A Pharmaceutical Intelligent Information System to Detect Allergies and Adverse Drugs Reactions based on Internet of Things

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***Abstract*— The incidence of serious and fatal Adverse Drugs Reaction (ADR) and harmful effects of pharmaceutical excipients in worldwide hospitals is extremely high. Some studies show a rate of ADR appearance about 6.5% in worldwide hospitals. The consequences of these cases lead to a rate of 80% of ADR incidences that require the patient admission, a medium bed stay of eight days, a cost of $847m and an overall death rate of 0.15%. Most of these consequences can be avoided. For this reason, a drugs checker based on Internet of things and a knowledge-based system is proposed in this paper to detect ADRs and allergy interactions. Specifically, the patient's terminal identifies the drugs by means of either NFC (Near Field Communication) or barcode, using common devices such as cellular phones, PDAs or PCs. This information is matched with the Pharmaceutical Intelligent Information System to detect whether a drug or product is compatible with its allergy profile and Electronic Health Record (EHR) or not. The system is being tested with a first approximation based on smart phones and a real patient which suffer a *non-steroidal anti-inflammatory drug* (NSAID) intolerance. This patient cannot tolerate some Active Ingredients (AI) such as *ibuprofen*. Therefore, when the patient checks a drug that contains one of the not tolerated AI, the system warns the patient about the incompatibility with his allergy profile and EHR, by means of a friendly interface.**

Keywords-*Internet of things; Ambient Assisted Living; Ontology; NFC; Barcode; Rule-Based System.*

I. INTRODUCTION

Adverse drugs reaction (ADR) and harmful effects of pharmaceutical excipients imply severe incidences, due to incompatibilities of the drug with the medical history. The rate of ADR appearance is extremely high in worldwide hospitals [1]. Hence, it represents an important clinical issue. Some studies have shown an ADR incidence about 6.7% of serious cases and 0.32% of deaths [2-3], over the total cases attended in worldwide hospitals. In Spanish hospitals the ADR ratio is 8% [4] and 6.5% in UK hospitals [5]. An example of ADR consequences are, according to the study carried out by the Royal Liverpool University Hospital (UK), admission in 80% of cases, with a medium bed stay of eight days, a cost of $847m and an overall fatality of 0.15%. Most of these consequences can be avoided with a review of drug interaction and allergies with some of the excipients. For this reason, we propose a drug checker based on Internet of Things and a knowledge-based system to detect ADRs and drug interactions. Our solution comprises a personal system to check the drug suitability using a wearable or mobile device, such as cellular phones, PDAs or laptops. The mobile device identifies the drug by means of NFC (Near Field Communication) or barcode. The compatibility of the drug with the patient profile is checked with the Pharmaceutical Information System (PIS), to detect whether the product is suitable according to the allergy profile and medical history (EHR). The Pharmaceutical Information System is composed of a database with all the drugs description, active ingredients, side effects etc., an ontology to define the patient's profile, including drugs concepts, and finally a rule-based system to detect allergies and adverse drug reactions. Some initial approaches to a Pharmaceutical Information System can be found in [6-9]. Concretely, a real deployment of the system is reached in [8-9], in Japan and Spain, respectively.

The goal of the system proposed in this paper is to prevent ADR by means of a pervasive interface using last mobile technologies. This is the reason why the terminal software has been developed for new smart phone, PDAs and PC platforms.

Currently, the proposed solution is being tested with a *Non-steroidal anti-inflammatory drug* (NSAID) intolerance patient profile. The patient cannot tolerate some Active Ingredients (AI), such as *salycilates, pyrazolone, indoleacetic derivates, anti-inflammatories* (e.g. *ibuprofen*), etc. Therefore, before he takes some drug that contains one of the AI previously mentioned, the system checks it and warns the patient about the incompatibility with his profile. In addition, adverse drugs reactions among different drugs are detected.

The rest of the paper is organized as follows. Section II presents the architecture of the pharmaceutical information system. Section III describes the different proposals to detect drugs and, finally, Section IV concludes the paper and lists the next steps to conclude the project.

II. PHARMACEUTICAL INFORMATION SYSTEM

The Pharmaceutical Information System comprises a knowledge-based platform to store and centralize drugs, allergies information and its effects on the patient. It is composed of three parts: an Oracle database [10], an ontology knowledge base defined with protégé [11] and a rule engine system based on Jess [12].

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A. *Knowledge-Based System (KBS)*

In order to define the PIS, an Oracle database has been developed to store all the information related to drugs, side effects, allergies, etc. This database is synchronized with the Spanish Pharmaceutical Association database [13] to embrace the whole set of current and future drugs of the market.

The structure of the database is presented in Fig. 1. It is explained showing two examples: the NSAID problem of the patient subject of study and an example of the drugs interaction problem.

The first example is based on the NSAID patient; his profile is stored in the Patient Table (PT) jointly with the Allergic Table (AT). PT contains the patient personal data, and AT the NSAID Active Ingredients not tolerated, such as: *salycilates, pyrazolone, indoleacetic derivates, anti-inflammatory* (e.g. *ibuprofen*), etc. In addition, a history Table (HT) with all the drugs used by the patient is stored in order to detect drug interaction and ADR incidences.

The second example is based on the detection of drugs chains, where a drug treats a symptom but causes a determinate side effect that is solved with the prescription of a second drug, instead of changing the first one to avoid the side effect. The database stores for each drug the Anatomical, Therapeutic and Chemical (ATC) classification system in the ATC table and the side effects in the Side Effects Table to detect that kind of interactions. A common error is prescribing a second drug to solve a problem caused by the first one, when the right solution is to change the first treatment. An evaluation of this problem is found in [7].

1. Knowledge Representation (ontologies).

The knowledge representation (KR) is based on ontologies; it has been carried out using Protégé. Fig. 2 illustrates the ontology used in the system to represent both the patient allergies and the drug information from the data base.

The patient allergies profile is composed of:

1- The Patient concept, which represents the patient general information (e.g. patient name).
2- The Allergic concept, which comprises the active ingredients and other excipients which are not tolerable by the patient. AI items represent the maximum dose tolerated for each via (because it is considered that the patient can tolerate low doses of some AI which are allergic).

The drug information represented is the dose, via, ATC and side effects, to detect problems related with interaction among drugs. For example, a drug consumed by the patient belongs to the ATC group *J01CR Combinations of penicillins, including beta-lactamase inhibitors* and he is currently consuming a drug from that ATC, such as *Augmenting,* which is an antibiotic. One of the side effects that may causes is nausea. Therefore, when the system finds other drugs such as *bismuth subsalicylate* to treat nausea, it advises about the possibility that nausea is caused by *Augmentine* and recommends this drug is changed for an alternative drug.

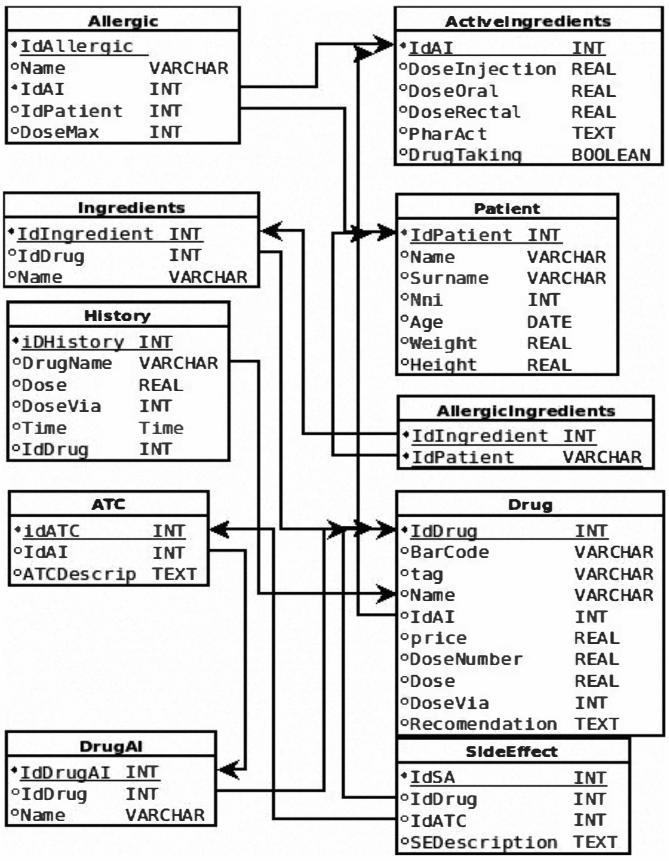

Fig. 1. Pharmaceutical Information System Database Structure.

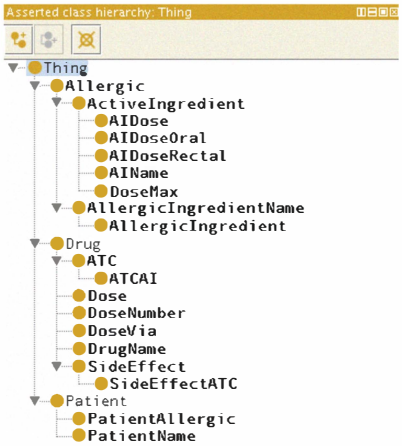

Fig. 2. Knowledge representation based on Protégé.

B. *Rules engine.*

Once the patient profile has been defined and the drugs information mapped on the ontology, the rule engine system is used to detect ADR, drugs interaction and allergies. The connection between Protégé and Jess is based on JessTab [14]. The current state of the rule system is limited to the detection of interaction among two or more drugs that the patient is consuming. It is planned to extend the system with the detection of complex interactions, such as the analysis of the impact of feeding habits, age, weight and other drugs with the drug absorption.

III. USE MODES BASED ON INTERNET OF THINGS

Internet of things (IoT) defines a new paradigm to identify and communicate with smart objects. One of the basis of IoT is Radio Frequency Identification (RFID) and, consequently, the integration of RFID in smart phones, NFC. For the identification of the drugs and patients, RFID/NFC tags have been considered. The problem is that devices integrating NFC are not extended yet. Therefore, barcode has also been considered, since it is used in all drugs of the market. Consequently, three different scenarios have been defined to identify drugs, one based on barcode and two based on NFC.

A. Access based on barcode using smart phones

Barcodes provides a unique number to identify a drug, but it is needed a way to decode this number and get information about the drug. Nowadays the majority of smart phones have a camera; hence, the solution can be based on this multimedia resource to scan barcodes.

For this project, a HTC G1 smart phone is used, which is based on Android operating system and Zebra Crossing, ZXing library [15] (an open source library to decode multi-format 1D/2D barcode).

Therefore, drugs are identified reading barcode. The resultant drug ID is then sent to the PIS, jointly with the patient's profile, using a wireless Internet connection (e.g. 3G or Wi-Fi). PIS matches the drug ID with its knowledge-base and the patient's profile, and sends an answer to the smart phone, which let us know whether this drug is either dangerous or is not. The Fig. 3 presents a use example based on the NSAID patient. The left image shows how a green screen indicates that the product is compatible with the patient (e.g. *paracetamol* is suitable for the test NSAID patient), whereas a red one warns about the contrary (e.g. *aspirin* is not suitable for the test NSAID patient).

Fig. 3. Reading barcodes using smart phone.

The smart phone application provides extended information about drugs, explaining why a drug is not compatible with the patient's profile. For example, the left screenshot of Fig. 4 lists *Aspirin* problems with the NSAID patient.

In addition, the smart phone solution enables the patient to define and update his profile. The middle screenshot of Fig. 4 shows the patient's profile, and the right one enables the user to update the patient profile using an intuitive and friendly interface.

Finally, the smart phone application allows to extend existing drug information and to add new ones to the PIS database, in order to improve the PIS knowledge base. Remark that information about new drugs added by the users is not stored directly in PIS, but it is saved into a verification subsystem instead, because it needs to be verified before being used by the system.

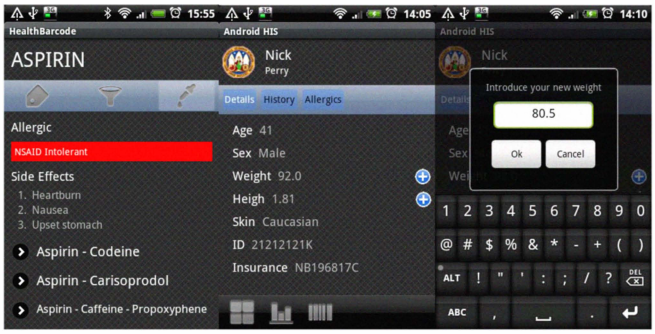

Fig. 4. Left: Drug extended information. Middle: Patient profile. Right: editing information.

B. Access based on NFC using Pocket PC

The second scenario takes advantage of IoT potential integrating NFC technology. In this case, for our test we have added an RFID tag to each drug box, which contains a unique ID in order to identify each drug without any doubt. The left image in Fig. 5 shows a drug box with an RFID tag (green sticker).

The NFC solution can be used in smart phones as well, but nowadays there are not many NFC-compliant models. This situation can change with NFC solutions based on MicroSD cards, which allows extending current cellular phones with NFC functionally. Meanwhile, the NFC test is being carried out using a Pocket PC, which uses the SDID 1010 NFC Card [16].

The process is similar to the barcode, but in this case the Pocket PC is approximated to the NFC-compliant drug, which reads the tag and starts the communication with PIS. When the mobile terminal receives the information it warns the patient about the compatibility of the drug. The right image of Fig. 5 presents the Pocket PC reading a drug tag.

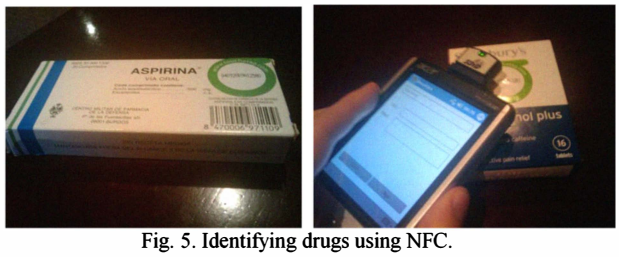

Fig. 5. Identifying drugs using NFC.

C. Access based on NFC using an USB Reader

While the previous solutions are oriented to the final users, the third approximation is especially useful to pharmacists. This is based on NFC as well, but in this case using a NFC USB Reader. The problem found from the pharmacists' point of view is that they cannot access to the patient profile and EHR, therefore they cannot detect the mentioned problems. This problem can be solved by two different approaches. On one hand, all the patient information can be stored at PIS, therefore it can be accessed by a pharmaceutical to identify users using his national insurance number or similar, and then the pharmacist may check the drug scanning it with the NFC Reader. On other

hand, it is proposed that the patient information is stored in a RFID smart card such as DESfire. It could be the same that the one used in many countries to identify patients, with the difference that this card provides a chip to store the PIS profile information. In addition, this card offers the security needed to manage confidential information [17]. The way to proceed is similar to the first case, but in this scenario the pharmacist does not have a web interface to get the patient drugs record. The information is obtained from the DESfire card, which can be read by pharmacists and doctors. After the chemist´s system reads the NFC DESfire card, it can process it, in the same way the first solution works, and finally the pharmacist can update the healthcare card with the new drug. A solution of electronic pharmaceutical card is proposed in [4].

The USB-based reader solution is being developed using the ACS 122 unit from Touchatag [18] and the libNFC library [19]. Fig. 6 shows how to identify drugs using a laptop and the USB reader.

Fig. 6. Identifying drugs using a NFC USB reader.

IV. Conclusion and Future Work

This paper presents an assisted living solution to solve the problem of adverse drugs reactions and allergy detection for patients attended in healthcare environments. The system proposes an innovative system that comprises two parts, the user front-end and a remote knowledge-based system.

At the user edge, drugs are detected by means of an interchangeable mobile device, considering the incipient NFC technology and a legacy identification solution such as barcode. Once the drug has been identified, this information is sent to the Pharmaceutical Intelligent Information System, where decomposed active ingredients are matched with the patient's allergy profile and electronic health record, in order to detect potential reactions. This information system uses ontologies to model the user profile and drugs, in order to apply inferring rules to detect side effects and potential problems with (combined) active ingredients. If so, the user is finally notified by using a friendly interface at the mobile terminal.

The system has been designed in a flexible way, enabling the extension to other mobile platforms or identification technologies. Moreover, the applicability in the real world can be direct. The drug database used is synchronized with the Spanish Pharmaceutical Association database, to embrace the whole set of current or future drugs. Even, a concrete patient, with an NSAID allergy profile, is considered to test the system under real conditions.

The current working point in the project is focused on the NFC-based solution for the mobile terminal. In next steps, we have planned to fulfill other cases of test, with other allergy profiles, and to extend the ontology and rule-based system to detect other kind of drug interactions, such as the impact of feeding habits or age with the drug absorption. Finally, we are currently waiting for the arrival of an NFC MicroSD card from RFinity, expected in Q1 2010. In this way, a wide spectrum of smart phones will support our NFC-based solution.

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