Abstract—Providing effective and appropriate healthcare is one of the most important objectives of information and communication technologies (ICT). Internet of things (IoT) is one of the last advances in ICT, providing a global connectivity and management of sensors, devices, users and information. Our contribution is a solution to examine drug related problems based on IoT technologies, i.e., smart phones and Web to support ubiquitous Access, 6LoWPAN technology to support ubiquitous data collection of patients, sensors and hospitals, and RFID/NFC to support global identification. These technologies offer a wide range of applications in healthcare, which improves the quality of services, reduce mistakes, and even detect health anomalies from vital signs. This paper presents how IoT technology is applied in a pharmaceutical system to examine drugs in order to detect Adverse Drugs Reaction (ADR), harmful effects of pharmaceutical excipients, allergies, complications and contraindications related with liver and renal defects, and harmful side effects during pregnancy or lactation. Thereby, the system provides an enhanced approach assisting physicians in clinical decisions and drug prescribing. The solution presented is based on NFC (Near Field Communication) and barcode identification technologies, which have been integrated in common devices such as smart-phones, PDAs and PCs. The drug ID is matched with the Pharmaceutical Intelligent Information System to detect whether a specific drug is suitable with respect to the patient’s health record or not.

Index Terms—Internet of Things, Pharmaceutical, Drug Checker, NFC, RFID, Barcode.

I. INTRODUCTION

Severe incidences take place in hospitals worldwide due to clinical errors and negligence are responsible for disabling injuries in about 1 in 25 hospital admissions [1]. Most of these injuries are caused by Adverse drugs reaction (ADR) events, which prolong hospital stay, increase care costs, and nearly double a patient’s risk for death [2], [3]. About one third of adverse drug events occur during drug administration, when interception is unlikely [4]. The confusion caused by expressing the concentrations of drug solutions in different ways is an important cause of dose errors [5]. Converting between ratios, percentages, international units, moles, micrograms, and milligrams causes substantial difficulty, especially for less experienced physicians. For example, Epinephrine, lidocaine, heparin, and potassium chloride are frequently associated with drug errors, it may be no coincidence that the strength of these drug solutions are typically expressed in ratios, percentages, international units, and millimoles, respectively. In addition, Adverse Drugs Reaction (ADR) and harmful effects of pharmaceutical excipients are important clinical issues due to the ADR rate appearance in hospitals. Some studies present an ADR incidence about 6.7% of serious cases and 0.32% of fatality [6], [7], over the total cases attended in hospitals worldwide. The ADR ratio is 8% in Spain [8] and 6.5% in the UK [9]. A recent study by the Royal Liverpool University Hospital (UK) shows an example of the ADR consequences; the 80% of the cases required hospital admission with a medium bed stay of eight days and a cost of $847m. The fatality rounded 0.15% of the cases. These problems may be avoided following a deep review of prescribed drugs, interactions and other complications. For this reason, we proposed a drugs checker using Internet of Things and a knowledge-based system to check dose, detect ADRs and drug interactions. Our solution comprises a personal system to check the drug suitability based on mobile devices, such as smart 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 Intelligent Information System (PIIS), to detect whether the product is suitable according to the allergy profile and medical history of the patient, i.e., Electronic Health Record (EHR). Each time the physician prescribes a new drug to the patient and this drug is added to the patient’s history record, the system checks any possible interactions, and warns the doctor the possibility of alarming interactions.

PIIS is composed of: a database, an ontology, and a rule-based system. The database is presented in the Figure 1, where arrows present the relations and link between the different tables, the content of this database is a detailed drug description, with details such as active ingredients and side effects. The ontology is used to define the patient’s profile, including drugs concepts. Finally a rule-based system to detect allergies and ADR.

Some initial approaches to the Pharmaceutical Information System can be found in [10], [11], [12]. An approach to deployment of PIIS in Ambient Assisted Living environments can be found in [23]. An approach close to the Internet of things, since it is also based on RFID tags as a medium to access to drug identification can be found in [24]. Finally, real deployments of this type of solutions has been carried out in Japan [11] and Spain [12].
The aim of the system proposed in this paper is to prevent ADR, such as the previous version of this system [13]. In addition, this new version detects active ingredient interactions, renal impairment complications, contraindications in pregnant and lactating women, and problems related with absorption in the stomach. The system has been already tested with Non-steroidal anti-inflammatory drug (NSAID) intolerance patient profile and will be further tested with other drug complications.

The rest of the paper is organized as follows: Section II presents drug related problems by various health services. Section III describes the architecture of the Pharmaceutical Intelligent Information System (PIIS). Section IV presents the different user interfaces and ways to access the drugs ID based on barcode and NFC. Finally, section V concludes this paper and presents the ongoing work.

II. DRUGS INTERACTIONS

Today, drug interactions are major problem in the pharmaceutical and the medical care. Diversity of drugs generates various long and short term complications, such as drug drug interactions and ADR. Undesirable side effects and drug related complications are in most cases unavoidable, but amendments and cautions are vital, even with commonly used drugs such as over the counter medicines.

As an example, a person who suffers depression may be treated with a Selective Serotonin Reuptake Inhibitor (SSRI) antidepressant, such as escitalopram. If the patients also suffer from pain such as headache or joint inflammation disorders, an OTC NSAIDS can be bought without a prescription or it can even get prescribed such as ibuprofen. NSAID’s interacts with escitalopram increasing the risk of bleeding especially in higher risk patients. Other factors that may cause drug related complications include include: age, gender, disease state, liver and renal defects. Assessing patient health profile, previously prescribed drugs and monitoring are essential for safe prescribing.

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A. Drug allergies caused by the active ingredient

Drugs may also produce allergic reactions in hypersensitive patients such as skin rashes and dyspnoea (breathing difficulties) when for instance taking penicillin. This intelligent system is capable of alarming the patient and the prescriber of any relevant allergic reaction risks. An example is presented in Figure 2.

B. Active Ingredient Interactions

This is a drug-drug interaction where the first drug effects the activity of a second drug, either increase or decrease its effect. It may even produce a new effect that would not be produced by its own. In some cases these interaction can be toxic and fatal, or produce undesirable side effects. The risk can be avoided using a such intelligent system that warns of any drug drug interaction and the effects it may produces and also a proposed solution.

C. Drugs Loop

A frequently problem in hospitals is the drugs loop. This problem occurs when an administered drug generates undesirable side effect, which is solved with a second drug instead of changing the drug which caused the side effect. For example, a drug belongs to the Anatomical, Therapeutic, Chemical drug classification (ATC) group J01CR Combinations of penicillins,
including beta-lactamase inhibitors and he is consuming a drug from that ATC such as Augmentine which is an antibiotic. One of the side effects that may causes is nausea. Therefore, when the system finds other drugs such as bismuth subsaliclylate to treat nausea, it advises about the possibility that the nausea is caused by Augmentine. Thereby, doctor changes the problematic drug by an alternative. The Figure 3 presents a diagram with this type of problem:

D. Renal Impairment

A number of drugs require dose adjustment according to the renal and liver function especially those drugs that are excreted by the kidney or liver respectively. Depending on the biological test (e.g. 45mL/minute/1.73 m²). Thereby, doctor is able to adjust the dose for prescribing drugs such as Perindopril Erbumine. An example of this situation is found using Lisinopril. Dose needs to be calculated in function of the Glomerular Filtration Rate, which are:

- Maximal initial doses 5 - 10 mg daily if GFR (Glomerular Filtration Rate) is 30 - 80 mL/minute/1.73 m² (max. 40 mg daily)
- 2.5 - 5 mg daily if eGFR 10 - 30 mL/minute/1.73 m² (max. 40 mg daily)
- 2.5 mg daily if eGFR less than 10 mL/minute/1.73 m²

E. Pregnancy

There are some drugs that must be either avoided or controlled during the beginning or during pregnancy and lactation, due to the potential damage produced to the fetus and/or the mother. Examples include:

- **Captopril**: should be avoided in the first few weeks after delivery, especially in preterm infants, since risk of profound neonatal hypotension.
- **Cilazapril**: is not recommended. However, alternative treatment options, with better established safety information during breast-feeding.
- **Ramipril**: is not recommended. Alternative treatment options, with better established safety information during breast-feeding are available. To be avoided in 2nd and 3rd trimester of pregnancy.
- **Quinapril**: should be avoided in the first few weeks after delivery, particularly in preterm infants, due to the risk of profound neonatal hypotension.

F. Optimizing the absorption depending on the time

It is important to optimize the absorption, knowing when the drug should be used. Sometimes is important from the point of view for getting better results, but other times, is important due to the possible ADR, which could cause the ingestion of two different drugs in a short period of time. This case is presented in the Figure 4.
III. PHARMACEUTICAL INTELLIGENT INFORMATION SYSTEM

The Pharmaceutical Intelligent Information System (PIIS) is composed by a knowledge-Based System which contains a rule-engine system to detect the possible interactions between prescribed drugs patient, and an ontology where is described the drugs concepts and patients information.

A. Ontology

The drugs and patient information is stored in a database which is mapped into the ontology. The ontology is developed based on Protégé [14], it is presented in the Figure 5.

The information showed on the Figure 5:

- **ATC**: is the Anatomical, Therapeutic, Chemical drug classification.
- **Dose, DoseNumber and DoseVia**: information about the dose recommended and the via through which is injected.
- **DrugName**: the name of the drug.
- **RenalInteraction**: information needed in order to detect renal interactions.
- **Indications**: show the drug indications. They are useful to detect other types of interactions.

Regarding to the allergies, it can be found:

- **ActiveIngredient**: is the active ingredient that causes an allergy.
- **AllergicIngredientName**: an ingredient that causes an allergic.

Examples of values for the ontology concepts described are found in the table of the Figure 6. Where are presented some drugs mentioned for the examples from the Section II.

B. Rules-based system

Once the patient health record has been defined and the drugs information mapped on the ontology, the rule engine system is used to detect drugs interactions and allergies. The connection between Protégé and Jess [15] is based on JessTab [16]. The current state of the rule system has defined rules to the detection of interaction among two or more drugs that the patient is consuming, allergies produces by some drugs or ingredient and drugs loops. In addition, the system detects other reactions taking into account another factors such as the age, the liver, the heart and circumstantial states such as the pregnancy or lactancy.

Some rules of the rules-engine are presented in the table of the Figure 7. For example, the first rule detects drugs interactions, the main properties used are; Active Ingredient and Active Ingredient Incompatible. Thereby, it is able to detect when an Active Ingredient is in the list of not compatible Active Ingredients from other drug. The second rule detects patient allergies, the main properties used are Active Ingredient and Patient Allergic Ingredients. Finally, the third rule presented is to detect drug loops, which is based on Side Effects and Indication properties.

IV. DRUGS IDENTIFICATION BASED ON IOT

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 the devices which integrate NFC are not very extended. Therefore, barcode has also been considered as legacy technology until the NFC is widely extended. In addition, barcode is found in
all the drugs from the market. Consequently, three different scenarios have been defined to identify drugs, one based on barcode and the rest based on NFC.

A. Access based on barcode using smart phones

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 Google Nexus One smart phone is used, which is based on Android operative system and Zebra Crossing, ZXing library [17] (an open source library to decode multi-format 1D/2D barcode). Therefore, drugs are identified reading barcode. Drug ID is sent to the Pharmaceutical Intelligent Information System jointly the patient profile using Internet connection (e.g. 3G or Wi-Fi). PIIS matches the drug ID with its knowledge-Based system and the patient profile, and send an answer to the smart phone, which let us know whether this drug is dangerous or not. The Figure 8 presents an use example based on the NSAID patient; left one shows that the screen is green when the product is compatible with the patient (e.g. paracetamol is suitable for the test NSAID patient) and red when is not (e.g. aspirin is not suitable for the test NSAID patient).

The smart phone application provides extended drugs information, where is explained because a drug is not compatible with the patient profile. For example, the up left Figure 9 presents the explanation of Aspirin problems with NSAID patient. In addition, the smart phone solution allows to the patient defines and updates his profile. The up right Figure 9 presents the screen with the patient profile and down Figure 9 presents how to update the patient profile using an intuitive and friendly interface. Finally, the smart phone application allows to extend existing drugs information and to add other ones to the PIIS database, in order to improve the PIIS knowledge-base. Remark, information added by the patients is not stored directly into the PIIS, it is saved into a verification subsystem PIIS since it needs to be verified before that it is available for the system and other patients.

B. Access based on NFC using Pocket PC

The second scenario uses the potential of Internet of things with NFC technology. In this case for our test we have added a RFID tag to each drug box, which contains a unique ID in order to identify each drug without any possible mistake. NFC solution can be used in smart phones too, but nowadays are not very extended the models with NFC technology. Meanwhile the NFC test is being carried out using a Pocket PC, which uses the SDID 1010 NFC Card [18]. The process is similar to the barcode, but in this case the Pocket PC is approximated to the NFC drug tag, which reads the tag and starts the

<table>
<thead>
<tr>
<th>Rule</th>
<th>Jess’ Rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drug Interaction Rule</td>
<td>(define rule1 (object (?x-a http://PIIS_amiptado.owl#Drug) (object ?d1)</td>
</tr>
<tr>
<td></td>
<td>(http://PIIS_amiptado.owl#ActiveIngredient ?ai)</td>
</tr>
<tr>
<td></td>
<td>(object (?x-a http://PIIS_amiptado.owl#Drug) (object ?d2)</td>
</tr>
<tr>
<td></td>
<td>(http://PIIS_amiptado.owl#ActiveIngredientI)</td>
</tr>
<tr>
<td></td>
<td>ncompatible ?aii)) (test (= (?ai ?aii)) =&gt; (printout &quot;Drug Interaction found&quot;))</td>
</tr>
<tr>
<td>Allergy Interaction Rule</td>
<td>(define rule2 (object (?x-a http://PIIS_amiptado.owl#Drug) (object ?d1)</td>
</tr>
<tr>
<td></td>
<td>(http://PIIS_amiptado.owl#ActiveIngredient ?ai)</td>
</tr>
<tr>
<td></td>
<td>(http://PIIS_amiptado.owl#PatientAllergic ?pa)</td>
</tr>
<tr>
<td></td>
<td>(test (= (?ai ?pa)) =&gt; (printout &quot;Allergy Interaction found&quot;))</td>
</tr>
<tr>
<td>Drug Loop Rule</td>
<td>(define rule3 (object (?x-a http://PIIS_amiptado.owl#Drug) (object ?d1)</td>
</tr>
<tr>
<td></td>
<td>(http://PIIS_amiptado.owl#SideEffect ?se))</td>
</tr>
<tr>
<td></td>
<td>(object (?x-a http://PIIS_amiptado.owl#Drug) (object ?d2)</td>
</tr>
<tr>
<td></td>
<td>(http://PIIS_amiptado.owl#Indication ?in))</td>
</tr>
<tr>
<td></td>
<td>(test (= (?se ?in)) =&gt; (printout &quot;Drug Loop found&quot;))</td>
</tr>
</tbody>
</table>

Fig. 7. Jess’ rules.
communication with PIIS. The Figure 10 presents the Pocket PC reading a drug tag.

C. Access based on NFC with USB Reader

Other solutions that were made are oriented to final user or customer so far. This new kind of solution is also based on NFC, but in this occasion using a NFC USB Reader. This scenario is oriented to pharmacists, the problem found from the pharmacists point of view is that they do not have access to the patient profile and EHR, therefore they cannot detect the mentioned problems. This problem can be solved from two approaches. On one hand, all the patient information can be stored in the PIIS. Therefore it can be acceded by pharmaceutics solution identifying users by his national insurance number or similar, and then the pharmacist may check the drug scanning it with the NFC Reader. On other hand, the patient information is stored in a RFID smart card such as DESFire. It could be the same that is used in many countries to identify patients, with the difference that his card provides a chip to store the PIIS profile information. In addition, this card offers the suitable security to manage confidential information [19]. 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 gotten from the DESFire card, which just can be read by the pharmacists and doctors. After the pharmacist had read the NFC DESFire card, they can process it, at the same way that the first solution, and finally the pharmacist can update the healthcare card with the new drug.

A solution of electronic pharmaceutical card is proposed in [8]. An optimized structure in NFC/RFID cards to reduce access latency, optimize capacity, and guarantee integrity has been defined for the pharmaceutical cards [20]. The information stored in the patient’s card is presented in the Figure 12, where are applied the mentioned optimizations.

The USB reader solutions is being developed using the ACS 122 reader from touchatag [21] and the libNFC library [22]. The Figure 11 presents how to read drugs using a laptop and the USB reader.

V. Conclusion and Future Work

This paper presents a solution to solve clinical errors from drugs reactions and dose. The system proposes an innovative system based on Internet of things for the drugs identification and a remote knowledge-based system (ontologies and rules-engine). Drugs are identified by means of an interchangeable mobile device and 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. The system has been designed in a flexible way.

A patient, with an NSAID allergy profile, has been considered to test the system under real conditions. The drugs database is synchronized with the Spanish Pharmaceutical Association database (PortalFarma), to embrace the whole set of current and future drugs, and keep it update. Ongoing work is going to be, on one hand, extend the solution with additional drugs interactions; in addition rules-engine system is going to be specialized to consider more specific cases from real cases. On other hand, NFC microSD card from Tyfone is going to be integrated for Q4 2010.
Fig. 11. Identifying drugs using a NFC USB reader.

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