NFC-Enabled Smartphone Application for Drug Interaction and Drug Allergy Detection

by

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Submitted in partial fulfilment of the requirements for the degree of Master of Computer Science

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Abstract

An estimated 70,000 preventable medication errors occur in Canada annually, causing 9,250 to 23,750 deaths. Medication errors increase when the number of medications being administered increases. Therefore, people with multi-morbidity who take several medications at once are more vulnerable to medication errors.

Medication errors can be prevented by developing and managing an efficient healthcare system integrated with technology. Recently, several wireless technology applications have been developed to prevent medication errors. Near Field Communication (NFC) technology, in particular, has been shown to improve the quality of health care and increase patient safety. NFC has a powerful ability to identify and track objects such as patients and medications; its identification and tracking abilities give it significant potential especially in detecting drug interaction and drug allergy.

The main objective of this thesis is to present a novel solution using a smartphone integrated with an NFC reader and an NFC application to detect and update drug allergies and drug interactions for people with multi-morbidity during medication administration. According to our literature review, this proposed system is the first of its kind. The system scope focuses on detecting a drug allergy or drug interaction, alerting the nurse, the physician, and the pharmacist, providing adequate information about the case detected, enhancing the communication among the treatment staff, updating the patient's health record in case of an unknown allergy or non-recorded allergy detected by the nurse.

The system has been implemented using Samsung Nexus S smartphone with Android 2.3.6 platform, MIFARE Classic 1K tags, and a database populated with 10 patients' record and 30 medications. The system was validated for the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), accuracy, and computational and communicational cost.

List of Abbreviations Used

NFC - Near Field Communication

RFID - Radio Frequency Identification

DAE – Drug Adverse Event

Chapter 1: Introduction

In 2007, at Australia's Prince of Wales Hospital, a 21-year-old leukemia patient died after being administered Vincristine instead of Vinblastine [1]. Moreover, the wrong-prescribed drug was injected into her vein instead of her spine. The tragedy, caused primarily by the similarity in the drug names, should serve as a wake-up call for health care teams world-wide, as the young victim was not the first nor has she been the last victim to die as a direct result of medication errors.

In the medical field, medication errors lead to significant clinical and financial consequences [2]. In Canada alone, medication errors are the third leading cause of death after cancer and heart disease [3]. An estimated 70,000 preventable medication errors occur in Canada annually, causing 9,250 to 23,750 deaths [4]. However, these numbers may be grossly understated, as more than 40% of medication errors are not reported [5] [6].

Moreover, medication errors increase when the number of medications being administered increases. Multi-morbidity patients with more than one chronic disease (such as cancer, heart diseases, chronic respiratory diseases, diabetes, mental illness, and musculoskeletal diseases) are more likely to take several medications at once [7] [8]. An average of 35 to 74 prescriptions are given to Canadian patients with multi-morbidity compared to an average of 14 prescription per Canadian; the older the patient, the greater the likelihood that the number of prescriptions will increase [7]. Consequently, people with multi-morbidity are more vulnerable to medication errors. The occurrence of medication errors such as adverse drug events in patients with multi-morbidity can have impacts that seriously affect patients' quality of life [6] [9].

Medication errors can be reduced depending on the detection method used [6]. However, as of yet, there is no method or strategy that has been effective in Canadian hospitals for preventing medication errors, especially for nurses. Whereas physicians and the pharmacists often have some software or documented information to rely on before prescribing or dispensing the medication, the nurses have nothing to aid them during medication administration but their own knowledge, which makes them more likely to commit errors [5]. In case of an error, the nurse usually tries to communicate with the case physician or pharmacist by making a call and/or writing a report to get instructions and critical information that will help to rectify the action. However, nurses find that this way of communication is ineffective, time-consuming, and keeps them away from attending to their patients. Moreover, phone calls cannot completely convey critical observations and a report may not be read. Therefore, nurses, physicians, and pharmacists need to get a better understanding of the case to be able to share the right information with each other [10]. A more effective form of communication would help them to avoid medication errors and increase patient safety [5].

Nowadays, technology plays a major role in improving health care quality and can even, to a certain extent, replace the nurse's senses of sight, smell, touch, and hearing to monitor a patient's conditions [11]. The need to enhance patient safety and control medication errors has increased attention on radio frequency identification (RFID) technology. RFID is a wireless communication technology that uses radio frequency to transfer data from a tagged object. RFID has the ability to identify, track and monitor objects. However, although RFID holds great promise in the health care sector, its benefits may not be realized due to four main limitations. These are: lack of patient information privacy and security; the potential for electromagnetic interference between medical devices and the RFID reader; the large size of an RFID system when integrated with a laptop or a PDA; and, the complexities of the RFID system interface [12] [13] [14] [15].

Another closely related wireless technology to RFID is Near Field Communication. NFC is a short-range radio communication technology. NFC

removes the interference, the security, and the privacy drawbacks of RFID because it operates within a ten-centimeter range. One of the biggest catalysts to NFC usage is the recent integration of smartphone with NFC technology.

The main objective of this thesis is to present a novel solution using a smartphone integrated with an NFC reader and an NFC application to detect and update drug allergies and drug interactions for people with multi-morbidity during medication administration. The novelty of our application uses an NFC-enabled smartphone, which has an easy-to-use graphical user interface to streamline the process of preventing drug allergies and interactions without threatening the patient's privacy and security or causing electromagnetic interference with medical devices. According to our literature review, this proposed system is the first of its kind

The system scope is the following:

- Detecting a drug allergy or drug interaction.
- Alerting the nurse, the physician, and the pharmacist.
- Providing adequate information about the case detected.
- Enhancing the communication among the treatment staff.
- Updating the patient's health record in case of an unknown allergy or non-recorded allergy detected by the nurse.

The motivations behind our novel application are as follows: the need to prevent drug allergy and drug interaction errors for patients with multi-morbidity; the need to enhance communication among members of the patient's treatment team; the need to decrease the time spent to get advice and critical information from physicians and pharmacists; need for an easy-to-use system; the need for a secure technology that does not compromise patient privacy or security; the need for a suitable technology that functions without interfering with other medical devices.

In this study, our hypotheses are:

- The NFC application system is able to detect drug allergy and drug interactions for people with multi-morbidity during the medication administration stage.
- The NFC application system can notify physicians and pharmacists about drug allergy and drug interactions immediately after detecting a drug allergy or drug interaction case.

The system has been implemented using Samsung Nexus S smartphone with Android 2.3.6 platform, MIFARE Classic 1K tags, and a database populated with 10 patients' record and 30 medications. The system was validated for the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), accuracy, and computational and communicational cost.

The rest of the thesis is organized as follows. Chapter 2 discusses the background and literature review of previous works and also gives a brief introduction to Near Field Communication (NFC) technology, providing a comparison between NFC and RFID in healthcare applications. As well, Chapter 2 presents a brief overview of medication errors and current applications that have been designed to reduce them, and discusses issues surrounding patients with multi-morbidity and the role of the treatment team in medication errors. Chapter 3 discusses the proposed framework for the NFC application to detect and update drug allergies and drug interactions in people with multi-morbidity. Chapter 4 shows the proof of concept for our application and demonstrates its feasibility. Chapter 5 analyzes the application's performance precision as well as the computational and communicational cost for sending a text message (SMS) to the attending physician and pharmacist. Finally, Chapter 6 discusses the limitation of our application and the future work.

Chapter 2: Background and Literature Review

2.1 Near Field Communication

Near Field Communication (NFC) is a short-range radio communication technology that operates on the 13.56 MHz frequency with data transfers up to 242 kbit/s. NFC relies on smartcard standard ISO 14443, which makes it compatible with a large number of contactless smartcards. In addition, it allows for a simple and secure information exchange, and typically operates within a tencentimeter range [16] [17] [18].

NFC technology has been applied in various mobile phones, such as Google, Blackberry, Nokia, HTC, and LG. NFC-enabled smartphones have a built-in NFC reader in the smartphone's shell. They also have a built-in NFC tag/smart tag with an antenna that helps transfer information from one NFC-enabled smartphone to another or to external NFC tags. Thus, the NFC-enabled smartphone can function as a contactless card and as a reader, which gives it significant potential. Moreover, NFC's technological capabilities make it widely applicable to several areas, such as payment, transportation, and healthcare [16] [17] [18].

2.1.1 NFC Modes of Operation

An NFC-enabled smartphone has the ability to adjust its operation mode to any of the following:

2.1.1.1 Card Emulation Mode

In this mode, the NFC-enabled smartphone functions as a smartcard with an ability to send information. For example, an NFC-enabled smartphone can be configured to be used as an access card, rail pass, or credit card [16] [17].

2.1.1.2 Reader Emulation Mode

In this one-way communication mode, the NFC-enabled smartphone functions as an NFC reader that can read a passive tag. In other words, the tag sends out data but cannot receive any from the NFC reader. An example of this is an NFC-enabled smartphone using an NFC reader to read a poster [16] [17].

2.1.1.3 Peer-to-Peer Mode

In this mode, two NFC-enabled smartphones exchange information where both devices generate their own radio fields [16] [17]. Figure 1 illustrates the three NFC modes of operation [17].

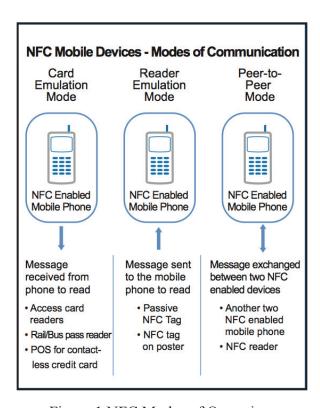


Figure 1.NFC Modes of Operation

2.1.2 NFC Compared with RFID

Although the recently-introduced NFC is an RFID-based technology, it has relatively short-range radio communication, while RFID has a longer range and has been on the market for some time. Both technologies can identify objects; however, the NFC is more secure due to its shorter range, whereas the RFID has a greater potential for unauthorized tag readings, known as eavesdropping. NFC's short-range reading capacity lowers its potential for eavesdropping, even if the tags are not sufficiently secured [16] [19].

There are currently numerous terminal devices for RFID (e.g., PDAs and laptops) that have been integrated with an RFID reader. However, RFID does not yet occupy enough space in the smartphone area compared to NFC, and having an NFC reader and tag in a smartphone gives it benefits in terms of availability and usability.

On the other hand, NFC requires more hands-on contact because the reader needs to be in close proximity to the tag, which is one significant benefit of RFID technology. Moreover, is that RFID can give the user the ability to monitor objects, which the NFC cannot do due to its short-range reading capacity [16] [17].

2.1.3 RFID and NFC Applications in Health Care

Wireless communication applications play a major role in health care environments. RFID and NFC technologies, in particular, have been shown to improve the quality of health care and increase patient safety. Figure 2 illustrates the modality of using RFID/NFC in medication care [16].

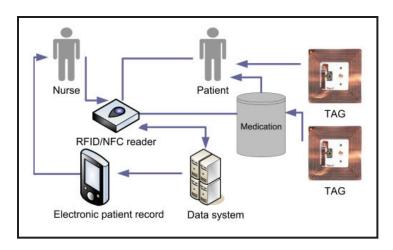


Figure 2. Modality of Using the RFID/NFC in Health Care Environments

Moreover, RFID has a powerful ability to track items. In a study by Halamka [20], RFID was used to track medical objects such as IV pumps, medical equipment, tools, devices, and even employees and patients. The purpose of Halamka's study was to determine whether RFID technology could replace barcode tracking, with RFID showing significantly favorable results. Another study by Wang et al [21] used RFID to track SARS (Severe Acute Respiratory Syndrome)-infected patients, aiming to track the occurrence of any new infections and to increase patient safety.

Additionally, due to RFID's high monitoring functionality, a study by Dalton and Rossini [22] used RFID technology for blood transfusion monitoring. In this application, the caregiver would read both the patient's tag and the blood tag; if these tags matched, then the transfusion could safely performed. The purpose of the study was to test the efficacy of RFID to supervise blood donations and transfusions.

Moreover, Bardram [23] developed a context-aware RFID system, where the patients and the caregiver wear tags while the system monitors their activities. This system was intended to develop hospital infrastructure and applications. Similarly, Laboratories [24] developed a hygiene monitoring system, where an

RFID reader was placed on a hygiene dispenser and RFID tags placed on a caregivers' badges. The dispenser collected information about its users and then made a report. The purpose of this system was to maintain proper hand hygiene for patient and employee safety.

In addition, RFID technology is useful for identification purposes, such as identifying patients, health care teams, and medications. Identification verification can be used to increase patient safety and enhance work quality [25] [12].

Unlike RFID, NFC has only recently been introduced to the health care environment and therefore has not yet been widely researched in studies. Nevertheless, a study by Iglesies et al [19] has applied NFC for health monitoring purposes at home. This application is intended for the elderly, who can use an NFC-enabled device to touch an NFC reader to be identified, after which health information, such as weight, blood pressure, temperature and heart rate, is wirelessly collected. This information is then used by caregivers for health monitoring purposes.

Other research by Swedberg [26] has applied NFC for home healthcare. In one application, a caregiver's visits are confirmed by an NFC tag attached to the wall of a patient's home. The caregiver uses an NFC-enabled cell phone to touch the NFC tag when he/she visits the patient. Information about the caregiver, the patient, and the services that have been provided to the patient is transmitted to a server.

Another NFC application presented for home health care tracks the medication being taken by a patient. It features a locked medication dispenser integrated with an NFC tag, which releases a specific amount of pills when an NFC-enabled cell phone touches the dispenser [26]

In addition, other research by Swedberg [26], briefly discusses an additional NFC application for home health care, where a patient uses an NFC-enabled cell phone to send an alert to a health care center in case of emergency.

In the study by Bravo et al [27], NFC was used to support Alzheimer patients, who are tagged with an NFC tag that stores all of the incidents that he/she has been involved in. With the aid of an NFC-enabled cell phone, a caregiver can read the information stored in the tag and appropriately determine rehabilitation exercises.

NFC research by Morak et al [28] has also been applied to monitor patients with chronic diseases, especially congestive heart failure. The patient does a self-measurement for blood pressure, body weight and other health-related parameters, where he/she touches the measurement device via an NFC-enabled cell phone to transmit her/his measurements to the monitoring center.

Moreover, like its predecessor RFID, NFC technology been applied for identification purposes. Each admitted patient is given an NFC tag that has corresponding information in the electronic medical record. This application gives caregivers access to the patients' database easily by reading the patients with a hand-held device [29].

2.2 Medication Errors

Recent literature in health care quality and safety reveals a crucial statistic regarding preventable medication errors. The U.S. Institute of Medicine reported an estimated 44,000 to 98,000 hospital deaths per year caused by preventable medication errors. Similarly, the Canadian Adverse Events Study reported an estimated 70,000 preventable medication errors, causing 9,250 to 23,750 deaths annually [4].

A medication error can be 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" [6]Medication errors can happen in any of the following stages:

- Prescribing stage (issuing the drug order), which is done by a physician.
- Dispensing stage (preparing the drug order), which is done by a pharmacist.
- Administration stage (providing the drug to the patients), which is done by a nurse [30] [25].

Research shows that the percentage of medication errors is highest in the administration stage, reaching up to 61% [6] [31]. Research suggests that these errors are attributable to nurses' lack of knowledge coupled with their intensive workload. In other words, as the number of medications being administered increases, the challenge of preventing medication error likewise increases [6] [5].

The various types of medication errors that can occur in the medication administration stage include: "wrong dose, wrong choice, wrong drug, known allergy, missed dose, wrong time, wrong frequency, wrong technique, drug interaction, wrong route, extra dose, failure to act on test, equipment failure, inadequate monitoring, [and] preparation error" [6]. Researchers state that drug interactions and known drug allergies are serious prevalent types that substantially appear during the administration stage and lead to an adverse drug event (ADE). ADE can be defined as "as injuries that result from medication use" [6]. The occurrence of an ADE not only increases the length of a patient's stay (thus increasing care costs) but also leads to higher instances of mortality [32].

2.2.1 Drug Interaction and Drug Allergy

Drug interaction can be generally defined as "the effects of one drug [being] changed in the presence of another drug" [33] Research indicates that the

occurrence of drug interactions range between 16.6 and 59.1 % of all ADEs [33], and that a single case of drug interaction may cost the hospital up to \$70,000 [34].

Drug allergy can be defined as "an immune-mediated hypersensitivity reaction to a medicinal product" [35], with studies reporting that drug allergies range from approximately 5 to 10% of all ADEs [36]. Significantly, allergies appear to be most associated with drugs that are commonly used as medications, such as antibiotics and nonsteroidal anti-inflammatory drugs, as well as with drugs that are rarely used or have never been tested for [6].

2.2.2 Currently Used Solutions for Medication Errors Using RFID and NFC

An overview of the current literature shows that technology such as RFID plays a major rule in controlling medication errors. Some researchers focus on the identification functionality of RFID to reduce medication errors. Yu et al [37] present a wireless mobile multimedia system based on RFID technology that aims to reduce medication errors by avoiding the potential of patient misidentification during the medication administration stage. The nurse in this system uses a PDA integrated with RFID to read the patient's RFID tag to access his/her electronic health record where all his/her treatment details are stored [37]. Similarly, another study by Aguilar et al [38] presents a model that uses an RFID technology to identify the patient to avoid serious risk to patient safety. The nurse uses an iPAQ pocket PC with a Windows Mobile 2003 platform that is integrated with an RFID reader to read the patient's wristband and access a summary of the patient's information. Figure 3 illustrates how RFID is used for patient identification [16].

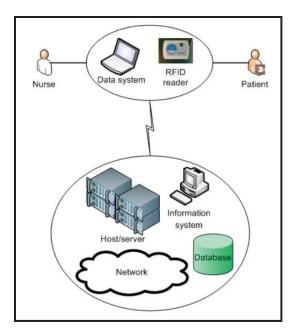


Figure 3. RFID System for Patient Identification

Other studies combine RFID and barcode technologies to reduce medication errors. In Wu et al model [25], a nurse reads a drug's barcode with a barcode reader and a patient's RFID tag with an RFID reader. If the information in the patient's tag does not match the information in the drug's barcode, the nurse will be alerted. A research by Sung et al [2] presents a similar system, Integrated Drug Information System (IDIS), which likewise aims to reduce medication errors. This system focuses on medication errors that occur in the medication administration stage. It uses a computerized drug cart in the patient's room that is equipped with an RFID reader as well as a barcode reader. The system has the ability to provide patient data, drug information, drug images, drug administration routes, and drugs interactions. This information helps the nurse to avoid medication errors.

Moreover, a study by Qin et al [1] proposed system for medication error uses an RFID-enabled smart point-of-care medication process. This system concentrates on preventing medication errors that happen in the dispensing room where the nurse takes the prescribed drug. The drugs in this system are stored in locked drawers that can only be unlocked if the original prescription matches the drugs stored in that drawer.

Unlike RFID technology, NFC does not yet play a large part in research devoted to medication error prevention at hospitals, perhaps because NFC was only recently introduced to the market. However, it does already play a role in research preventing medication errors in home health care environments, as mentioned previously. This is the main gap addressed in this thesis.

2.2.2.1 Advantages of the Currently Used Solutions

RFID-based solutions have major advantages that improve the quality of health care. As we have seen, current RFID-based solutions exhibit clear benefits in terms of preventing medication errors and increasing patient safety by providing real-time data access to patients' electronic health record and treatment information. Moreover, it reduces the time spent on medication administration and waiting time, thus lowering costs and enhancing patient satisfaction levels [12] [13].

2.2.2.2 Disadvantages of the Currently Used Solutions

Although the current RFID-based solutions improve the quality of health care, they also have barriers that make their application in hospitals a complex issue. One serious issue with applying RFID in hospitals is its lack of security and privacy. Patients and health care staff are highly concerned about this issue, which makes the reliability of applying such a system very difficult. Electromagnetic interference is another challenge, as the electronic medical devices may fail in the presence of a high-frequency RFID reader. In addition, even though researchers indicate that RFID can reduce costs related to medication errors, RFID infrastructure is itself costly. In addition, health care teams face usability issues when they deal with RFID system interfaces [12] [13] [14] [15].

2.2.3 Reducing the Medication Errors Cost by Using NFC and RFID

As the number of medication errors increases, the financial and clinical costs caused by these errors significantly increase as well. However, there are massive savings to be had in the health-care sector if hospitals are willing to invest in NFC and RFID technology [39].

For example, a single drug interaction case cost about \$70,000. If hospitals applied the NFC-enabled smartphone to reduce medication errors, that coast can be reduced to about \$200-\$700. In addition, if hospitals applied RFID for medication errors reduction, that cost can be reduced to \$700 - \$2000 [40] [41].

Applying NFC-enables smartphone to prevent medication errors cost less than applying RFID. The NFC system cost involves the purchase of the NFC-enabled smartphones (\$200-\$700) along with tags (few cents per tag). On the other hand, RFID system cost involves a separate RFID reader (\$700 - \$2000) and an external antenna (\$200 and up) along with tags (few cents per tag).

	RFID	NFC
Reader Separate device		NFC-enabled smartphone
Reader Cost	\$700 - \$2000	\$450 -\$700
	(depends on the features	(depends on the
	in the RFID reader)	smartphone company)
Tag Cost	Few cents	Few cents
Antenna	Yes	No
Antenna Cost	\$200 and up	-

Table 1. Comparison between RFID and NFC Cost

Not only can the financial cost be reduced, but also the length of patient's stay can be reduced as well. An extended length of stay caused by the medication errors reaches up to 10.89 days. The length of the stay can be reduced to 0 days if hospitals use NFC and RFID systems to reduce medication errors [42].

2.3 Multi-morbidity

2.3.1 Multi-morbidity Definition

Multi-morbidity is defined as "the co-existence of two or more chronic conditions, where one is not necessarily more central than the others" [43]. In

other words, a patient may have two or more chronic diseases for a long period of time such as heart disease, diabetes, arthritis, chronic lower respiratory tract disease and stroke. Figure 4 illustrates a conceptual diagram of Multi-morbidity [43].

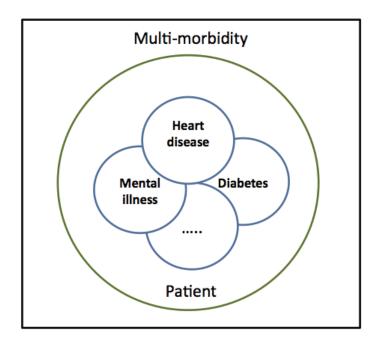


Figure 4. Conceptual Diagram of Multi-morbidity within a Patient's Circumstances and Preferences

2.3.2 Multi-Morbidity Prevalence

The prevalence of multi-morbidity increases in elderly populations. Researchers estimate that one in four adults has two or more chronic diseases, while fifty percent of older adults have three or more chronic diseases. In addition, researchers are predicting a dramatic increase in the number of patients with multi-morbidity in the future [43] [44].

2.3.3 The Impact of Medication Errors on Patients with Multi-morbidity

As the number of medications administrated to patients with multi-morbidity increases, the chance of medication errors increases as well, especially drug interactions and drug allergies. While drug interactions can happen to any patient admitted to a hospital, patients with multi-morbidity are more vulnerable to drug interactions and drug allergies, due simply to the large amount of drugs they take [9] [6].

The occurrence of drug interaction or drug allergy in patients with multimorbidity can cause serious consequences that affect a patient's life and may leads to death [45]. It can also lead to delays in medication administration [46]. For example, a delay in giving an antibiotic to a patient may leads to death; a study of 187 cases showed that mortality can jump to 33% if antibiotic treatment is delayed in a hospital environment [47]. Furthermore, delays in medication administration may also lead to suboptimal alternative medications and excessive investigation [46].

2.4 Treatment Team's Role in the Presence of Medication Errors

Medication errors can arise as a consequence of a treatment team's heavy workloads. The treatment team includes all of the physicians, pharmacists, and nurses attending a patient. A physician may make an error when issuing the drug order; a pharmacist may make an error when preparing the drug order; and a nurse may make an error when administering a drug to a patient. For example, the physician may make an error and prescribe a drug that the patient is allergic to; the pharmacist may not notice the error during the dispensing process, after which the nurse will administer the drug to the patient, who then suffers an adverse reaction. Thus, although the error is exposed only at the medication administration point, every member of the treatment team is involved [30] [25] [5].

Effective communication and collaboration among members of the treatment team contribute significantly to patient safety. Collaboration in health care can be defined as "health care professionals assuming complementary roles and cooperatively working together, sharing responsibility for problem-solving, and making decisions to formulate and carry out plans for patient care" [10]. O'Daniel and Rosenstein state that "when health care professionals are not communicating effectively, patient safety is at risk for several reasons: lack of critical information, misinterpretation of information, unclear orders over the telephone, and overlooked changes in status" [10]. The lack of communication within a treatment team may cause a severe medication error that leads to death. Other researchers emphasize this point and state that miscommunications have been linked to preventable patient mortality [48]. Therefore, the patient needs an effective open communication system to ensure his/her safety.

Summary

This chapter presented a literature review of Near Field Communication technology, covering NFC modes and comparing NFC to RFID. Healthcare applications were also presented, as was a literature review regarding medication errors involving drug allergies and interactions. Current applications that been designed to reduce medication errors were overviewed, along with their advantages and disadvantages. In addition, a general overview of Multi-morbidity was provided with regard to the negative effects of medication errors on people with Multi-morbidity. Finally, we discussed the treatment team's role in the presence of medication errors.

Chapter 3: Proposed Framework

3.1 NFC Application to Detect and Update Drug Allergies and Drug Interactions

In this chapter, a system framework for an NFC-enabled smartphone application to detect and update drug allergies and drug interactions for people with multimorbidity is proposed. This application is intended for deployment in hospital patient rooms, to be used by nurses when administering medication. In addition, the NFC application aims to enhance communication amongst health care team members – namely, nurses, physicians, and pharmacists. Better communication will aid health care givers in making the right decision when the application detects an allergy or interaction scenario, and will also enhance the quality of health service and patient safety (Figure 5).

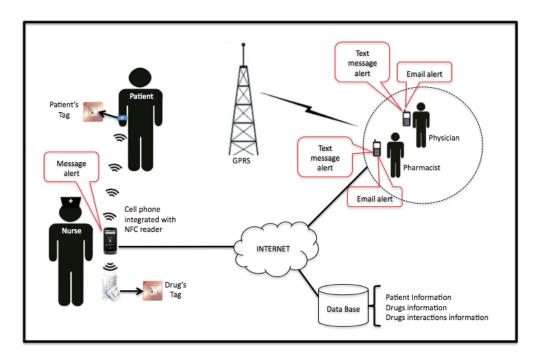


Figure 5. Framework for the Proposed NFC Application

As shown in the application interface, the application has two main functions: testing and updating (Figure 6). The testing function helps to detect a recorded

drugs' allergy or drug interaction, and the updating function helps to update a patient's drug allergy information in case of an unknown or not-recorded allergy. In the following subsections, we discuss the assumptions and the functions of the NFC application in greater detail.



Figure 6. NFC Application Interface

3.1.1 Assumptions

In our application, we assume the following:

- The four rights of the administrating medication, which are: the right patient, the right dose, the right time, and the right way. The fifth right is the right medicine, which we are assuming is not be applicable and our application will detect it.
- The patient is wearing a wristband integrated with an NFC tag that has a unique ID.

- The drug to be administered to the patient has an NFC tag with a unique ID.
- The availability and reliability of a wireless connection.
- The availability and reliability of a cell phone signal.
- The availability of a treatment team, comprised of a nurse, a physician, and a pharmacist.
- The hospital uses electronic health record

3.1.2 Testing Function

The system in the testing function works in three sequential phases, as follows:

- 1. Reading tags phase.
- 2. Retrieving information phase.
- 3. Proceeding or sending alert phase.

Each phase has its own function. However, these functions are connected to each other in a logical form. In other words, phase two relies on the output of phase one, and phase three relies on the output of phase two. Essentially, in phase one, the patient's tag and the drug's tag will be read and their unique IDs will be used in phase two. In phase two, the unique IDs will be used as references to retrieve the required information from the hospital database. In phase three, the retrieved information will be used to indicate whether or not a drug allergy or drug interaction is detected. These three phases will be discussed in detail in the following subsections.

3.1.2.1 Phase 1: Reading Tags

The Reading Tags phase is the starting point in our framework. It takes place in a patient's hospital room, when medication is administered by a nurse. This phase includes three main components: the nurse, the patient, and the drug. The patient is wearing a wristband that has an NFC tag with a unique ID that corresponds to information in the hospital database. Similarly, the drug has an NFC tag with a

unique ID that corresponds to information in the hospital database as well. The nurse carries a smartphone that connects to the hospital database through a wireless connection. This smartphone is integrated with an NFC reader and has the proposed NFC application. The NFC application has the ability to do the following: read tag IDs and send them to the hospital server (database); receive the response from the hospital server; and display the response to the nurse.

The workflow in this phase is as follows:

- 1- The nurse reads the patient's NFC tag by using the NFC reader in the smartphone.
- 2- The NFC application stores the patient's unique ID that has been read from the patient's tag.
- 3- The nurse reads the drug's NFC tag by using the NFC reader in the smartphone.
- 4- The NFC application stores the drug's unique ID that has been read from the patient's tag.
- 5- The nurse presses the button marked "Test" in the NFC application to send these two unique IDs to the hospital server to verify whether or not the patient is allergic to the drug or whether there might be a potential drug interaction (Figure 7).

Step 5 is the final step in the Reading Tags phase. These two IDs will be sent to the server for processing in the Retrieving Information Phase.

In summary, this phase explains the technique of reading and storing the patient and drug ID tags. The following subsection discusses the Retrieving Information Phase.

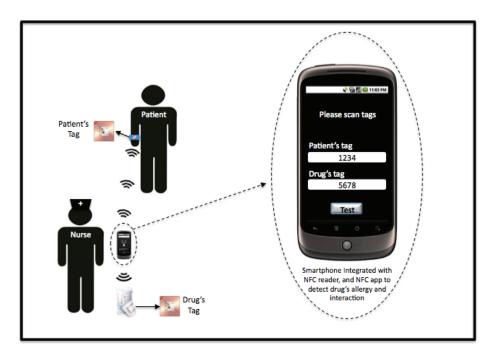


Figure 7. The Workflow of Reading Tags

3.1.2.2 Phase 2: Retrieving Information

The Retrieving Information phase is the processing phase of the Testing function, and it starts immediately after the Reading Tags phase. This phase determines whether or not there was a drug allergy or drug interactions detected in the previous phase. It has two working sides: a smartphone side, which includes the NFC application, and a server side, which includes the hospital server and database. These two sides are connected by a wireless network.

The hospital server works as a link between the NFC application and the hospital database. The hospital database includes patient information such as active medication(s), names of treatment team members, and allergies. It also includes drug information such as the drug's name and usage and drug interactions information (e.g., whether drug X interacts with drug Y, how it interacts, and the severity classification of the interaction).

In this way, the hospital database works as a trusted source for providing the required data.

The workflow for this phase is as follows (note that the Retrieving Information Phase starts where the reading tags phase ends):

- 6- After the nurse hits the test button, the NFC application sends the patient's and the drug's unique IDs to the hospital server via wireless connection.
- 7- The hospital server receives the unique IDs and passes them to the hospital database to be processed.
- 8- The hospital database receives the unique IDs and then runs queries (using the unique IDs as parameters).
- 9- The queries scan through the hospital database (patient data, drug data, and drug interactions data) to check whether or not the patient is allergic to the given drug or if there is a potential drug interaction.
- 10-Then hospital database sends the reply (result) to the queries to the hospital server.
- 11- The hospital server receives the reply from the hospital database and analyzes it. In other words, it checks if the reply indicates a drug allergy or drug interaction, or if it safe to proceed. Based on this analysis, it sends the report to the NFC application (Figure 8).

Step 11 will be demonstrated in the Proceeding or Sending Alert phase.

In summary, this phase explains the connection between the smartphone side and the server side. It also explains the unique IDs process, which takes place in the hospital database. The following subsection discusses the Proceeding or Sending Alert Phase.

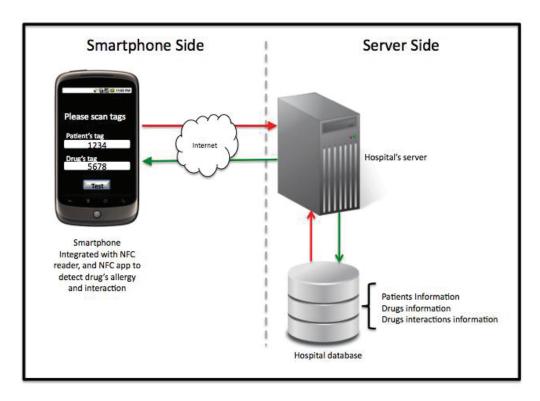


Figure 8. The Workflow of the Retrieving Information Phase

3.1.2.3 Proceeding or Sending Alert Phase

The Proceeding or sending Alert Phase is the final phase in our framework. It involves the patient's treatment team (the nurse, the physician, and the pharmacist) and is responsible for informing them if a drug allergy or a drug interaction is detected. This phase also involves the hospital server, which is responsible for sending the Proceeding message or the Alert Message to the treatment team via a wireless connection.

As mentioned in step 11 in the previous phase, the hospital server receives and analyses the output from the hospital database. According to its analysis, the workflow will be either of the following cases:

3.1.2.3.1 Detecting Case

If the output indicates that a drug allergy or drug interaction has been detected, the workflow is as follows:

- 12-The hospital server performs the following actions, in synchronizing manner:
 - a. Sends an alert message to the NFC application (the nurse), informing the nurse that a drug allergy or drug interaction has been detected. The message also gives a description of the case detected.
 - b. Sends an alert email to the patient's physician and pharmacist, informing them that a drug allergy or drug interaction has been detected for patient X. The message gives information about the patient as well as a description of the case (allergy or interaction).
 - c. Sends an alert text message (SMS) to the patient's physician and pharmacist. This text message informs them that there is a drug allergy or drug interaction detected, and asks them to check their email for more details about the patient and the case (Figure 9).

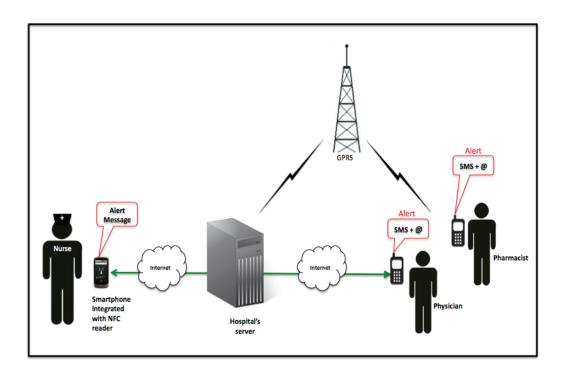


Figure 9. Alert Message

3.1.2.3.2 Safe to Proceed Case

If the output indicates that no drug allergy or drug interactions have been detected, the workflow will be as follows:

- 1- The server sends a message to the NFC application (the nurse only). This message informs the nurse that no drug allergy or drug interaction has been detected. The message then requests that the nurse administer the drug to the patient.
- 2- No issues having been detected, the nurse can proceed to administer drug without any harm to the patient see (Figure 10).

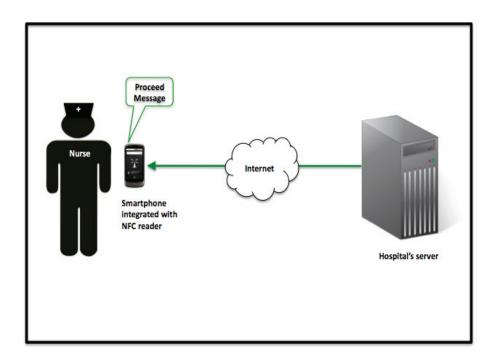


Figure 10. Proceeding Message

3.1.3 Updating Function

The NFC application also has the ability to update patient drug allergy information in the hospital database. This means that the application allows a nurse to update a patient's allergy information even during administration of a medication, if she/he detects a new allergy by observation after administering the

drug. For example, a patient has an unknown allergy to a prescribed drug X or has no allergy recorded to that drug in his/her record in the hospital database. The patient is given the drug, and the nurse observes a negative reaction by observing the patient's body. This reaction can then immediately be recorded by using the update function in the NFC application. Consequently, the patient's information in the hospital database will be up-to-date.

The system in the updating function works in two sequential phases, as follows:

- 1- Entering the patient's information.
- 2- Posting the information in the patient's record at the hospital database.

Although each phase has its own function, they are connected. In the first phase, the patient's and drug's unique IDs and a description of the observed allergy will be entered and then used in the second phase. In the second phase, the unique IDs and the allergy description will be posted in the hospital database. These two phases will be explained in the following subsections.

3.1.3.1 Phase 1: Entering the Patient's Information

Although the Entering the Patient's Information phase is very similar to the first phase in the Testing Function, its purpose is different. This phase takes place in a patient's hospital room during the medication administration stage performed by a nurse. It includes three main objects: the nurse, the patient, and the drug. Both the patient and the drug have tags with unique IDs. The nurse carries a smartphone that is connected to the hospital database through a wireless connection. The smartphone is integrated with an NFC reader and has an NFC application designed to update drug allergies. The NFC application has the ability to do the following tasks: read the tag's ID and allergy description, post them in the hospital server (database), and update the hospital database.

The workflow in this case is as follows:

1- The nurse reads the patient's NFC tag using the NFC reader in the smartphone.

- 2- The NFC application stores the patient's unique ID that is read from the patient's tag.
- 3- The nurse reads the drug's NFC tag by using the NFC reader in the smartphone.
- 4- The NFC application stores the drug's unique ID that is read from the drug's tag.
- 5- The nurse writes a description of the observed allergy case in the NFC application.
- 6- Finally, the nurse clicks the update button to send the unique IDs and the description to the hospital database to be posted there (Figure 11).



Figure 11. Entering the Patient's Information

In summary, this phase shows how to read the tags' unique IDs as well as the allergy description written by the nurse. In the following phase, we discuss the process of posting the sent information in the hospital database.

3.1.3.2 Phase 2: Posting the Information in the Patient's Record at the Hospital Database

The process for this phase is similar to the second phase in the Testing function. Namely, it has the same working sides – the smartphone and the server – as discussed earlier. However, in this phase, the NFC application does not use the unique IDs to retrieve information from the hospital database as it does in the Testing function. Instead, it uses them to post the allergy information in the right place at the hospital database.

The workflow in this phase is as follows:

- 7- After the nurse hits the update button, the NFC application sends the patient's and the drug's unique IDs as well as the allergy description to the hospital server via a wireless connection.
- 8- The hospital server receives the unique IDs and the allergy description and then passes them to the hospital database to be processed.
- 9- The hospital database receives the unique IDs and the allergy description and then runs queries (using the unique IDs as parameters) to insert the information in the right place at the hospital database.
- 10- Finally, if the database successfully updates, the Server sends a success message to the NFC application. Otherwise, it sends an error message (Figure 12).



Figure 12. Successful Update Message

In summary, this phase is responsible for posting the information that been passed by the server in the right place at the hospital database. Consequently, if the nurse runs the Testing function and scans the patient's and the drug's tags, she/he will get the same information that she/he entered earlier.

Summary

In this chapter, we discuss the proposed framework for the NFC application to detect and update drug allergies and drug interactions for people with multichronic diseases. The application takes a place in the patient's hospital room during the medication administration stage performed by the nurse. The application involves the health care team (nurse, physician, and pharmacist). We believe that this application enhances communication between the treatment team and consequently increases the quality of health services by allowing the team to make the right decisions in case of an emergency.

In addition, we discussed the two main functions in our application (the Testing function and the Updating function) as well as the three phases in the Testing function: Reading Tags, Retrieving Information, and Proceeding or Sending Alert. We also explained the two phases in the Updating function, which are entering the patient's information, and posting the information in the patient's record at the hospital database. In the following chapter, we will discuss the proof of concept of the proposed framework for both functions.

Chapter 4: Implementation

In this chapter, we show the proof of concept for our application and demonstrate its feasibility. We implemented and tested a model of our application in the Computer Science Lab at Dalhousie University, Halifax, Canada. In the following sections, we discuss, respectively, the various experimental tools that we use, the experimental services, and the experimental model for the NFC application.

4.1 Experimental Tools

In this section, we explain the experimental tools we use in our application. Further information on how we use them is discussed in the experimental model section.

4.1.1 NFC Tags

In this application, we used an MIFARE Classic 1K tag. It has 1024 bytes of data storage and operates at a 13.56 MHZ frequency range, which typically requires a distance of four centimeters or less to be readable. We used four NFC tags for identification purposes. One tag was assigned to a patient and three tags were assigned to three different drugs. Each tag has a unique ID used to identify the patient and the drugs [49].

4.1.2 Cell phone Integrated with NFC reader

In this application, we used a Samsung Nexus S smartphone with Android 2.3.6 platform, a 1GHz Hummingbird processor, and16GB of internal memory. We used one Samsung Nexus S smartphone to install our Android NFC app that we created for this application, and to read the unique ID of the NFC tags by the NFC reader [50].

4.1.3 MySQL Workbench

MySQL Workbench 5.2 is a visual tool for database developers. It helps to visually design and manage databases as well as create and execute SQL queries. We used the tool to create a database that simulates a small part of a hospital database, with the simulated database containing all of the necessary data for the application's needs. In our test, we considered that one nurse would administer drugs to ten patients. This ten-to-one ratio was selected according to the nurse-to-patient maximum ratio of 1:8, adding two more patients to create a worst-case scenario [51]. Each patient has at least 20 active medications assigned to him/her.

The database features two major parts comprising patient information and drug information. The patient information section includes the following data specific to the patient: personal information, tag ID, drug history, known allergies, and treatment team (physician, nurse and pharmacist). The drug data includes the following: drug information, drug tag ID, and drug interaction information.

4.1.4 Drug Information Database (Drug.com)

Drug.com is a Drug Information Database that is supported by many medical-information suppliers¹. Since we are trying to simulate the hospital database content, we used this database as a source to add the following information to our database: the most commonly used drug for certain chronic diseases; side effects. In table 1 and table 2, we show the classification and their description that we used for both drug allergies and drug interaction [52].

¹ Medical-information suppliers: WoltersKluwe Health, American Society of Health-System Pharmacists, Cerner Multum, and Thomson Reuters Micromedex

34

Classification	Classification Description			
Major	Highly clinically significant. Avoid combinations; the risk of the			
	interaction outweighs the benefit.			
Moderate	Moderately clinically significant. Usually avoid combinations; use it			
	only under special circumstances.			
Minor	Minimally clinically significant. Minimize risk; assess risk and			
	consider an alternative drug, take steps to circumvent the interaction			
	risk and/or institute a monitoring plan.			

Table 2. Drug Interaction Classifications

Classification	Classification Description	
Major	Get emergency medical help	
Moderate	Stop and Consultation	
Minor	Continue and Consultation	

Table 3. Drug Allergy Classifications

4.1.5 Generate Data

Generate Data is an open source script that helps to generate custom data that can be used for creating a database. We used this tool to create some data for our database, especially in the patient information part [53].

4.1.6 Eclipse IDE

Eclipse is a Java development tool used to develop applications in Java. We used Eclipse IDE because its abilities can be extended to more functions. Hence, we extended its ability by installing the Android SDK to give us the ability to create

an Android app. By using this tool, we were able to create an NFC app to detect drug Interactions and drug allergies for people with multi-chronic diseases [54].

4.1.7 PHP

PHP is general-purpose scripting language used for web development. We used PHP in this application because in order to connect a remote MySQL to an android device, we needed a web service in the middle. Thus, we used the PHP script to pass the request to the database and then return the response to the android app [55].

4.2 Experimental Services

4.2.1 Email Service

We used an email service (Gmail) to send urgent emails if the NFC application detected a potential drug allergy or drug interaction. This email would be sent to the physician who prescribed the drug as well as to the pharmacist who dispensed it. The main content of the email is a description of the drug allergy or drug interaction. We also used the email service to send urgent short text messages to their cell phones, asking them to check their emails in case they did not notice the email.

4.2.2 Short Text Message

We used a text messaging service to send an urgent short text message if the NFC application detected a potential drug allergy or drug interaction. This message asks the physician who prescribed that drug and the pharmacist who dispensed it to check for emails.

4.2.3 Wireless Connection

We used the wireless service Dal-WPA 2 to make a connection between the smartphone and the database through the PHP.

4.3 Experimental Model

In this section, we describe the implementation of the NFC application to detect and update drug allergies and drug interaction for people with multi-morbidity. The implementation includes Testing and Updating functions that we describe in Chapter 3. In the following sections, we respectively describe the interface for the NFC app, the process of the Testing function, and the process of the Updating function.

4.3.1 NFC Application Interface

As the end-user for the NFC application is the nurse, the application will be installed in the nurse's smartphone, as shown in Figure 13. The interface has two options that the nurse can choose from: Test or Update (as shown in Figure 14). Each option has its own function, as discussed in Chapter 3. The Test button leads to an interface that tests drug allergies and drug interactions, while the Update button leads to an interface that updates s patient's drug allergy record. In the following subsections, we illustrate the implementation for these two functions in greater detail.



Figure 13. NFC Application Icon on the Nurse Smartphone

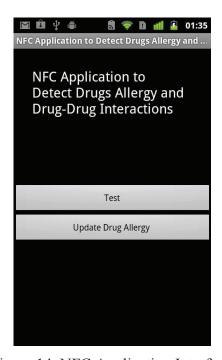


Figure 14. NFC Application Interface

4.3.2 Testing Function

As mentioned earlier, the testing option enables testing for drug allergies and the drug interactions. By clicking on the Test button in the NFC application interface, we get the testing screen, as shown in Figure 15. The testing screen has two text boxes that hold the tag IDs after the NFC reader reads them. It also has a test button that initializes the connection between the NFC app and the PHP.



Figure 15. Drug Allergy and Drug Interaction Testing Interface

In this implementation, we tested three potential cases that our NFC application can detect: drug allergies, drug interactions, and safe to proceed.

As mentioned in Chapter 3, the Testing function has three phases. In the following subsections, we illustrate the implementation of these phases.

4.3.2.1 First Phase: Reading Tags

As indicated in Chapter 3, this phase is the initial phase in our application, where the nurse reads the patient's and the drug's tags during the medication administration stage.

We used a Samsung Nexus S smartphone with an Android 2.3.6 platform to read the four NFC MIFARE Classic 1K tags as well as to store the tags' unique IDs in the NFC app run on this smartphone.

The three potential cases that the NFC Application is able to identify (drug allergy , drug interaction, and safe precede) were tested. We used one NFC tag that was assigned to a random patient in our database who has an allergy to some drugs and active medication (drugs) in his/her medical file. In addition, we used three different NFC tags that were assigned to three random drugs to be given to the patient. In other words, we tested the patient's tag with each of the drug's tags. The purpose of doing three tests is that we wanted to show the output for our application for three different cases.

In this test, we read the patient's tag, noting its unique ID stored in the first text box. Then we read the drug's tag, likewise noting its unique ID stored in the second text box (as shown in Figure 16). Next, we click the test button to initialize the connection with PHP to obtain the test results, which are discussed in the following phases.



Figure 16. The Testing Interface after Reading the Tags

4.3.2.2 Second Phase: Retrieving Information

A connection between the NFC app and the PHP is initialized after clicking on the test button, and the unique IDs are sent to the PHP. The PHP passes them to the MySQL (hospital database) to run drug allergy and drug interaction queries. The query scans through the hospital database to check whether or not the patient is allergic to the drug or if there is a potential drug interaction. After running the query, the MySQL will send the results to the PHP. Finally, the PHP analyzes the results and sends the analysis to the NFC application to be displayed to the nurse. Figure 17 illustrates the connection between the NFC application, PHP, and MySQL.



Figure 17. Retrieving Information from MySQL

4.3.2.3 Third Phase: Proceeding or Sending Alert Phase

As mentioned, in the second phase, the PHP analyzes the query results and sends the analysis to the NFC app. There are two potential outcomes: detecting a drug allergy/drug interaction, or safe to proceed.

4.3.2.3.1 Detecting Case

Should a drug allergy or drug interaction be detected, the PHP does the following in a synchronizing manner: sends an alert message to the NFC application (to the nurse), sends an email alert to the physician and pharmacist, and sends a text message alert to the physician and pharmacist.

Figure 18 and Figure 19 show the message alert that was sent to the NFC application and displayed by the nurse to signal that a drug allergy or drug interaction was detected. In Figure 18, the alert message indicates a detected case of a drug allergy and displays the main information about this allergy. The

information includes the name of the USED DRUG (Cataflam) recorded in the patient's file due to allergy reasons, and the name of the NEW DRUG, which is the prescribed drug, (Cataflam)that is the same drug that the patient is allergic to. In addition, the information shows the CLASSIFICATION based on the severity for this allergy, so the nurse can take action depending on this classification. Furthermore, it shows a brief DESCRIPTION about the allergy, which in this case is Nausea, so the nurse gets a better understanding of the patient's situation when he/she had this drug in the past.

In Figure 19 the alert message indicates a detected case of drug interaction, and displays the main information about this interaction. Similar to the allergy case, the information includes the name of the USED DRUG (Insulin) listed in the patient's record as well as the name of the NEW DRUG, which is the prescribed drug, (Gatifoxacin).

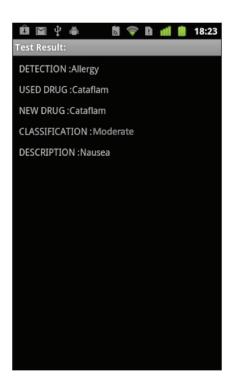


Figure 18. Detecting Allergy Case

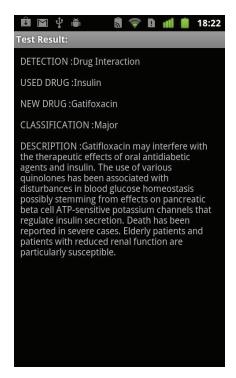


Figure 19. Detecting Drug Interaction Case

In addition, the information shows the CLASSIFICATION based on the severity for this drug interaction (Major). Furthermore, it shows a brief DESCRIPTION about the interaction, so the nurse can have a better understanding of it and know how severe this interaction will be for the patient.

Figure 20 shows the text message that was sent from the hospital's email address (which is the researcher's personal email address in the experimental model) to the patient's physician and pharmacist. The text message acts as an urgent alert, asking them to check their email as soon as possible to obtain more information about the detected error. The text message includes the patient's name, so the physician will likely recognize the patient before he/she checks the email.



Figure 20. The Urgent Short Test Message

Figure 21 and Figure 22 illustrate an example of an email that has been sent in response to a drug allergy or drug interaction from the hospital's email to the patient's physician and pharmacist. This email provides the same information that the nurse receives in the NFC application; however, it has more information about the names of the patient's treatment team (nurse, physician, and pharmacist). Furthermore, it has the patient's file number, so the physician can access to his/her file.

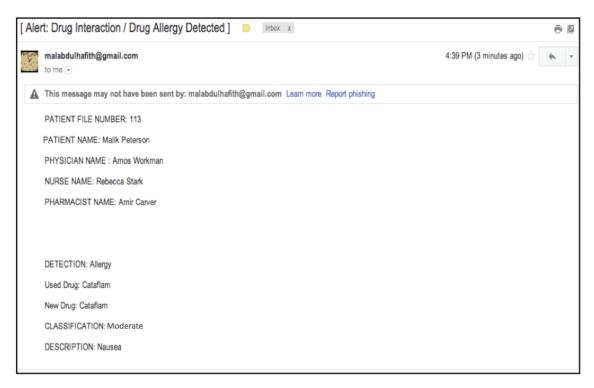


Figure 21. Urgent Email about Drug Allergy Detected

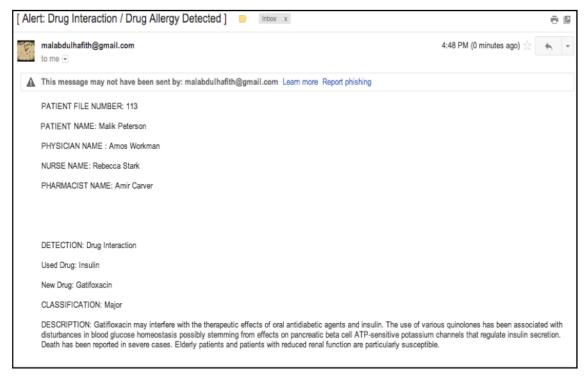


Figure 22. Urgent Email about Drug Interaction Detected

The information sent to the treatment team helps them to better understand the detected case and the patient's situation, thereby enhancing the team's knowledge and leading to better decision-making with regards to patient safety.

4.3.2.3.2 Safe to Proceed Case

safe to proceed cases happen when queries do not detect any drug allergy or drug interaction in the hospital database. In this case, the PHP sends a message only to the NFC application (the nurse), informs the nurse to proceed in giving the drug to the patient, as shown in Figure 23.

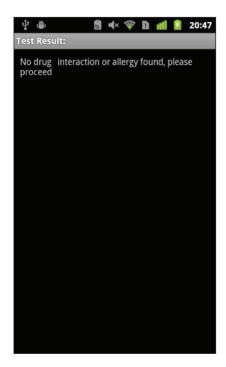


Figure 23. Proceeding Message

4.3.3 Updating Function

As mentioned in Chapter 3, the updating function helps to update the patient's drug allergy information in case of an unknown or non-recorded allergy. Click on the update allergy option on the main screen (see Figure 14), we arrive at the Drug Allergy Update screen, as shown in Figure 24. The screen has two text

boxes for the tag IDs after the NFC reader reads them. It also has a drop-down list that has various severity classifications for the allergy (see Figure 25). In addition, the last text box is for describing the allergy detected by the nurse's observation, and the update button is responsible for initializing the connection between the NFC application and the PHP.

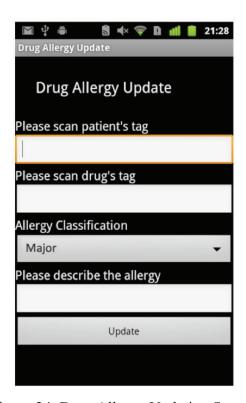


Figure 24. Drug Allergy Updating Screen

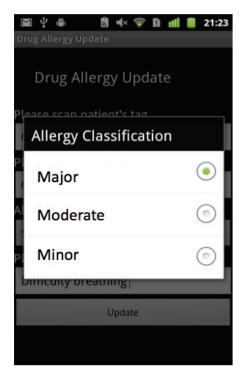


Figure 25. Drop-Down List for Allergy Classification

As mentioned in Chapter 3, the Update function has two phases: entering the patient's information in the NFC application, and posting the information to the patient's records at the hospital database. In the following subsection, the implementation for these phases is described.

4.3.3.1 First Phase: Entering the Patient's Information

Update entries are almost exclusively input by nurses, so they need to scan the patient and drug tags to post the correct information in the right record in the hospital database. In Figure 26, we scanned the tags by the NFC reader and randomly selected the classification (Major). We then wrote a random description about the allergy (Difficulty breathing). Finally, we clicked on the update button where the connection between the NFC application and the PHP initialized.

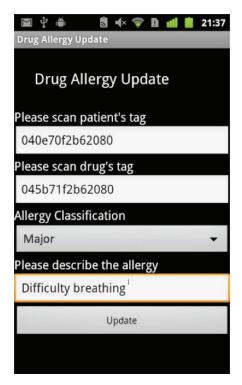


Figure 26. Entering the Patient's Allergy Information

4.3.3.2 Second Phase: Posting the Information in the Patient's Record in the Hospital Database

After initializing the connection between the NFC application and the PHP (Figure 17), the NFC application sends the entries to the PHP, which passes them to the MySQL. The MySQL receives them and (according to the tags' IDs) inserts them into the correct record in the hospital database. The database is then updated, after which the PHP informed and sends a successful update message to the NFC application to inform the nurse that the database was successfully updated, as illustrated in Figure 27.

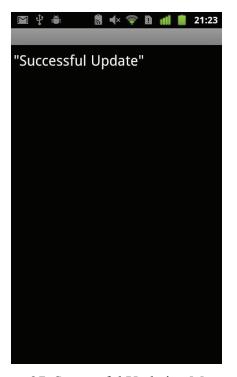


Figure 27. Successful Updating Message

To prove that the database was successfully updated, we tested the same tags in the testing option (Testing Function) as shown in 28, going through the same process discussed previously in the Testing Function. As a result, we obtained a drug allergy case that includes the same information that we entered, which demonstrates the reliability of the Updating function.

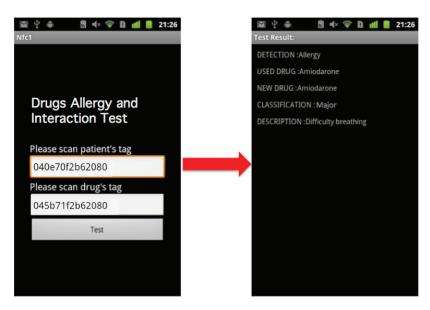


Figure 28. Drug Allergy and Interaction Test

Summary

This chapter discussed the proof for the NFC application's concept, which was implemented and tested in the Computer Science Lab at Dalhousie University. We first described the experimental tools and services that were used in the application and then illustrated the experimental model, demonstrating the feasibility of its Testing and Updating functions.

In addition, we showed three instances of the Testing function where the NFC application effectively detects drug allergy, detects drug interaction or safe to proceed. We also discussed the reliability of the Updating function.

Chapter 5: Analysis and Discussion

In this chapter, we analyze the application's performance precision as well as the computational and communicational cost for sending a text message (SMS) to physicians and pharmacists. We present the evaluating method, the results, and a discussion of our application results.

5.1 Evaluating Method

5.1.1 Performance Precision

To evaluate the NFC application's performance precision, we assess its sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy. The same method has been used by other researchers to evaluate the performance of a number of drug interaction software [56] [57]. According to their results, we believe that this method is adequate to evaluate the performance precision of our application.

Sensitivity¹ is defined as the ability of an NFC application to correctly detect a drug interaction and drug allergy. Conversely, specificity² is defined as the ability of the NFC application to correctly reject a drug interaction and drug allergy. PPV³ indicates the probability that, if a drug interaction or drug allergy is detected, it is a true detection. PNV⁴ indicates the probability that, when a drug interaction and drug allergy is rejected, it is a true rejection. Accuracy⁵ indicates the degree of proximity of drug interaction and drug allergy detection and rejection quantity to that quantity's actual true value [56] [57].

¹ Sensitivity = number of true-positives / (number of true-positives + number of false-negative).

² Specificity = number of true-negatives / (number of true-negatives + number of false-positives).

³ PPV = number of true-positives / (number of true-positives + number of false-positives).

⁴ PNV = number of true-negatives / (number of true-negatives + number of false-negatives).

⁵Accuracy = number of true-positives + number of true-negatives / (number of positives + number negatives).

A total of 30 drugs and 10 patients (each patient is taking 20 drugs) were tested. Each drug was tested with every patient. The following flow chart (Figure 29) illustrates the testing method.

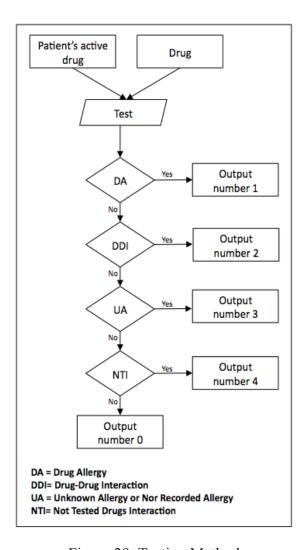


Figure 29. Testing Method

The test result gives us one of the following outputs:

- Number 1: if there is drug allergy detected
- Number 2: if there is drug interaction detected
- Number 3: if there is unknown allergy or not recorded allergy
- Number 4: if there is no tested drug interaction
- Number 0: if any of the above cases are rejected (safe to proceed)

Because these numbers have been used for experimental purposes only, numbers 3 and 4 may not be applicable in a real-life scenario. Instead, they should be 0, because the nurse would not know if there is no recorded allergy, or an unknown allergy, or no tested drug interaction unless they were recorded in the hospital database. However, we assumed numbers 3 and 4 to show possible cases that our application cannot detect.

5.1.2 Computational and Communicational Cost

We evaluated the computational and communicational cost for sending a text message to the case physician and pharmacist by calculating the Mean and the Standard Deviation. Specifically, we tested the time spent to send a text message at the IWK health center lobby during lunchtime. The IWK Health Centre is a hospital in Halifax, NS, Canada that provides care to women and children. We used this busy time on the cellphone network to see how long would take to send a text message in a worst-case scenario. The test was repeated 50 times using Bell Aliant cellphone service.

5.2 Evaluating Result

5.2.1 Performance Precision Result

As mentioned earlier, we tested a total of 30 drugs with 10 patients, obtaining 300 results. From these results, we defined the values of true negative, true positive, false negative, and false positive. Then, accordingly, we calculated the sensitivity, specificity, PPV, NPV, and the accuracy for both drug interaction and drug allergy. Table 4 shows the expected and the detected results for drug interaction and drug allergy.

	Total	Total	Drug	Drug
	Detection	Rejection	Allergy	Interaction
Expected	135	165	46	89
Detected	106	194	36	70

Table 4. Expected and Detected Result for Drug Interaction and Drug Allergy

There are noticeable differences between the expected-result's output and the detected-result's outputs. In the expected result in Figure 30, the total detection was about 45%, where 30% was drug interaction and 15% drug allergy; the total rejection was about 55%. On the other hand, in the detected result, the total detection was 35%, where 23% was drug interaction and 12% drug allergy; the total rejection was about 65%.

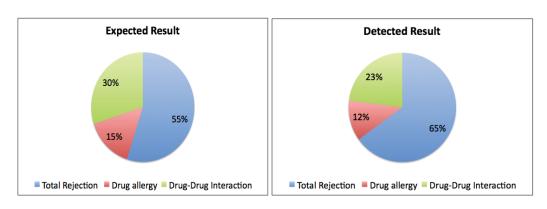


Figure 30. Output of the Expected Result and the Detected Result

According to the comparison between the output of the expected result and the detected result, we defined the true negative, true positive, false negative and false positive, as shown in Table 5.

	Drug Interaction	Drug Allergy
True Positive (TP)	70	36
True Negative (TN)	211	254
False Positive (FP)	0	0
False Negative (FN)	19	10

Table 5. Analysis of Drug Interaction and Drug Allergy Positives and Negatives

For a drug interaction, the correct reporting value of an interaction was 70, the correct reporting value of no interaction was 211, the incorrect reporting value of an interaction was zero, and the incorrect failure value to report an interaction was 19. For a drug allergy, the correct reporting value of an interaction was 36, the correct reporting value of no interaction was 254, the incorrect reporting value of an interaction was zero, and the incorrect failure value to report an interaction was 10.

According to the above values, we calculated the sensitivity, specificity, PPV, NPV, and the accuracy, as shown in Table 6.

	Drug Interaction	Drug Allergy
Sensitivity	78.6%	78.2%
Specificity	100%	100%
PPV	100%	100%
NPV	91.7%	96.2%
Accuracy	93.6%	96.6%

Table 6. Analysis of Sensitivity, Specificity, PPV, NPV and Accuracy

The above values (Table 6) show the similarity between drug interaction and drug allergy for sensitivity, specificity, and PPV. The proportion of the NFC

application's ability to correctly reject a drug interaction and drug allergy was 100%, which means that the application did not detect such a case when it was not recorded in the database. However, the proportion of NFC's ability to correctly detect a drug interaction and drug allergy was around 78%, which means that the application may reject such a case when the case actually existed. In addition, the probability that, when a drug interaction or drug allergy was identified, the true drug interaction or true drug allergy was 100% means that the NFC application did not identify a drug interaction or drug allergy when it was supposed to reject such a case.

Furthermore, the values show a slight difference between drug interactions and drug allergies in terms of NPV and accuracy. The probability that a drug interaction rejection was a true rejection was 91%, while the probability that a drug allergy rejection was a true rejection was 96%. This means that the NFC application may fail to identify some drug interactions or drug allergies. Moreover, the degree of proximity of drug interaction detection and rejection quantity to that quantity's actual true value climbed to 93%, while a drug allergy reached 96%. Figure 31 illustrates the similarities and differences between drug interactions and drug allergies.

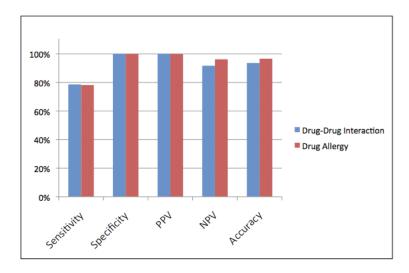


Figure 31. Differences between Drug Interaction and Drug Allergy

5.2.2 Computational and communicational Cost Results

As mentioned earlier, 50 text messages were sent to the case physician and pharmacist during the busiest time of the day, from which 50 results were obtained. The period of time required to obtains results varied slightly, with differences ranging from a few milliseconds to 12 seconds. The mean for time spent to send a text message was around 6.1008 seconds, while the standard deviation was around 2.1972 seconds. In addition, the minimum time spent to send a text message was 1.585 seconds, and the maximum time was 13.482 seconds. Figure 32 demonstrates the time spent to send a text message.

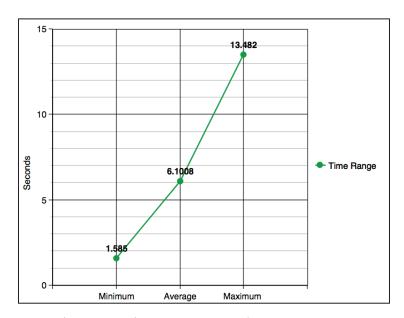


Figure 32. Time Spent to Send a Text Message

5.3 Discussion

5.3.1 Performance Precision Analysis

The NFC application performance shows satisfactory outcomes. A detailed examination of the results shows that, in the expected drug allergy result (Table 4), 10 out of 40 were either not recorded or unknown allergies, which by our assumption meant that the allergy existed in real life but not in the database. Similarly, in the expected drug interaction, 19 out of 70 were not tested drug

interactions, which again by our assumption meant that the drug interaction existed in real life but not in the database. Taking that into consideration would clarify the influence behind the results for sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy.

The NFC application achieved 100% specificity because it did not reject any case that was recorded in the database. In other words, if we tested a given drug with a patient's active drug and this test had no corresponding drug allergy or drug interaction information in the database, it will be rejected by the NFC application, proving its validity. From a theoretical point, researchers state that achieving 100% specificity in an experimental study is possible because of few or non-existent false positives [58]. Nonetheless, calculating the specificity by itself was not enough to evaluate the performance precision of the NFC application.

In addition, the results show that the NFC application in actuality achieved approximately 78% sensitivity, as it rejected cases that we assumed existed in real life but not in the database. The PPV, however, achieved 100% because every existing case in the database was identified by the NFC application. Furthermore, the NPV achieved 91% for the drug interaction and 96% for drug allergy because (if we considered the cases that were missing in the database but existed in real life) not all of the NFC application's rejections were true. Finally, the NFC application's accuracy achieved 93% for drug interaction and 96% for drug allergy. Such a high percentage of accuracy shows how our application can achieve a close measurement of a quantity to the quantity's actual value. In other words, it proves that the NFC application has a high potential of detecting or rejecting drug interaction and drug allergy cases.

Generally speaking, the NFC application cannot identify a case that is not reported in the database, such as a drug allergy that is not recorded, an unknown allergy, or an untested drug interaction. We assumed an unrecorded drug allergy, an unknown allergy, and an untested drug interaction to show some examples that

the NFC application cannot detect due to their absence in the database. Despite these limitations, the NFC application has the ability to identify every case that is recorded in the database.

5.3.2 Computational and communicational Cost Analysis

According to the computational and communicational cost results, we found that the time spent to send a text message may vary for any number of reasons, ranging from a busy cellphone network to availability of signals. Nevertheless, the results were quite acceptable, as it only took an average of about 6 seconds to send a text message to notify the case physician and pharmacist of a drug interaction or drug allergy. Even the maximum time required to send a text message (13 seconds) is ultra-fast compared to the current methods of notifying the physician (i.e., writing a report or making a phone call) [5].

Summary

In this chapter, we analyzed the NFC application's performance precision as well as the computational and communicational cost for sending a text message (SMS) to the attending physician and pharmacist. We presented the evaluating method that we used for the performance precision, measuring the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy. We also presented the evaluating method for the computational and communicational cost by measuring the means, the standard deviation, the minimum time, and the maximum time. Furthermore, we discussed the evaluation results for both performance precision and computational and communicational cost. Finally, we analyzed the evaluation results and found satisfactory outcomes that support the usability of our application.

In the following chapter, we discuss the limitations of the NFC application and suggest future work.

Chapter 6: Conclusion and Future Work

Drug allergies and drug interactions are serious problems for patients with multimorbidities, and these errors usually happen during the medication administration stage. In this study, we proposed a novel solution of using a smartphone integrated with an NFC reader and an NFC application to detect and update drug allergies and drug interactions for people with multi-morbidity when being administered medications.

This application helps to improve patient safety by detecting drug allergies and drug interactions before they happen. It also helps to increase the quality of health care by promoting, enhancing and better enabling communication between the patient's treatment team members. In addition, in considering differences in education and training levels, the application bolsters the treatment team's knowledge by providing important information about the detected case.

Moreover, NFC provides a better way of informing the physician in case of drug allergies or drug interactions by saving the nurse time and giving the right information to the attending physician and pharmacist. As well, using NFC technology can prevent electromagnetic interference between the NFC reader and medical devices and assure patient privacy and security. For a nurse, using a smartphone to do these tasks is more convenient than using a PDA or laptop due to the phone's light weight and the nurse's familiarity with using it.

Although NFC findings show promising results for real-life situations, it is still worth mentioning some of the application's limitations that we encountered while testing it in the lab. It is difficult to eliminate some medication errors using the NFC application only, if the corresponding information is absent from the database. Moreover, because we applied the NFC application solely in a laboratory setting, we cannot foresee all of the limitations it may have if it were applied in a real-life scenario.

In future work, we would like to apply the NFC application to detect and update information on drug allergy and drug interactions for people with multi-morbidity during the medication administration stage in a real life scenario, to assess its functionality on a larger scale. We may also try an alternative way of connection such as wireless ad-hoc network instead of the internet connection. We would also like to know at what drug allergy and drug interaction classification (i.e., major, moderate, minor) the treatment team would like to receive an alert, to encourage them to heed the alerts rather than ignore them. Another research option would be to find a way to make the system work in different wireless networks.

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