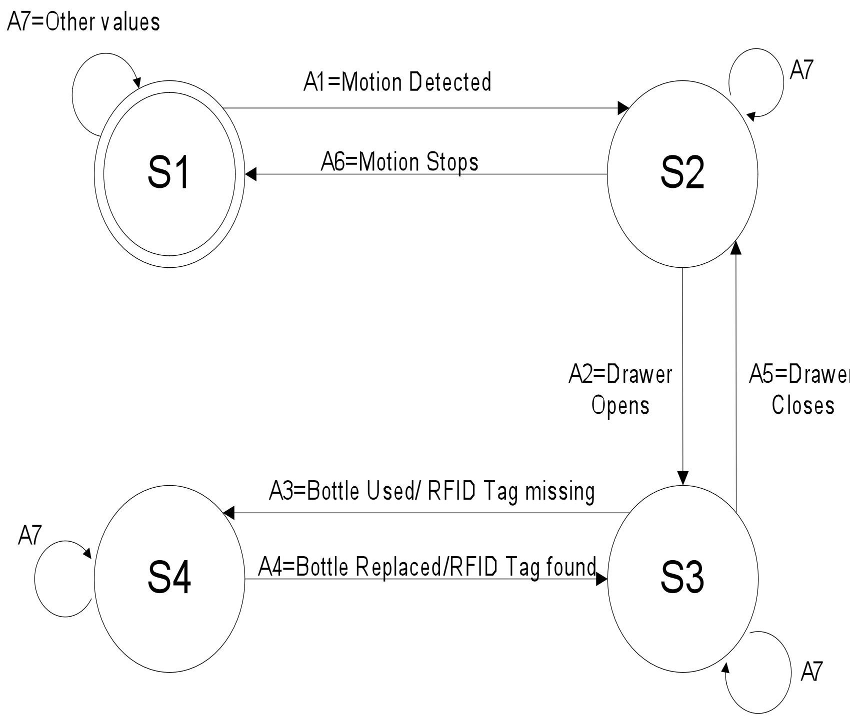

Figure 3.3. State Machine.

When the motion detector is triggered by the presence of a user, the machine will transition to state S2. State S2 remains unchanged until it is triggered by a drawer event where it changes its state to S3. A set of values are used primarily to detect the state of the system and hence we have five different states which constitute the overall performance. State S4 indicates that the medication bottle has been removed from the drawer, and its absence should be noted by the system. When the medicine is replaced, then the balance should record the new weight.

In Figure 3.3, we use A1 through A9 to symbolize the action events. A9 are those set of action events which could be determined to be external noise, or don't care cases for the given state. A1 through A8 describe the main transitions between the states themselves.

3.2.2 Sequence Diagram

We can describe the whole process using a sequence diagram as shown in Figure 3.4. When a patient enters the room and opens a drawer, the sunspot attached to the drawer triggers an event and the RFID reader on the weight sensor, starts scanning for the available RFID tags in the drawer. The RFID tags are attached to the bottle of each medication to identify the unique bottle bearing the unique RFID tag. When a reader misses a tag, this can be a case where the patient is using the bottle in the drawer for a while. The system will create a corresponding RFID event from the raw RFID data. The event of bottle/medication usage is reported and this event enables the weight sensor to record the change in weight

Next, our system will measure the weight difference between the time intervals of a RFID event. If the weight changes within this time, system records the weight difference and logs the time, which is eventually displayed to the caregivers through the monitoring medicine intake interface. The system also keeps track of all the activities such as individual drawer event, RFID event in order to identify some useful information about the patients behavior. The system will summarize the entire drug taking activities for a patient whether it is close to normal or deviating from normal and will convey this information to the caregivers or doctors through the generating statistics interface.

3.2.3 Drawer Events

Several key sensors are part of the overall system being accessed by the web tool. One of the sensors mounted on the medicine drawer is a SunSPOT wireless sensor mote mounted with an accelerometer with three axes. Empirical tests were done with a drawer, on which a SunSPOT sensor mote was mounted on the front. The drawer was then opened and closed while readings of the raw data were recorded

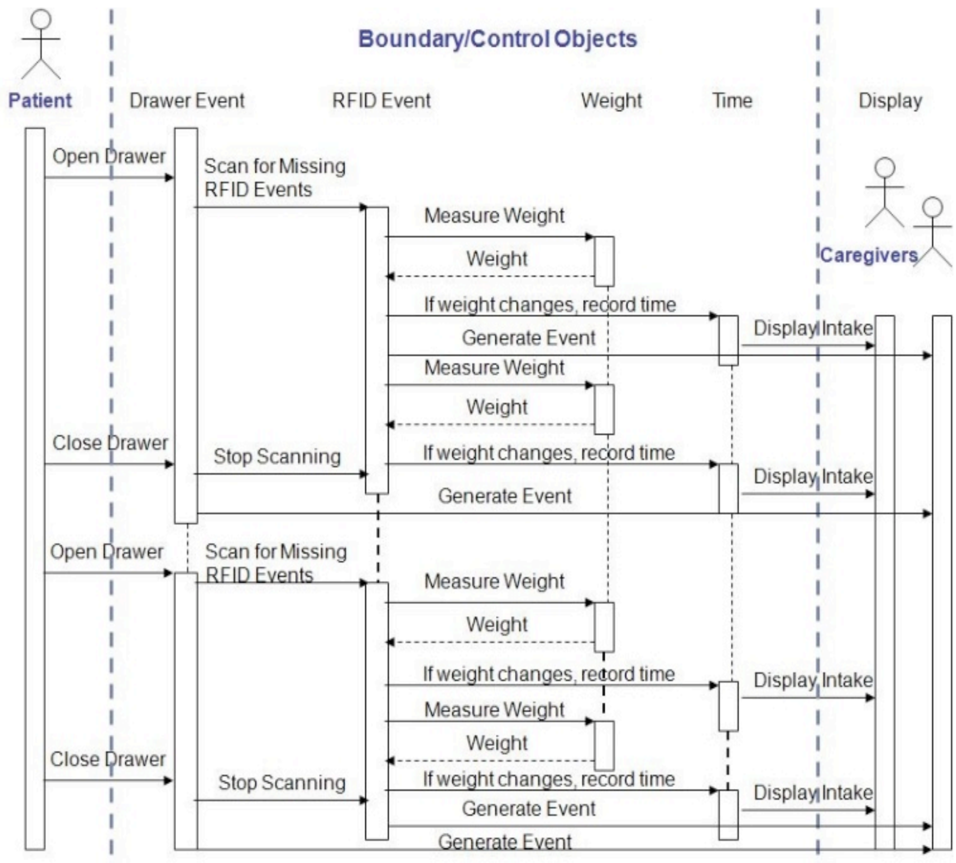

Figure 3.4. Sequence Diagram.

for analysis. As a result, two methods were applied to determine when the drawer would be in use, to be open or to be shut. We call this detection of the drawer motion the drawer event to indicate the usage. The first method of calculating the drawer event was a simple approach to finding a threshold that indicated that the drawer was in motion.

3.3 Database Communication and software prototypes

3.3.1 MySQL Backend Database

The MySQL database serves as a repository of information. All the information about caregivers, patients are maintained in the database for ease of access and privacy. Each of the medicine bottles have a unique entry with respect to its unique tag id. We have two set of data sets. One for having a support database and other for Fusion database. The support database has all the valid set of data entries before fusing all the data values from different sensors. The fusion database contains the aggregated clean data which are queried frequently from the care giver for web display. The data stored in the database are separated into a number of categories according to their time to live. Some of the data types are discarded at the end of the day, Whereas other are kept for longer periods for later use. In experimental trials the database access time was approximately 0.00004 seconds which is quite fast for the intended application and does not raise any issues regarding the direct access of the database every time an event happens. In addition to the fast access time, having a database helps is in using complex queries which would not be possible on traditional CVS based log file. Also when necessary, the data stored in the database could be converted to any other format for analyzing the data further.

3.3.2 Events and Episodes

We define an event and an episode. An event is a response of a sensor when it satisfies certain condition. We let ei an event, where i is an event ID, which is a combination of encoded number of physical location of sunSPOT and enumerated value of incidents. Activity include entering a room,Opening drawer and path incident. Entering a room is to detect a person's behavior such as getting on the bed to sleep or getting out of bed or using the bottle inside the drawer. Using the Y and Z directions of accelerometers in sunSPOT, it will report the measurement when the sensed value exceeds certain threshold value that is pre-determined. The bump incident is defined only at a movable object such as a chair or a table that can sense the change of value of X, Y, and Z accelerometers caused by a movement of an object. This incident includes hitting or bumping a movable object. Path incident is to detect a person's path from one place to another place. We utilize light sensors so that a series of SunSPOT installed along with a hallway can detect a person's path. The rule of determining event ID is that we simply combine two digits of encoded number of physical location of sunSPOT and enumerated value of simple incidents. For example, if an encoded physical location that is attached on a bed is 10, and enumerated value of bed incident is 1, the event ID is 101. Therefore, if we have an event e101, that means a sunSPOT attached on a bed detected a bed incident. Now, we are interested in multiple number of events instead of an individual event. We define episode pk as a series of events. pk = e1; e2; :::; en where k is an episode ID and n is an event ID. The order of events is determined by the time when sunSPOT reports individual incident. For example, when a person walks from a bedroom to a kitchen, a series of events will be a bed sensor detecting bed incident, a bedroom sensor detecting path incident, several hallway sensors detecting path incidents, and a kitchen sensor detecting path event.

3.3.3 Interface Prototypes

We have implemented a series of software tools to study the advantages and limitations of the system. We distinguish three parties interested in this system related information resulting in the development of three different tools; the Patient Interface (PI), the Caregiver Interface (CI), and the Maintainer Interface (MI). In Addition we have developed a number of auxiliary interfaces to facilitate our evaluation process. Examples include the Drawer Display Interface (DDI) and the Medicine Management Background (MMB) interface. These programs have been developed using different tools and technologies such as Java and MySQL from the C# prototypes.

The Patient Interface (PI) is intended to provide valuable information to the actual patient, to remind the patient, and provide proper visual and sound alarms on his daily routine of medicine consumption. When the patient attempts to take medicines out of the dictated order, or if the patient tries to consume the wrong medicine at the wrong time, the patient interface will alarm the person that he is attempting to consume the wrong medication. The user is alerted daily with visuals and sound of his pill consumption routine. The user is provided with touch screen buttons in case of emergency at any time.

The Caregiver Interface (CI) program logs in to the system using a web page. Each of the caregiver is required to register themselves once and use their unique combination of username and password for subsequent logins. On successful logon, the system scans the drawer at specific intervals and stores the detected tags and the time of their detection to the database. Each tag detected by the reader is associated with a medicine. The caregiver is provided with menu options to create, load, and store different medicine configurations for the drawer. Medicine information includes, name, description, daily consumption count, expiry date, and the corresponding RFID. The program is designed to read ISO 15693 tags. When a medicine is removed from the drawer, the corresponding information is displayed on screen

The Maintainer Interface (MI) is intended for administration and research purposes. It provides access to the time, and drawer maintenance and history functionality. The main purpose of the knowledge collaboration interface is to facilitate the job of researchers and administrators in analyzing how the system is functioning and to help maintain it and facilitate its integration with a bigger assistive environment.

3.4 Physical Setup

The medicine intake tracking system has various real-world components that make up how the tool will have to be constructed. The furniture containing the Smart Drawer will be part of a simulated apartment. And for this drawer to operate, it will be necessary to identify when the drawer is open in addition to the previous problems of identifying the bottles.

3.4.1 Experimental Layout

The web tool and data fusion described in this paper are being used in conjunction with a sensor-equipped drawer, the Smart Drawer. The Smart Drawer system being used for this paper is part of the @Home assistive Living apartment. Figure 3.5 shows the floor plan of the bedroom from our experimental setup at the Heracleia Laboratory. The drawer to the right of the bed, which is encircled in red, contains the equipment used to measure the medication.

An RFID reader is placed inside that can read the values from the individual bottles. Next, a precision balance, which has a resolution of 0.001 g, has been placed in the drawer and has a serial connection to report a stream of the current weight of the contents. A SunSPOT sensor is mounted to the front of the drawer to detect the position of the drawer. In addition, a Motion

Detection sensor, from Phidget, is mounted on the leg of the lounge chair to detect when a person has entered the bedroom. This combination of sensors and spaces define the workspace for the sensor input that will need to be combined into a functioning application.

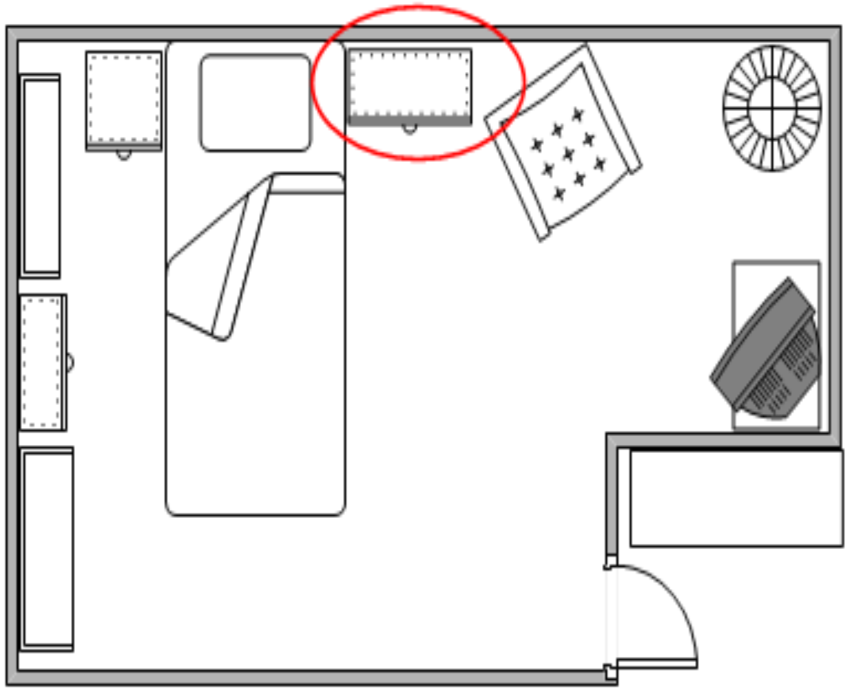

Figure 3.5. Layout at Heracleia.

3.4.2 Hardware Implementation

In an assistive environment, patients may need to take different types of medicine each day, so, a RFID technique may help patients by reminding them to take their prescription on time and with the correct quantity. We designed a smart drawer, which contains a RFID reader, and each medicine bottle is deployed with a RFID tag. If a patient takes a pill bottle from the drawer, then the tool will track which medicine was taken, and when the medicine was taken. If there is anything inconsistent in the drug taking events with the doctors instructions, the smart drawer will reach some decision, and prompt the patient or report to the doctor.

3.4.2.1 Sunspot technology

Based on a 32 bit ARM-7 CPU and an 11 channel 2.4GHz radio, Sun SPOT radically simplifies the process of developing wireless sensor and transducer applications. The platform enables developers to build wireless transducer applications in JavaTM using a sensor board for I/O, an 802.15.4 radio for wireless communication, and use familiar Integrated Development Environments (IDEs), such as NetBeansTM to write code.

The Sun SPOT system uses JavaTM technology to up-level programming. Developers can write a program in Java, load it on a wireless sensor device, run it, debug it, as well as access low-level mechanisms with standard Java IDEs. The inherent portability of JavaTM makes it simpler to migrate applications among platforms and enables developers to build new wireless sensors devices using off-the-shelf hardware components. Java also eliminates or streamlines many of the low-level tasks of traditional development languages such as C, and for the millions of developers who already write code in Java there is little additional learning curve for building wireless sensor/transducer programs. The Sun SPOT system features the Squawk VM, a small J2METM virtual machine (VM) written almost entirely in Java. It provides the ability to run wireless transducer applications on the metal, (directly on the CPU without any underlying OS), saving overhead and improving performance. End users also gain the flexibility to experiment with different implementations of low-level services, such as networking protocols, which are typically buried inside an OS. A set of Java libraries under development will provide access to the sensors, the I/O pins on the sensor application board, and the integrated on-board radio. By running multiple applications on the one virtual machine, and by using a more compact representation of class files, the Squawk VM makes better use of the small memory space available on SPOT devices. For gathering the data for these experiments, SunSPOT motes were deployed in an apartment layout in the Heracleia Laboratory. A set of rooms are defined by using a set of partitions, and the rooms are then populated with furniture. Next, the SunSPOT motes are attached to the walls of the rooms and onto the furniture to detect various changes in their readings on their sensors.

3.4.2.2 RFID technology

The first step in designing the smart drawer, was to select the RFID technology best suited to the task .We considered three types of RFID implementations: Low Frequency (LF), High Frequency (HF), and Ultra-High Frequency (UHF). LF RFID is a cheap technique or RFID, but the drawback for LF is that the bandwidth is very low. The LF RFID cannot exchange a useful amount of information for our purposes. HF RFID has a higher communication data rate than LF, and seems adequate for the SmartDrawer tasks. UHF RFID has longer distance as well as much higher bandwidth, but right now the UHF technique is too expensive. One UHF reader costs around 5,000USD per unit, while a HF reader only costs 300USD per unit. We compare these three categories in Figure 3.6.

Based on the above observations we chose to use HF RFID technique to implement the SmartDrawer. We assume only one RFID reader is located on the bottom of the SmartDrawer, and each medicine bottle has a single RFID tag. We also assume all the pill bottles are normally stored in the smart drawer, and a dose of medication can only be taken after its container leaves the drawer.

The whole system architecture has four components, as shown in Figure 3.7: The components of the system are as follows.

1. All the pill bottles have RFID tags attached.

RFID	LF	HF	UHF
Frequency	< 250 khz	10Mhz < f < 100 Mhz	F > 400 Mhz
Communication Speed	Low	Middle	High
Price	Low	Low	High
Range	< 10cm	5-20 cm	>1m

Figure 3.6. RFID technology types.

2. An RFID antenna is embedded into the bottom surface of the drawer where bottles are stored.
3. The RFID reader connects with RFID antenna to detect and access RFID tags. A RFID reader is also shown in Figure 3.7
4. A computer is connected to the RFID reader.

This computer stores all data collected from RFID reader in a database. The database can be used for decision making to help patients. The experiments with the RFID readers were done to solve two issues of whether the current RFID tags and RFID readers were good enough to implement the SmartDrawer.

First, to decide if the sensing range is far enough for the RFID reader to detect the tags attached to the pill bottles. Second, the experiments determined if multiple

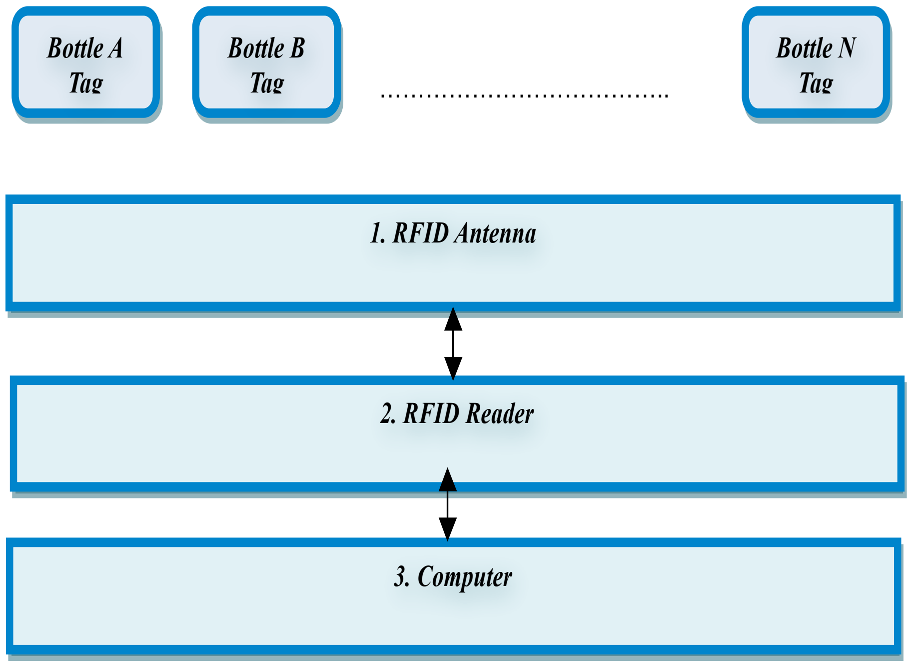

Figure 3.7. RFID reader system architecture.

RFID tags interfere with each other. The first experiment was to make sure the sensing distance for RFID reader to detect small, medium, and large tags is far enough to be useful. We measured the sensing distance between each of the different types of tags and the RFID reader. In the SmartDrawer, several medicine bottles with RFID tags will be stored together. So in the second experiment was to test multiple tags for ISO-14443 and ISO-15693. We performed three combinations in this experiment. In the first combination, we tested multiple ISO-14443 tags with our RFID reader. The reader can only read one ISO-14443 tag. In the second combination, we tested multiple ISO-15693 tags. From our experiment, we found up to 8 tags could be read successfully. Finally, in the third combination, we tested whether different types of RFID tags can be read successfully by one RFID reader. In this trial, we used a mixed group of ISO-14443 and ISO-15693 tags. The results showed that one ISO-14443 tag and multiple ISO-15693 tags can be detected simultaneously using the RFID reader. We next tested the sensing range for different sizes of RFID tags.

CHAPTER 4

EXPERIMENT AND SIMULATION RESULTS

In this chapter, the experiments that are done at Heracleia Laboratory and its results are described. A pair of motion sensor phidgets, a sunspot sensor and a base station, an RFID Reader with multiple tags and an analytic weight sensor precision balance were used. The base station is attached to a workstation which is a Windows XP machine.

4.1 Physical Setup

4.1.1 System Components

The system is composed of four components.

1. Motion Sensor
2. Sunspot mote with base station
3. RFID reader with multiple tags
4. Weight sensor.

These four components implement an efficient information flow which makes the system energy efficient and also achieves extended system lifetime.

4.1.2 Simulation Results

The main purpose of the simulation is to inspect the results visually. The above system setup is also simualted to view and sample all the possible sequence of activities during the entire simulation. Shown below are the screen shots of the implemented simulator.

Figure 4.1. Simulator result on Open Drawer Status.

4.2 Energy Efficiency

The main reason for having four different sensor devices in this system is to make it energy efficient. Each of these component devices in the system consume a positive unit of power when active which range between +2V to +12V. In the motion sensor Phidget, when the device is enabled, the maximum voltage returned on the Analog Input should be the +5V nominal power provided by the PhidgetInterfaceKit. The Sunspot senor device is based on a 32 bit ARM-7 CPU and an 11 channel 2.4GHz radio, Sun SPOT radically simplifies the process of developing wireless sensor and

Figure 4.2. Simulator result on Using Bottle.

transducer applications. The platform enables developers to build wireless transducer applications in JavaTM using a sensor board for I/O, an 802.15.4 radio for wireless communication, and use familiar Integrated Development Environments (IDEs), such as NetBeansTM to write code. The Sun SPOT system uses JavaTM technology to up-level programming. Developers can write a program in Java, load it on a wireless sensor device, run it, debug it, as well as access low-level mechanisms with standard Java IDEs.The RFID reader is connected to the basestation using a USB hub and the amount of power consumed is a positive unit which ranges between 0 to 5V when active. The analytic Weight sensor power has it between 5 to 12 V range when active. Shown Below is the result of our energy efficient system against the baseline system.

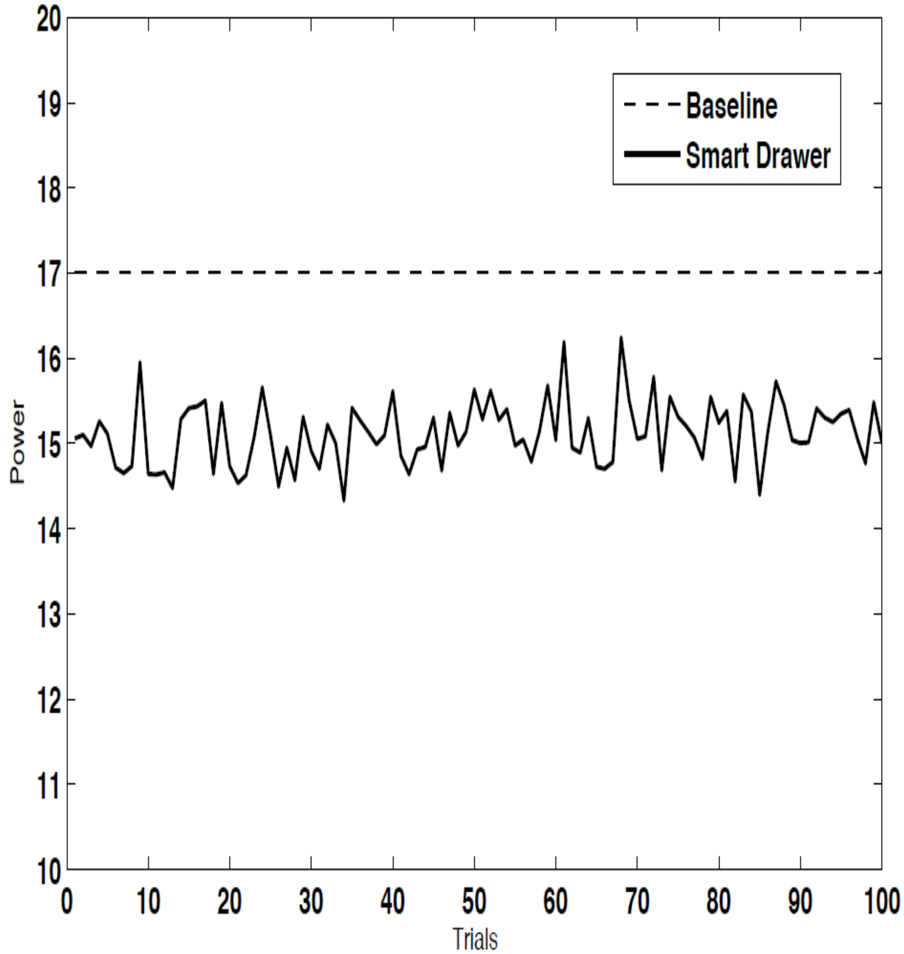

Figure 4.3. Energy Consumption Graph.

In Figure 4.3, the power consumed by the Smart Drawer system is lesser than the Base line curve. This can be explained as follows. The smart drawer system is an event based module where one event results in triggering the next module in a pipeline fashion. In case of Baseline system, the due to the absence of pipelining, the power consumption is constant and shows no variation as all the devices in the system are constantly listening and hence run out of system lifetime.

4.3 Web Tool

After describing all the necessary major components or modules for the execution of the experiment with the results of energy efficiency, this unit gives the screen capture of the web tool. Here the caregiver or the doctor login to the system by means of a web based tool whose snapshot is shown in Figure 4.4.

Figure 4.4. Web Tool Display with functions.

The caregivers who use this system have to authenticate themselves to the web based module or a new caregiver can register (as shown is Figure 4.5) and enter their details. On successful registration, the caregiver can make use of all the services provided by this tool. By using a web based module, this tool exploits all the web based technologies.

Figure 4.5. Web Tool registration.

On successful logon into the system, all the sensor devices are currently ready to listen to signals which will make to sensor mote to go to active state. If motion is detected in the bedroom area, the motion sensor detects motion and reports it to the backend system. This path event is recorded which makes a sequence to determine the presence of the person in the bedroom area. The caregiver can view the details of their patients which is shown in the Figure 4.6.

The details that can be seen by the caregiver includes the time at which the patient has taken his medication ,the type of medication taken in quantity and also this system reminds the patients to take his medication at the prescribed time by sending an alert message.

On detecting the name of the medication taken by using different RFID tags for different medicine bottles , our web based medicine intake tool further determines the quantity of medication taken by the patient by having an analytic weight sensor attached to this environment. We place all the medicine bottles bearing the RFID tag on the analytic weight sensor balance and record the changes in weight when the bottle is placed back. The weight balance can detect changes in weight of the order of milligrams.

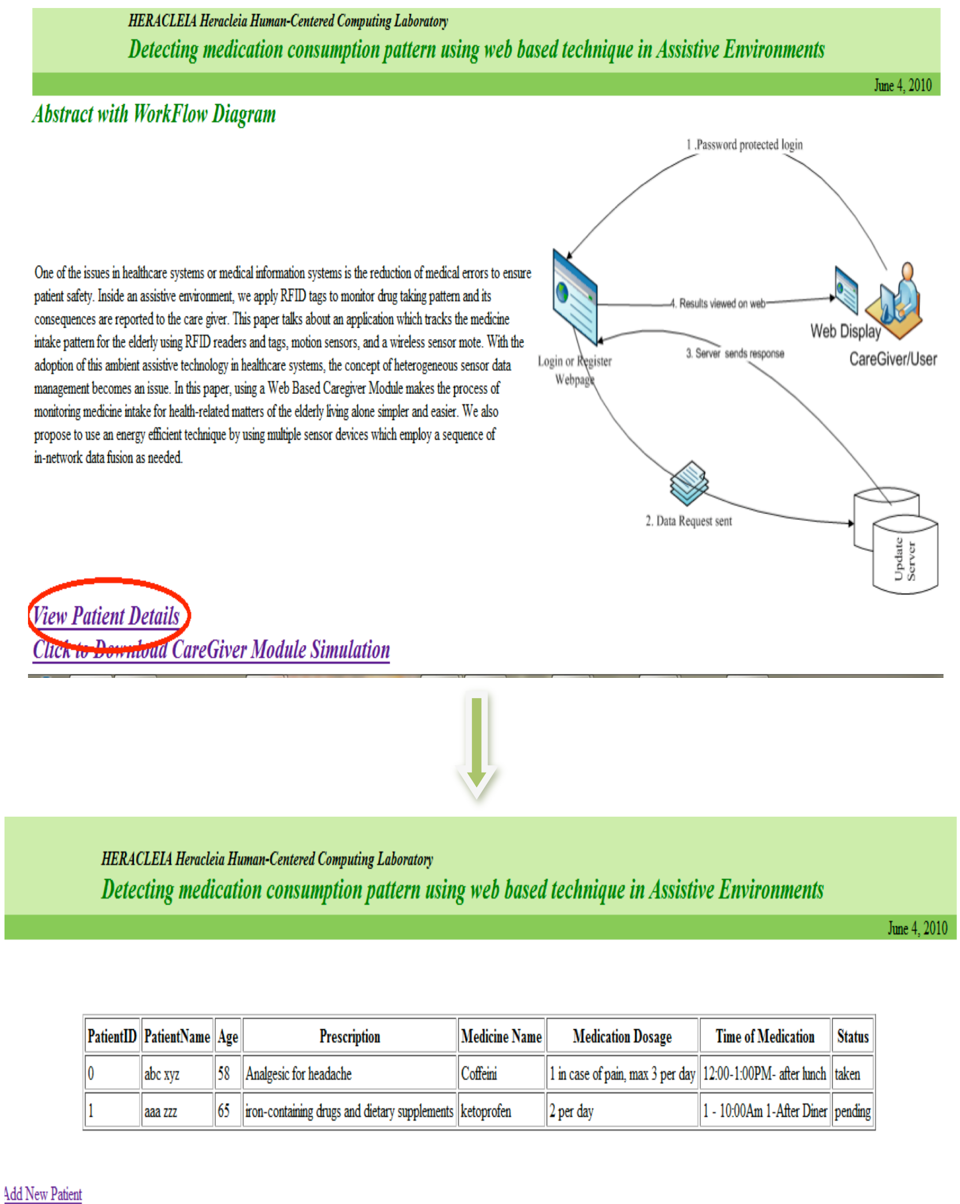

Figure 4.6. View Patient Details with medication Status.

CHAPTER 5

CONCLUSIONS AND FUTURE WORK

All the components making up the system have been congregated, assembled and tested. The motion detectors which trigger a motion event on patients entry into room, the SunSPOT sensor attached to the drawer to detect drawer status, RFID on pill bottles and the analytical weight sensor to monitor the change in weight send their values to the base station where all function as a collective unit. Multiple sensors have been integrated in order to reduce energy consumption. As a result of reduced energy consumption, the duration of battery life of each of the sensors have increased considerably thus increasing the system lifetime.

We try to track prior and subsequent activities of a person before they remove a pill from the drawer in order to derive useful information about the persons behavior. A person may open or close the drawer several times but forgets to take the medicine from it. On the other hand, the person may remove the medicine out from the drawer but put it back again without consuming a pill. Therefore, our system identifies useful patterns from a persons activities over the time.

This approach results in the development of the tracking tool using the web. Internet plays a crucial role from the care giver login being the primary authentication step till the determination of the quantity or the amount of medication consumed by the patient at the prescribed time. This makes the system to be accessible from a remote workplace. For this web based tool, the applications have been extended to creating the caregiver interface and a maintenance view using the web. Our future goal in developing the material side of the system is to combine these different sensors using the state and sequence diagrams to achieve data fusion. Due to involvement of large temporal data set, heterogeneous data management stages an important role. The raw data from different sensor units that form a heterogeneous data set leads to necessitate data fusion.

Our future goal in developing the system is to combine these different sensors using the state and sequence diagrams to achieve data fusion on the large data set and use the collected data set for monitoring the detailed activity of the patient over a long period of time. For the data aspect of the project, the expansion of the collection of data to be fused must be compared to known prescriptions. The sequence of events for each medicine will need to be compared to the description from the prescription. Dynamic programming methods, such as Dynamic Time Warping, will be investigated as a means for making a match between the different sequences.

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BIOGRAPHICAL STATEMENT

Jyothi K Vinjumur received her B.S. degree from Bangalore University, India, in 2007. After her Bachelor degree she was working an a software developer for one year and then decided to pursue MS degree. She began her graduate career at the University of Texas at Arlington from the Fall of 2008. Her research interests include Computer Networks and Telecommunication.