Automatic Prevention of Medication Errors
Mobile System Based on Near Field Communication (NFC) Technology

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Abstract: In this paper a mobile system aimed to avoid medication error in home environments is described. It is based on unambiguous identification of pillboxes or drugs packages with a Near Field Communication (NFC) tag. This tag, whose information can be quickly read with a mobile phone equipped with an NFC interface, can also store information about the patient and the prescribed dose. These data can be actualized with the smartphone whenever the patient confirms a new medication-take just by approaching the smartphone to the labelled box. The information is also locally saved in the phone and can be sent by SMS to caregivers if necessary. The information into the NFC tag converts a simple mobile app into an ubiquitous computing (ubicomp) context aware tool that avoids drug or patient confusion. To ensure that even patients with low technological experience will be able and, more important, wish to use this system, we have followed a user centered design methodology. The system adapts to different patients profiles, and to different degrees of digital literacy.

1 INTRODUCTION

Patient's safety is one of the quality goals of the healthcare systems. Possible risks to this security are medication errors that can occur both in hospitals and in the usual patients' place of residence. A medication error is defined as "any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of the health care professional, patient, or consumer." (NCCMERP, 1998) Medication errors are the cause of up to the 5% of hospital admissions (Pasto-Cardona, 2009)

In this work we have developed a software tool to be used in an android device with a Near Field Communication (NFC) interface. The application allows the user to visualice on the device screen the information about a medicine that he considers necessary. The application also controls that the drug taking occurs in a correct way. Every drug case is labelled with a NFC tag. These labels have a double function. They stored information about the medicine that can be actualized every time the patient takes a new dose. Besides, tags are the control element that inform the device about the exact drug that it is going to be taken and when it was last ingested. In this way, the application prevents drug confusion or repeating a take. The systems is aimed at people that want to avoid this kind of mistakes and will not be useful without the patient's collaboration.

In order to create an application that really fulfills the needs of patients, we have followed a user centered design methodology. The information collected from users with different profiles has lead to the definition of specific and functional requirements and has guided the design process of the user interface. Also, we pursue that persons not familiarized with the use of smartphones could feel encouraged to use this application due to a simple and intuitive performance. NFC technology facilitates this interaction since the application is started and the information is available and updated, just by approaching the phone to the labelled drug.

In the next section, the use of automatic identification technologies and mobile applications to control drug management are revised. In section 3, we describe and justify the design methodology. The results obtained at every step of the process are shown including the software requirements, the structure of the system and the interface of the application. We end this paper summarizing our

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main conclusions and advancing the next steps of our research.

2 RELATED WORK

To avoid error medication, the right patient must take the right dose of the right drug at the right moment in the right way (Benjamin, 2003). It implies the management of a great amount of data about patients, drugs and illnesses. This information must be always available and correctly cross-checked. The clear identification of patients and drugs is essential

For this reason, automatic identification systems have been widely used as a tool to prevent medication errors. In our case, elements based on radiofrequency communication have been chosen.

2.1 RFID Systems to Control Drug Treatment

The radiofrequency identification, RFID, belongs to the group of the automatic identification and data capture (AIDC) technologies, like code bars, smart cards or techniques of biometric identification. It is based on the use of a unique identification code for every element. This code is known as Unique Identifying Digit (UID) and it is stored in the internal memory of a RFID tag. In order to automatically identify one item, a RFID tag is attached to it. The UID that stands for this tag and for the object can be read and communicated to a control system by means of an RFID reader that interrogates the tag using a radio frequency electromagnetic wave. The tag answers with its own radiofrequency signal. No precise alignment between the reader and the RFID tag is required.

The basic elements of an RFID system are the RFID tag, the RFID reader and the RFID software known as middleware (Glover, 2006). The RFID tag acts as the identification element. It's formed by an electronic chip, an antenna and a storage memory. This memory has always reserved, locked blocks where the unique code UID is saved. The tag memory can have a bank, the user memory zone, where new data can be written, read and modified by the reader. In this way, pertinent information about the medication-taking process can be dynamically saved inside the identification element. RFID systems can access to information and save new data with no connection to a data management system though they generally work fully integrated to them.

NFC technology stands for a RFID subsystem that works in the 13.56 MHz frequency band and shows a short read-range (below 5 cm). NFC readers are integrated in small mobile devices, as smartphones. A short operation distance enhances safety and security on the exchange of information.

The use of RFID tags in both, medicaments and patients, has been successfully implemented in several hospitals (Lai, 2007) (Lahtela, 2008) (Darianian, 2008a) (Sun, 2008) (Oztekin, 2010) (Chien, 2011) (Qin, 2011) (Alabdulhaftih, 2013). Every patient is uniquely identified by a RFID wristband. When a RFID reader connected to the hospital database reads the UID, the entire patient's data are available to the caregivers. Labelling drugs makes it possible to crosscheck data by reading simultaneously the patient's wristband and the medicament tag. Errors can be immediately detected prevented and recorded.

Similar systems have been developed aimed to reduce errors in medical treatments at home environments (Agarawala, 2004) (Bardram, 2004) (Bravo, 2013) (Chen, 2007) (Darianian, 2008b). Medicaments are integrated into the information management system when they are RFID labelled, since RFID/NFC readers allow direct communication with databases (Internet of Things). The storage capacity of the RFID/NFC tags allows to different caregivers, with different devices, recording the daily events. In this way, the information is saved just at the moment it happens and all those involved in the care of a patient get to know what has occurred when they are absent. If mobile devices are used, the system can go on working even if the patient moves to a different place. NFC control systems based on the use of smartphones, have been implemented as a communication channel between patients, caregivers, pharmacists and doctors (Iglesias, 2009) (Vergara, 2010) (Engel, 2013) (Swedberg, 2009). The doctor creates a NFC tag with pertinent patient's data such as the medicaments to be provided by the pharmacist, their dosage or the patient's known allergies. Every authorized user can collect this information with its smartphone and can also add more information. In the case of patients with physical or mental disabilities the phone can be used to automatic warn caregivers.

2.2 Android Apps for Medicine Adherence Control

The new information and communication technologies are being quickly integrated in our everyday activities. They provide access to information anywhere, guarantee communication at any moment and improve people's life quality. Smartphones and the development of open operating systems as Android have brought forth a great number of mobile applications aimed at entertainment, personal organization or access to specific information. In this context, many apps have emerged, focused on the health self-control in general, and particularly to the medicine adherence control.

We have analyzed the functionality of three of the most used apps. Their performance is based on the following tasks:

- To introduce general information about the medicament.
- To configure specific information about dosage. It is possible to work with different users.
- To set flexible alerts.
- To generate reports from the information stored in a database.

None of these apps use NFC tools, so problems as mistaking a drug for a different one cannot be avoided. Besides, the information about the process is only stored in a local database hosted in the smartphone. So, if this phone is not operative or accessible, no one can check the last medication takings. Also, all these applications are intended for users that are fond of smartphones and like to experiment with this kind of apps. A degree of previous digital experience is needed to use them properly and, above all, without increasing the time and effort required to accomplish an everyday task.

3 USER CENTERED DESIGN METHODOLOGY

3.1 Justification. Ubiquitous Computing Systems

In the previous section, several experiences about the use of RFID/NFC technology to control drugs taking have been referenced. In all cases, doctors and/or pharmacists are the ones to configure the information saved in the identification tags. Therefore these examples are integrated in a healthcare organization and, in many cases are reduced to successful pilot experiments, mainly, when home environment is involved.

Our approached seeks that the patients (or their caregivers) configure the information related to every medicament and save it on the NFC tags. So, only if they consider the system as indeed useful, they will incorporate the tool as a support for their daily care. We have followed a user centered design methodology from the initial step of requirements definition to the test of the prototype with real patients. We complete the steps of a model process (Resatsch, 2010) associated with ubiquitous computing systems.

We develop a mobile computing system. This kind of system is considered a subsystem of ubiquitous computing systems. Physical objects (in this case, the different drugs containers) are linked to the virtual world by mean of the NFC/RFID tags attached to them. RFID tags are considered natural ubiquitous elements that have provided a new form of interaction between men and machines. One of the possible definitions for ubicomp system is a network and communication infrastructure defined by the presence of various, miniaturized, networked and often invisible technology situated within the range of everyday human actions encompassing applications, supporting interactions and processes with ease of use (Resatsch, 2010). In our mobile system, the devices are smartphones that are not invisible and imply a clear interaction human-device. In some cases, these elements are fully integrated in people's everyday life and will not imply a special effort related to the task of taking medication. But depending on the degree of users' digital literacy, we must ensure both, perceived usefulness and ease of use. So, we have to integrate our application in the scenarios in which users carry out their daily task reducing the awareness of the interaction with the ubicomp infrastructure.

The first step of the model process is to define an initial idea. We have introduced this starting point in the first section of this paper. We analyze the information from different potential users to refine this idea, define the software requirements, and create a low fidelity prototype which is assessed by selected users. Finally, a working prototype is developed.

3.2 Motivation. Functional and Non-functional Requirements

3.2.1 Selecting Information Sources

In order to foster the user acceptance, we must know more about its intents, identities, needs and desires. The first step of the model process is to collect information to identify the functions that are really needed and, more important, that will not be rejected.

Searching for a wide user acceptance, two different profiles have been analyzed:

- Polymedicated chronically ill patients;
- Patients with a temporary disease that required up to three medicaments simultaneously.

In both cases we have identified lead users that will contribute to the whole design process. Besides, in some steps we have collected information from a larger group of users, especially in order to create the proper interaction scenarios.

Two group interviews have been carried out to caregivers of Parkinson patients. Besides, a low fidelity prototype has been shown and discussed. This group of users that stands for the first studied profile is not familiarized with the use of smartphones. So, we have selected as lead user a younger patient, with a wide experience in the use of this kind of devices, which suffers from multiple sclerosis.

In the case of the second profile, the researchers themselves perform as lead users. We form a heterogeneous working group which includes engineers, doctors and psychology students. The level of familiarity with new technologies is quite different. In order to limit the specific functionality a web multiple choice questionnaire, based on (Morisky, 1986), was sent to multiple users.

3.2.2 Collected Information

The interviews with the group of polymedicated chronically ill patients aimed to describe the context where the medication process takes place. The main conclusions extracted, in the case of Parkinson patients' caregivers, are listed below:

- Patients are not able to control their medication intake. Caregivers are usually aged people that are not familiarized with smartphones, but they can be helped by younger relatives.
- Parkinson patients must take a great amount of drugs. Therefore, labelling every medicament is not efficient. They require support to set up a pillbox.
- Parkinson treatments are very specific. It can be said that no two patients are alike.
- The caregivers have developed a personal system to control medication. They are not interested at all in changing it unless the new system shows clear advantages and does not involve a great learning effort.

In the case of general users (sporadic, non-multiple medication), researchers have shared their own experience. Besides, a web multiple choice questionnaire has been send to multiple users to stablish which bad habits are more common. The questions (with possible answers are *Never, seldom, often, always*) are:

- Do you forget to take your medication?
- Are you careless with the intake time?
- Do you leave the treatment unfinished if you feel better?
- Do you leave the treatment unfinished if you feel worse?
- Do you mistake a medicament for another?
- Do you forget the instructions given by your doctor?

The method use to spread the questionnaire, electronic mail, reduces the information from aged people that do not use this kind of communication tool. However, this kind of patients can be mainly included in the group of polymedicated chronically ill patients. The poor habits more frequent are the carelessness in the time of taking the medication (more than 25% of participants often forget the exact time) and the cessation of allocated medication when the patient feels better (almost 5% do it always and more than 30% often stop taking it).

3.2.3 Functional and Non-functional Requirements

Two roles are defined in the ubicomp structure. The first one is a local role which manages the application and the labelled drugs. It is necessary to have the specific software installed in the smartphone and access to the NFC tags. The second one is a remote role that just needs a smartphone connected to the mobile phone network ready for receiving SMS when the medication protocol is not fulfilled. In what follows, we described the specific software functionality, so when users are mentioned, we referred to local role users. These users can be patients, caregivers or doctors.

The main functional requirements are listed below:

- Users can **configure** medication-taking issues (drug information and dosage) both in the smartphone and in the memory of the NFC tag;
- Users can **control** medication intake just by approaching the smartphone to the labelled tag.
- Users can **program** alarms related to their medication events.
- Users can **configure** when an emergency contact person will receive a **warning** in case a medication error takes place.

- Users can **access to the information** generated during the medication process.

An overview of these tasks is shown in figure 1 that shows the system workflow.

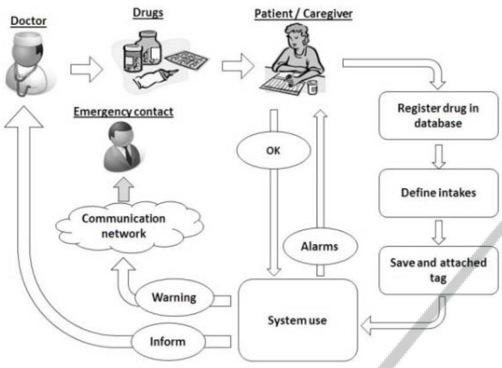

Figure 1: System workflow.

Going into more detail, the configuration function will adapt to two different scenarios:

- Single-medicament intake
- Pillbox set up.

The control function must be context sensitive:

- Personal context: adapted to the specific patient.
- Action-related context: adapted to the medicament read by the NFC interface.
- Time-specific context: adapted to the drug dose configured and the time where the action is done.

Depending on these context parameters different actions must be conducted. The software can just mark an intake as done in both, phone and NFC tag or must send a SMS to a remote user because the intake of a pill is forgotten or the patient has taken the wrong one.

Regarding to non-functional requisites, the control function of the system is designed to interact with users with different degrees of digital alphabetization. In this way, for users not familiarized with the use of smartphones, the interaction with the system is based on reading the NFC tag and simple voice commands. At the same time, expert users can interact with the application as they do with similar, well-known ones. The main non-functional requisites are:

- Work in mobile devices with Android operative system and NFC interface.
- Correct visualization on screens with different sizes and densities.
- Fast response. The NFC interaction is almost instantaneous.
- Configuration flexibility. The systems needs a minimum set of data to work, but the user can increase the saved information.
- Possibility to access to the basic functionality (medication-taking control) without using the touch screen.

3.3 Low-fidelity Prototype

Two different low-fidelity prototypes have been created. The first one was aimed to show the initial idea during the first group interview hold at the Parkinson association. Together with a tagged medication box, researchers play a simple dramatization to make it clear how to interact with the tagged box in order to configure the information stored in it, control medication taking and recover information about past intakes. In this way, users could see the technology in action and express their feelings about it, the advantages they perceived and their fears about using it.

After the information collection that led to the requirement definition, a simple mock-up prototyping was developed and evaluated by the lead users. They will also perform their medicament intakes with the initial working prototype that is going to be described in the next section.

3.4 Initial Working Prototype

The overall architecture of the system is shown on figure 2. The central device is an android smartphone where the specific software is installed. The application includes a local SQLite database where all the configuration and control information is stored. The app makes use of phone resources as the camera and the NFC reader. The camera is used to add a photograph of the medicament as configuration information. The NFC reader is indispensable to control the medication intake with the tagged pill container. This device must also be able to connect to a provider's mobile network to send a warning by SMS when the process goes wrong.

There are two main modes of operation. One is intended to people used to working with mobile apps. The second one allows controlling the medication intake just by approaching the phone to the medicament and confirming the process using simple voice commands.

The first mode of operation begins with patient selection. Next, three possible actions are accessible: configuration, intake-control and reports. The **configuration function** allows to introduce the

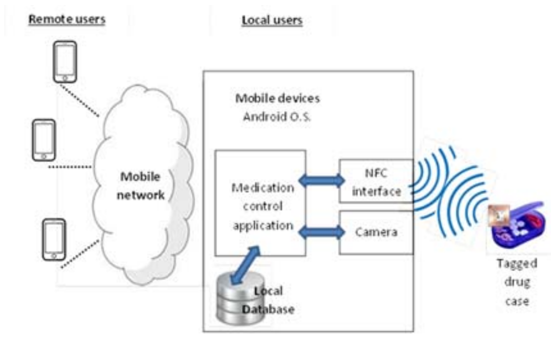

Figure 2: System architecture.

general information of a drug and to define intakes. To adapt to the two both studied profiles, two kinds of intakes can be configured:

- Single medicament.
- Pillbox.

To determine an intake one or more (in the case of pillboxes) medicaments are chosen and the dosage (amount and time) fixed. It is also possible to define an alarm for the patients and to stablish the criteria that will result in the dispatch of an SMS.

The configuration of an intake ends after the relevant data are saved into NFC tag. This tag is attached to the medicament box or to the pillbox. In figures 3 and 4 the interface to introduce patient's data and the information summary of a configured intake respectively are shown. So far, Spanish is the only language covered.

In figure 5 the flowchart for the **control function** is shown. The data saved inside the tag memory are the name of the medicament (or the identification of the pillbox case), the patient that must take it and the date of the last three intakes. The information about user, drug and time from both, NFC and local database are cross checked to decide if the action is correct and warn to the patients if an error is about to happen.

Finally, user can access to a report screen that collects and show information corresponding to a date and medicament chosen by the user.

The second mode of interaction only allows to access to the control function. When the patient approaches the smartphone to the labelled medicament, the application opens directly the control screen for the patient whose data are included in the NFC memory. A voice command, as a welcome message, names the patient that can check if the context defined by the data recovered from the NFC tag (patient, medicament, last intake) corresponds to the actual situation. All the warning and confirmation interactions will be performed by simple voice commands. It could be said that the user is not aware that the device he is handling is a smartphone, but it is just the bridge to a natural, simple interaction with the system that eases the process of medication. At this stage, an experienced user must help with the configuration function.

Figure 3: Patients' data configuration screen. New user's (nuevo usuario) data must be provided: Name (nombre), date of birth (Fecha Nacimiento) and comments (Observaciones).

Figure 4: Intake information summary. We can see the instructions for the breakfast (Desayuno) intake.

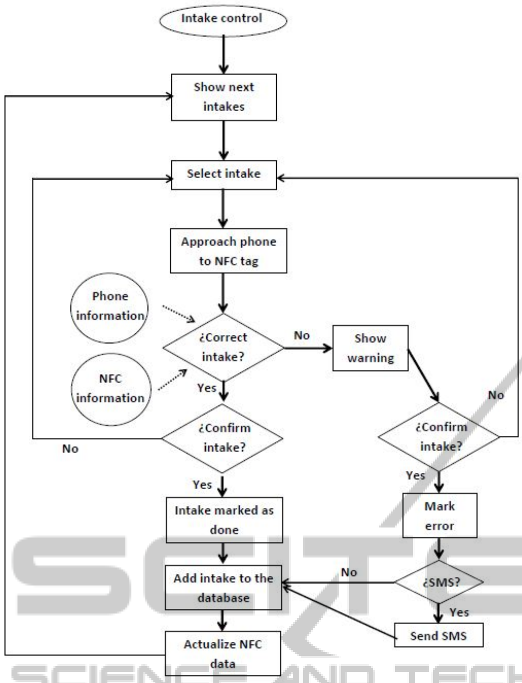

Figure 5: Flowchart of the control function.

4 CONCLUSIONS AND FUTURE STEPS

The use of radiofrequency identification to prevent incidents in the medication process has been widely used in both, hospital and home environments. The configuration of the RFID tags and devices was generally done by doctors or pharmacists. All the elements involved were integrated in the complex hospital information systems and cannot be used by patients and caregivers in an independent way. One of our main aims is to allow patients themselves to configure the system, as long as they are provided with NFC tags. Smartphones applications for adherence control are specially intended for the personal or familiar care, but cannot control that a drug is mistaken because there is no automatic data cross-checking as our system in a novel way implements. The NFC information prevents that a drug can be confused with another or that a patient takes a medicament not prescribed to him. In an emergency, if the phone is operative, a complete 24-hours report can be consulted. One of the main new contribution of our systems is that, even if it is impossible to collect the information saved in the phone (for example, patient unconscious, phone turned off and no one knowing the password) the data stored in the NFC tag will confirm if a specific intake was done or not. The data stored in the NFC tag are written following the NFC Data Exchange Format (NDEF) and can be read by the basic NFC apps installed in every NFC device.

Our application is flexible and adapts to patients that takes medication sporadically and to chronic polymedicated patients as different kinds of intakes: single medicament or pillbox are possible. Besides, the control action has been designed in order to reduce the cognitive load required to accomplish the task. The use of NFC as well as a simple speech recognition system eases the human machine interaction. We hope that this interaction will be natural enough to encouraged chronic patients to integrate this tool in their everyday actions.

The main next step of our work is the system evaluation by led users in order to get an improved product that could be published in the android Play Store. Our aim is to conduct a long term observation of patients that use the app and patients who take their medicines as usual. In this way, we can measure the error reduction.

To reduce the digital knowledge required to perform the configuration function, the information about the drugs and their prescribed dose could be automatically saved in the phone database from a website controlled by doctors and/or pharmacists. The device could save the selected data in the NFC tag just by approaching to the medicament.

As recently the new iPhone 6 has NFC interface (The Verge, 2014) the system could be also developed in iOS platform.

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