SmartDrawer: RFID-Based Smart Medicine Drawer for Assistive Environments

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ABSTRACT
Radio Frequency Identification (RFID) is an emerging technology, being used in monitoring including healthcare. 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 paper 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.

Categories and Subject Descriptors
K.4.2 [Computing Milieux]: Social Issues - Assistive technologies for persons with disabilities, I.2.9 [Computing Methodologies]: Robotics - Sensors

General Terms
Management, Measurement, Design, Human Factors

Keywords
Smart Furniture, Sensors, RFID, Human Activity, Ambient Intelligence, Assistive Environments.

1. INTRODUCTION
It is estimated that half the people taking prescription medication fail to stick to the regimen laid out by their doctor [1]. 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.

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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 [2]. 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 doctor's 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 [3].

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.

We 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.

This paper proceeds as follows. In section 2 there is a discussion of the background and the work related to the project. In section 3 we give a definition of the SmartDrawer, its usability and the users involved. In section 4 we make an investigation of the RFID technology for use in the SmartDrawer project and we describe our findings. In section 5 the software tools developed to date and the ongoing design of more complex interfaces are shown. In section 6 we discuss possible enhancements of SmartDrawer by adding more sensors beyond the RFID. Finally, in section 7 we present our conclusions.

2. BACKGROUND AND RELATED WORK

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 [4]. 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 [5]. 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 [6]. 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 [7]. But RFID tags are now started being added to the medicine bottles in the supply chain by the pharmaceutical companies themselves [8]. 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 [9], In order to block counterfeiting, major distributors of drugs are already putting RFID tags onto their bulk packaging [10, 11]. 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 [12]. 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 [13].

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 [14]. 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 [15]. 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 subject’s position and posture from the various events [16]. 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 [17]. 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 patient’s plan with various devices such as telephones and PDAs [18].

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 [19]. 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 [20] 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 [1], which is from Vitality, a startup company based in Cambridge, Massachusetts. Their reminder system targets the health and business problems with an Internet-connected bottle-cap. 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.

3. 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.

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. The cases for when the drawer is actively scanning in relation to its condition can be seen in the state machine in figure 1.

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 he 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.

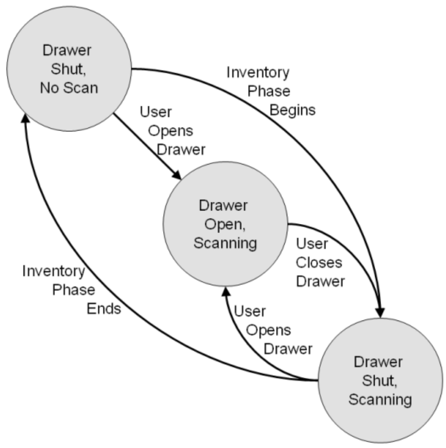

Figure 1: State Machine of Smart Drawer Behavior

In the next sections we describe the technologies that we have used to create a “smart drawer” prototype, the challenges that we have encountered in our effort to make it usable in real-life and the outcomes of our experimentation process.

4. HARDWARE INVESTIGATION

The first stage of the SmartDrawer project was to implement an RFID reader system and to first establish the constraints imposed by the hardware. The type of radio tags to be used, the distances involved, and the general architecture of the system were considered. Next, utilities based on the reading of the RFID tags had to be built, including the basic user view, the connections to the MySQL database, and a reminder program.

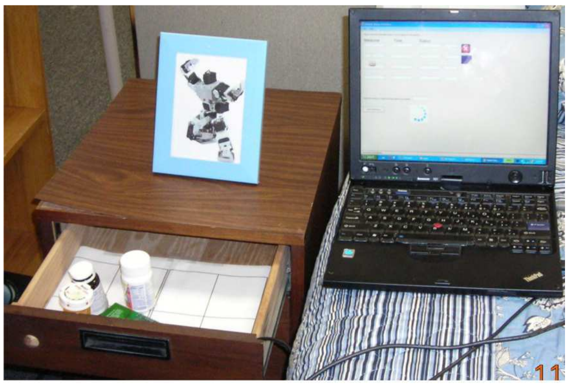

Figure 2: A Smart Drawer in Heracleia Lab., Arlington, TX. Here, the laptop is used to show the current status of a smart drawer, RFID reader is used to read the tags that are attached to the bottles of medicine.

4.1 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 as seen in Fig. 2. 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 doctor's instructions, the smart drawer will reach some decision, and prompt the patient or report to the doctor.

4.1.1 Which RFID technology is best

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 Fig. 3.

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

Figure 3: RFID Technology Types

Based on the above observations we chose to use HF RFID technique to implement the SmartDrawer.

4.1.2 Hardware Implementation

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.

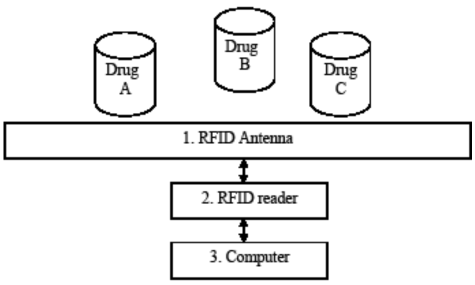

Figure 4: Smart Drawer System Architecture-

The whole system architecture has four components, as shown in Fig. 4:

The components of the SmartDrawer are as follows.

1. All the pill bottles have RFID tags attached. A RFID tag on a bottle is shown in Fig.5

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 Fig. 5

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.

Figure 5: RFID reader and RFID tags on a bottle

4.1.3 Notice Results and Visualization

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 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. The average sensing range is around 4.6cm for small tags, 6.5cm for middle tags and 7.2cm for large tags as shown in Fig. 6. The average of these ranges can be seen in Fig. 7. The current sensing range is great enough for our target application.

We also experimented whether an RFID reader can support multiple RFID tags of the same type, and also multiple RFID tags of mixed types. Experimental trials found the ISO 15693 tags to be far more accurate and easily detected by the RFID reader compared to the other tags. Especially, ISO 1443A tags are inaccurate and take considerable amount of time to be detected by the reader.

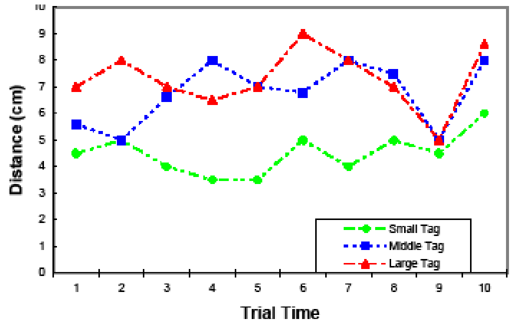

Figure 6: The maximum sensing distance between the different types of tags and the RFID reader

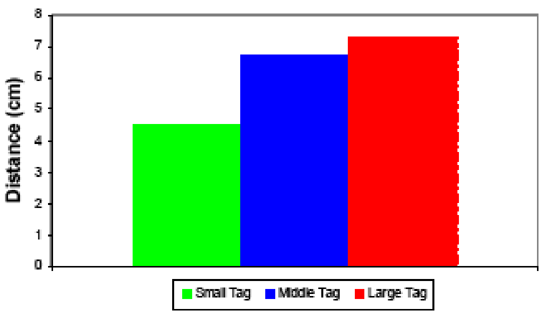

Figure 7: The average of maximum sensing distance for the different types of tags

5. SOFTWARE PROTOTYPES

5.1 MySQL Backend Database

The MySQL database serves as a repository of information. All the information about each medicine bottle and when it was detected is stored in this database. 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.

5.2 Interface Prototypes

We have implemented a series of software tools to study the advantages and limitations of the *SmartDrawer*. We distinguish three parties interested in SmartDrawer 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.

5.2.1 The Patient Interface (PI)

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. This is illustrated in Fig. 8.

Figure 8: Touch screen interface with sound alarms for the patient

5.2.2 Caregiver Interface (CI)

The Caregiver Interface (CI) program 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 as seen on Fig. 9.

Figure 9: The current drawer status and medicine usage information

5.2.3 Maintainer Interface (MI)

The Maintainer Interface (MI) is intended for administration and research purposes. It provides access to the time-line screen, 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 *SmartDrawer* is functioning and to help maintain it and facilitate its integration with a bigger assistive environment.

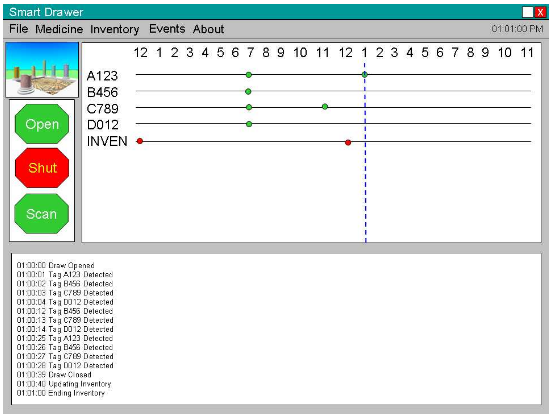

Figure 10: Time-line of medicine consumption

5.2.4 Drawer Display Interface (DDI)

The Drawer Display Interface monitors if the scheduled medicine has been taken on time by the patient. This program reads its data from the MySQL database to determine if the medicine was taken as scheduled. The program can monitor a maximum of 4 medicines concurrently. Before running this program the user has to enter the information for each medicine such as the name of the medicine, time the medicine has to be taken. The user is provided with textboxes on the interface to enter the relevant information. The working of the interface is given below (Fig. 11) and its purpose is mainly the evaluation of the system since it provides more information than an actual patient would need to use.

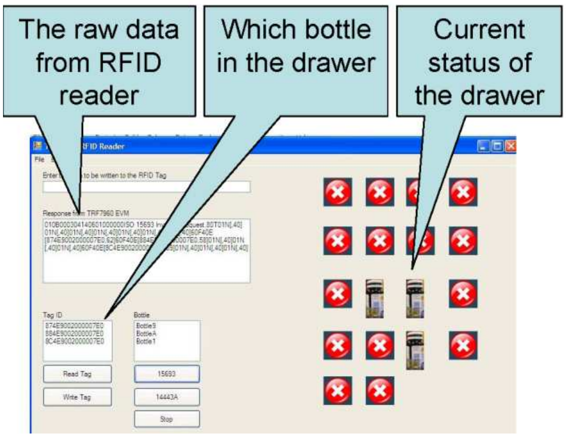

Figure 11: This tool is implemented to be able to record the events associated with the medicine bottle tags. The data includes the time the bottle was removed from and returned to the drawer.

Assume that the medicine has to be taken at time t2. Let t1= t2-5 represent the time 5 minutes before the medicine has to be taken. At time t2 the interface would access the MySQL database and count all the records in between t1 and t2 for the respective medicine. For instance, if the patient has to take the medicine Aspirin at 17:30:00, the patient interface would access the MySQL database from 17:25:00 to 17:29:59 and count all the records between these times.

5.2.5 Medicine Management Background (MMB)

The Medicine Management Background (MMB) program scans the drawer at set interval and stores the detected tags and the time of their detection to a MySQL database. Each tag detected by the reader is associated with a medicine. The data stored in this database could be accessed by the MMB to detect if the medication has been taken by the patient on time. The MMB program can increase its scanning interval to a maximum of 1scan per 300 milliseconds for achieving better accuracy if needed. Currently, this program can read ISO 15693 tags. The program can support the following commands: Inventory 15693 tags, Inventory 1443A tags, Read 15693 tag, and Write 15693 tag. (Fig. 12)

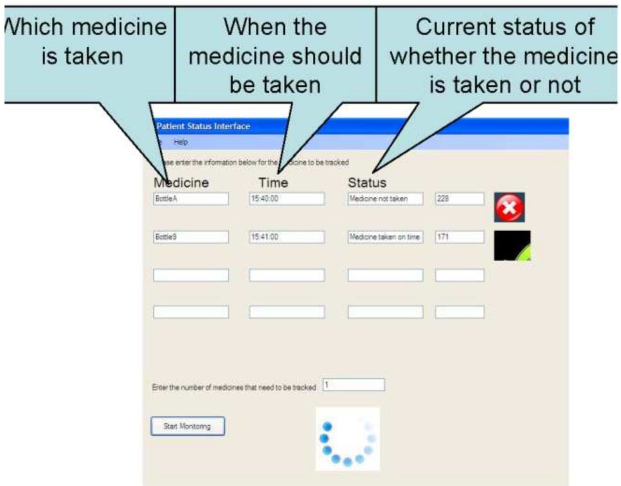

Figure 12: This tool is designed to be able to compare medicine instructions with recorded events from the DDI This interface is for displaying the events, and comparing the events to prescription.

6. SMART DRAWER ENHANCEMENTS

6.1 Measuring the bottle weight

In our current experiments we have mainly focused on using the RFID technology to track the drug taking behavior of the patient based on the assumption that when a bottle is removed from the drawer and then placed back, it means that the patient has taken the drug. This assumption is not always realistic because there may be cases where the patient performs such an action without actually taking the drug. An example of such a case can be when a patient grabs the wrong bottle and then realizes that that is not the bottle he intended to grab, and so he puts it back without using it. In the current implementation we try to handle such cases by using simple rules of the form “if a bottle is removed and placed back in less than 10 seconds ignore the event”. However, this is not the best way to handle such situations. Ideally we want to be able to tell exactly if any pills have been removed from the bottle, and if yes, how many. The existing technology enables us to achieve that with high accuracy by measuring the weight of the bottle before and after replacement. The enhancement can be done by putting a load/force sensor at the bottom of the drawer to record the weight of each bottle. Such sensors are commercially available and have been used in the past for similar applications. FlexiForce [24] for example produces such sensors in the form of thin tapes which are suitable for our application.

6.2 Detecting when the drawer is open

In the current setup, in order to detect if the drawer is open or closed we use a Sun SPOT mote (Sun Labs) which is easily adaptable to our system, since it is Java based and can be used out of the box, and it provides us with two different ways of detecting if the drawer is being opened or closed. Those are, the intensity of the light that falls onto the sensor and the drawer acceleration direction. For the light intensity we assume that when the light increases, the drawer is being opened when it decreases it is being closed. Although the above technology produces satisfactory results it is still in experimental phase and it is not widely available. For that reason we intent to examine other more widespread and possibly less costly solutions. Such a solution can be a magnetic contact switch or a photo cell switch.

7. CONCLUSIONS

The SmartDrawer is an ongoing project that will expand a current RFID medicine chest program from the prototype phase into a form that will have more user-oriented views. RFID tags today are already in place both in the supply chain and in hospitals and other medical facilities. Furniture and even environments can be fitted with RFID enhance the quality of life in an assistive living environment. Combining all these features and conditions gives rise to the idea behind the SmartDrawer. That an interactive medicine cabinet can be constructed and connected with user views and a database to be a reminder system for patients as well as being an asset to both caregivers and researchers. A hardware investigation has already been completed and prototype user interfaces have been developed. The work will be expanded beyond these prototypes to fulfill the needs of the three types of users. Additionally, the furniture itself can be upgraded to include sensors to detect the state of the drawer and even fitted with a scale to see if there has been a change in the tare weight of the contents of the drawer.

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