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Touch-based Magnetic Communication through Your Hand

Arvind Allawadi, Kaikai Liu
Computer Engineering Department
San Jose State University (SJSU)
San Jose, CA, USA
Email: {arvind.allawadi, kaikai.liu}@sjsu.edu

***Abstract*—Near field communication (NFC), which emerged only a decade ago, has been rapidly adopted in business services including point-of-sale (POS) systems, payments, identification, ticketing, and various other types of services. NFC offers great and varied promise in providing secure and implicit paired communication capability in smartphones. As a short-range wireless communication technology, the level of "secure" is contributed by the short-range nature. Compared with other competitive technologies, NFC achieves physical-level security but sacrifices convenience. For example, NFC cannot achieve device-free or hands-free payment transactions like the service provided by PayPal called PayPal beacon which utilizes Bluetooth-low-energy (BLE) technology. In this paper, we propose a low-cost wearable device that can achieve better physical-level security than NFC provides. This system is compatible with existing NFC-based POS systems and can help users realize a convenient hands-free payment transaction. Specifically, a custom NFC wristband was designed to channel its magnetic field through the human arm. By confining the magnetic field in NFC to the area around the body, we could minimize energy radiation, reduce the possibility of communication sniffing and hijackings, and improve security. To evaluate this approach, we conducted various experiments via different configurations. The results showed that the communication range for the human body channel was greater than that of the air and water channels. In addition, through this study we demonstrated that the human body is a naturally secure channel, and hacking and nearby interference are minimized during such communication. Our system also defines a new way of communication, for example, people can share confidential information with a simple handshake without pulling out and touching, or tapping smartphones.**

***Index Terms*—Near field communication, magnetic fields, electromagnetic coupling, communication channels**

I. Introduction

Near field communication (NFC) is an evolving technology which—as the name suggests—works in proximity to the connected devices. One of the most important aspects of NFC technology is its inherent security since the communication range is extremely short. NFC is a result of the advances in Radio Frequency Identification (RFID) and its promotion by Nokia, Sony, and Philips in 2004. A dedicated controlling body called the NFC Forum is serving as a promoter of NFC, which receives contributions from over 190 organizations. The NFC Forum is dedicated to ensuring the most effective use-cases for NFC by: a) actively developing solutions that appropriately meet the users' and manufacturers' requirements b) defining protocols and specifications for the security features for NFC tags c) developing interface specifications that ensure the deployment of NFC in a variety of applications [1], [2]. NFC not only brings simplicity to our lives but also creates additional opportunities for business and entrepreneurs as well. As of today, most smartphones are sold with an integrated NFC hardware module, and almost all newly released smartphone have NFC support, which is important evidence of its popularity and usefulness through the dissemination of technology.

The strength of NFC technology arises from its ease of use by triggering communication just by bringing two devices very close to each other and terminating communication immediately by separating the devices beyond a certain range. NFC is compatible with the existing infrastructure spawned by the RFID technology such as passive RFID tags and contactless ISO 14443 compatible readers [3]. In order to engage in an NFC interaction, users need to touch their smartphone alternatively to an NFC tag, another smartphone, or an NFC reader. The level of "secure" depends on the communication distance and antenna beam pattern. Compared with Bluetooth and WiFi technology's range of a few meters to hundreds of meters range, NFC limits the energy radiation to a range of a few centimeters. This limited radiation reduces the possibility of communication sniffing and hijacking. However, existing smartphone-based NFC approaches still leverage the "air" channel for data communication and key exchanges, which leaves room for communication sniffing, and possibly hijacking. The inherent physical-level security of the NFC can be further enhanced by reducing the transmission power, but this suffers from communication loss and intermittent connection errors. There are also some scenarios where NFC technology is not convenient to use compared to competitive technologies like BLE. For instance, current mobile applications of NFC follow either a touching, or tapping paradigm [4], [5]. These paradigms really restrict the communication range between the smartphone and point-of-sale (POS) systems, and the users needs to pull their smartphone out of their pocket or purse for the payment. New convenient payment scenarios like PayPal Beacon and the Amazon Go [6] cannot be realized based on NFC.

Another evolving technology that works in the short range is human body communication (HBC) [7]. This is a non-RF based technique and works on the principal that the human tissues are loosely dielectric so they serve as a transmission

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channel. Communication is achieved by using either electric or magnetic fields channeling through the human body. HBC using electric fields can be achieved in one of two ways: a) through electrostatic (also, galvanic) coupling, b) through capacitive coupling. Both techniques produce a small electric field in the human body, and the human body completes the communication channel from the transmitter to the receiver. This technology has its major application in the body area networks (BANs). Since the human body channel results in lower power losses compared to the RF-based technologies, this makes HBC a more favorable option for BANs [8]. Compared to electric fields, HBC using magnetic fields achieves better efficiency in some environmental setups. Park and Mercier compared the power losses for a 4-turn coil, single turn coil, and capacitive coupling for wrist-to-wrist communication [9]. For a transmission channel length of 40 cm, power losses were reduced by 20 decibels (dB) when using magnetic fields in comparison to electric fields, and 10 dB lower in comparison to the measurement in the air channel [9]. However, at present, there are issues associated with HBC. Different research studies in this domain are concerned with different coupling techniques, different frequency and data rates, and different modulation techniques–APK, FSK, BPSK, which make HBC an even more diverse technology [10]. As a result, different prototypes developed and proposed in HBC are incompatible with one another, which limits their use cases to a single application.

In this paper, we propose merging two technologies (HBC and NFC) to improve and enhance the communication. Blending these technologies brings improvements in the overall design. We designed a custom NFC wristband that is highly flexible, secure, and easy-to-use. The key idea is borrowed from HBC to confine the magnetic field around the human body during communication. Using the human body as a magnetic channel, we can minimize the energy radiation to the air and reduce the communication sniffing and hijacking possibilities. To evaluate our proposed system, the communication range for three channels (air, water, and the human body) is evaluated and compared using the NFC chip in various orientations. The communication range for the human body channel comes out to be greater in comparison to air and water channels. For sideways communication with an offset from the NFC chip, the range is significantly reduced in the human body channel. Based on these results, we conclude that the human body channel is a naturally secure channel, which limits the magnetic energy in proximity to the human body and the energy degrades sharply when moving away. Therefore, hacking and nearby interference with other similar devices can be avoided, which improves the inherent security level of communication. Our proposed prototype, i.e., a custom NFC wristband, could be applied in a multitude of applications scenarios. One possible application of such communication would be the sharing of confidential or other data with a handshake.

II. System Design

A. System Overview

The key objective of this research was achieved by using NFC in human proximity, such that most of the magnetic fields were channeled through the body. The NFC loop antenna was used at the receiver end such that no modification is required in the antenna design. Specifically, a wristband was designed which is an NFC receiver/transceiver. The wristband can work in any mode selected by a user, such as read or write, or the card emulation mode. When writing to an NFC receiver, users can choose among the different NDEF formats available in NFC; for example, write a plain text string for storing a contact, read or write a URI link, or store a smart-poster-type payload. The key benefit of the proposed system is that it brings flexibility in the wristband-use by appropriately letting users to choose the mode and the payload-type as per their requirements. With this technique, man-in-the-middle attacks can be avoided as well. In such attacks, the attacker comes in the middle of communication between the devices and can control communication at its own discretion without being detected by the concerned devices [11]. However, when the communication channel is the human body, most of the magnetic flux is channeled through the body, rendering such an attack impossible to be successfully achieved.

Fig. 1 shows the general workings of such a technology in different scenarios, such as on a bus, to share information with another person wearing a similar wristband, in hospitals to easily access patients' information, in buildings requiring gate-access, in shopping malls for mobile payments, and inside the home for personalized setting of home appliances. The salient features of the proposed system described in this paper are security, power-efficiency, ease of use, and flexibility. These features have been evaluated by doing various experiments that are articulated in a later chapter titled Experiments. Subsequent sections describe the approach used by discussing the hardware and software modules, as well as concluding the approach to experimentation.

B. Working of the NFC bracelet

1) Software Module: The software developed for this project can be divided into two parts: a) software for the NFC chip using Arduino Uno and b) software for the NFC-enabled Android phone using PhoneGap (Samsung Galaxy is used). Different technology cards required loading and compiling different libraries on the NFC chip to establish successful communication. For instance, MIFARE Classic, MIFARE Ultralight, and NTAG 2xx cards follow different communication protocols so different libraries were implemented for each of these cards. Libraries were also implemented based on the different communication modes including peer-to-peer (P2P), card emulation, and read or write (passive) mode. Different libraries form different layers in the NFC library framework, thus forming a stack hierarchy. An NFC application was developed for the Android platform to write and read the NDEF-type cards. A user communicates using the NDEF

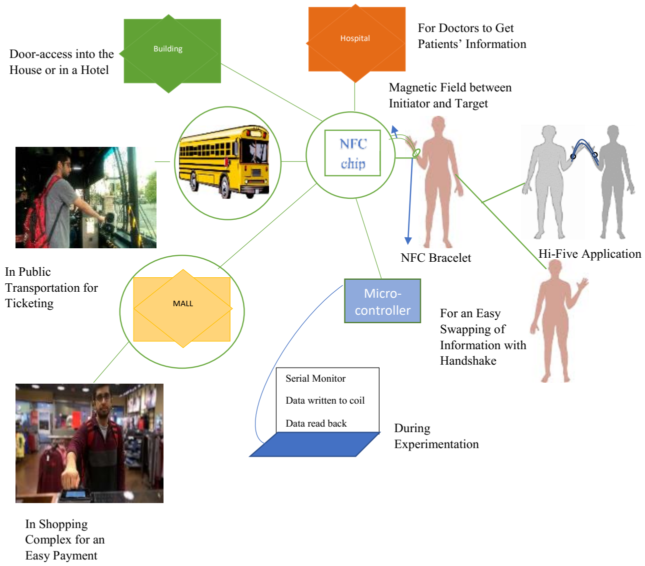


Fig. 1. Human body magnetic communication.

library as this is the standard for NFC Forum-type tags. Below the NDEF library is the PN532 library that converts the records in bytes for data manipulation. The application was written using Cordova CLI (cross-platform workflow) and installed using an "npm" (Node-js package manager). Cordova is a cross-platform framework for developing mobile applications using web technologies such as HTML5 and Javascript. To develop an NFC writer app in compliance with the NDEF, it is important to understand the NDEF message structure, or NDEF frame. An NDEF frame consists of NDEF records that contains the Type Name Format (TNF), payload type, and payload. In the NDEF frame, a message with a length of $2^{3}2$ can be sent, as an NDEF frame allocates up to 4 bytes of space for the payload. Another important parameter in the NDEF record frame is the Record Type Definition (RTD). Still further below is the library for handling different card types including NTAG, MIFARE Classic, and MIFARE Ultralight. Another step down towards the machine-level interaction is the PN532 SPI library, which is needed for communication between the NFC chip and the micro-controller. When using this library, data read by the NFC chip from the card or phone can be seen at run-time on the PC's serial monitor.

We utilized different NFC card in our experimentation. **1) MIFARE Classic** was one of the receivers used in experimentation. It has 1K (1024) bytes of EEPROM memory of which 752 bytes are available to write and the first 16 bytes contains the card's ID information and are read only. Memory is divided into sectors and blocks. For a card of 1K memory, there are 16 sectors in total with 4 blocks of 16 bytes each, which makes it a total of 64 bytes per sector. Out of each sector's four blocks, only the first three blocks (0, 1, and 2) can be used for data storage. The fourth block (block number 3) called a "trailer" block, stores two keys, Key A and Key B. It also stores the access bits that are used to set a sector to a particular access configuration, such as read, or write. Each sector can have a different key value and different authentication setting. **2) NTAG 2xx** is a generic name for cards such as NTAG 213 and 216. These cards are the NFC forum type-2 cards that are formatted as NDEF cards. They are supported to be used with the latest NFC readers. In this paper, NTAG 216 and NTAG 213 cards were used. The NTAG 216 is the size of a standard business card with a usable memory of 888 bytes, whereas the NTAG 213 is a small sticker of round shape having an approximate size of 3 cm in diameter and a usable memory of 144 bytes. Even though the NTAG 216 can be written for 216 pages, during experimentation a few NDEF records were sufficient for writing. It was unnecessary to read all 216 pages each time, as most of the pages would not have stored any information in them. In the experiment this was achieved at the software-level by setting the loop's upper bound to 42, which was equal to the number of pages in the NTAG 213 card. This simplification ensured the same working code for both the cards, NTAG 213 and NTAG 216. The libraries utilized for reading the NTAG 2xx were a) Don's NDEF library repository and b) The PN532 library repository by Seeed Studio.

2) Working of NFC: NFC technology works on the principle of mutual induction between the receiver and the transmitter antenna. This transmitter antenna is a loop antenna that works on the principle of magnetic coupling; therefore, in order for the devices to communicate, they must be in proximity to each other. NFC works in a target-initiator configuration in which one of the devices, the initiator, is in the active mode, and the other device, the target, is in the passive mode. The initiator powers the target by generating the magnetic field at a frequency of 13.5 MHz, which links with the coil of the target to power it (see Fig. 2). Both the initiator and the target antennas communicate at a resonant carrier frequency and form an LC-resonant circuit.

The mathematical equation for the magnetic flux produced by a circular coil of N turns is as follows:

$$B_z = \mu_o \times I \times N \times a^2/2(a^2 + r^2)^3/2 \tag{1}$$

where B_x - Magnetic field intensity along x-axis, I - current, r-distance from the center of the coil, μ_o - permeability of free space ($4\pi \times 10^7$ Henry/meter), a-radius of the coil.

By taking the first derivative of equation (1), we have,

$$\frac{\mathrm{d}}{\mathrm{d}a}(NI) = K \times \left(a^2 - 2 \times r^2\right)\left(a^2 + r^2\right)^{(}1/2)/a^3 \tag{2}$$

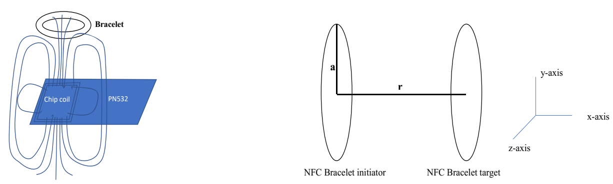
For optimized loop, the derivative should reduce to zero, which will be when:

$$a = \sqrt{2} \times r \tag{3}$$

(3) implies that a circular coil with a radius of 7cm will work effectively as a chip coil in NFC for a distance of 10 cm. The passive coil of MIFARE classic technology has been tested around the human body. The newer NFC cards including DESFire and NTAG 21x do not have coils, but a thin plastic on which the coil is etched. MIFARE classic's

security has been compromised, as its encryption was decoded in 2008. The latest cards, however, are highly secure and have indecipherable encryption. Precisely because the fundamental concept behind the working of all NFC cards is the same at the hardware level, the results concluded for the MIFARE classic also apply to the latest technology cards.

Permeability of the human body is very close to the permeability of air which makes the human body an excellent communication channel for magnetic-based communication. In addition, very little magnetic fields are radiated into the air as most of the fields are channeled through the body. This leads in improvement in the efficiency of such communication system in comparison to the systems that leverage the air channel. Study on how the communication range of NFC inside or around the human body is affected was done through the experiments, which is explained in the Experiments section.



(a) Flux linkage (b) Theoretical range

Fig. 2. NFC Bracelet Communication of a) Flux linkage with Bracelet, and b) Theoretical optimal communication range of NFC Bracelet.

3) Hardware Implementation: The hardware architecture for this paper is very simple. It consists of a micro-controller, an NFC chip, a communication channel, and an NFC receiver to establish NFC communication. We utilize the NFC chip called PN532, which belongs to the PN52x family of transceivers/receivers from NXP and communicates at 13.56 MHz frequency. The chip communicates in an active mode during communication with the MIFARE Classic card, MIFARE Classic coil, and NTAG 21x card at a bit rate of 106 kbit/s.

Additionally, the chip communicates with the smartphone (Samsung Galaxy SIII) in two modes: a) card emulation mode, and b) peer-to-peer (P2P) mode. For this thesis, the communication range of P2P was not significant hence this communication was not used in the experiment. In the card emulation mode, the NFC chip can either be in active or passive mode, depending on whether the smartphone is receiving or transmitting data. An Android application was written for communication between the smartphone and the NFC chip. It is discussed in the Software Implementation chapter.

The NFC chip can establish a connection with different cards including MIFARE and feliCa following these protocols: ISO/IEC 18092, ISO/IEC 21481, ISO/IEC 14443 A/B, and the NFC Forum. It requires 3.3V to work, and can communicate using UART, SPI, or I2C communication. The PN532 chip and its antenna are embedded in the Arduino breakout board. The antenna, which is tuned to work at 13.56MHz, is a strip-line antenna. This board can communicate with a micro-controller using different communication protocols, such as UART, SPI, and I2C. A communication protocol is selected by configuring the select pins on the breakout board using the two sets of jumper. An Arduino Uno R3 micro-controller was used to power the PN532 breakout board. Arduino serves as an important part of the hardware because it is used to 1) power the breakout board, 2) put PN532 in different modes and read different kinds of NFC cards, and 3) receive real time data, read by PN532 from a passive card (or smartphone) and display it on the serial monitor. Additionally, a CD4050B hex-buffer was used as a high-to-low voltage level shifter, converting 5 V digital output from the Arduino board to a digital level of 3.3V. This chip (CD4050B) is a non-inverting voltage level shifter chip. It consists of six identical units of a CMOS invertor pair (buffer), which helps to produce a stable output of 3.3V. Three pins of PN532 are connected through the Hex-buffer. They are SCK, SSEL, and MOSI. MISO pin can be directly connected to the Arduino Uno and does not require a hex-buffer, as it sends the signal rather than receives it from the Arduino.

To get the NFC antenna, we tried many coils along with the cards. The coils used in our bracelet were carefully taken out from the inside of the MIFARE Classic card. To take out the coil without damaging the body, we put the plastic MIFARE Classic card in a 100% acetone solution. The plastic body of the MIFARE Classic dissolved in the acetone in approximately an hour, and the coil was then removed. Experiments were performed using two coils so as to make the readings less prone to human error and the results more conclusive.

III. Experimental Setup and Evaluation

As shown in Fig. 3, experiments are done for the verification of the theoretical concepts of magnetic communication through the human body and to evaluate the performance of NFC in the human body channel. For experiments, different NFC tags, such as MIFARE classic cards, and NTAG 21x cards have been used. The coils used in experimentation are MIFARE classic passive tags, which will be referred to as MIFARE coil. The coils are taken out from the inside of the plastic encasement of the MIFARE classic card by dissolving it in the acetone solution. Different experiments are performed by changing the transmission channel for NFC. Experiment 1 is done with the air as a communication channel, which will also serve as a reference when comparing results for the other communication channels. For experiment 2, the water bottle is used as a communication channel; the passive MIFARE coil has been rolled up onto the water bottle. In the third experiment, the MIFARE coil has been worn on the arm. Fig. 4 describes all three communication channel used. Later, in the following sections, the explanation of these experiments and the readings recorded in each experiment has been presented. First, a brief description of the experiment environment and the methodology followed in experimentation is given.

A. Experiment Environment

In this research project, we use an NFC chip called PN532, which belongs to the PN52x family of transceivers/receivers

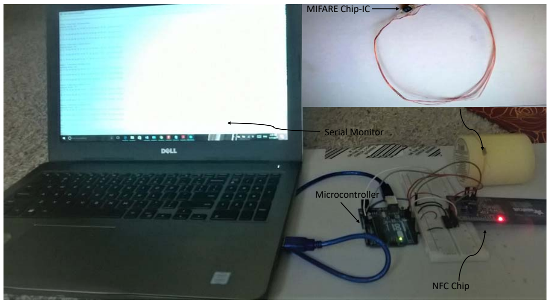
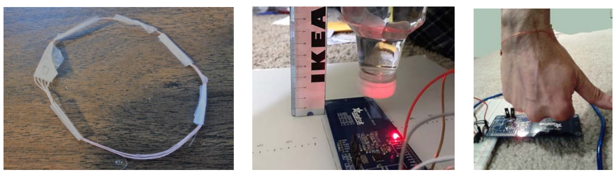
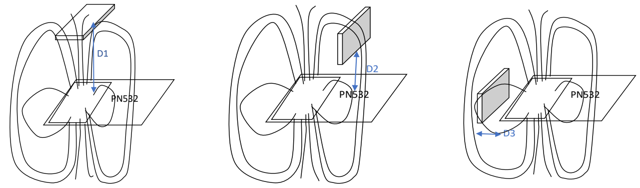


Fig. 3. Experiment Setup.



(a) Air Channel (b) Water Channel (c) Arm Channel

Fig. 4. Three different communication channels used in experimentation.



(a) Above Orientation (b) Edge Orientation (c) Sideways Orientation

Fig. 5. Three different orientations used in experimentation.

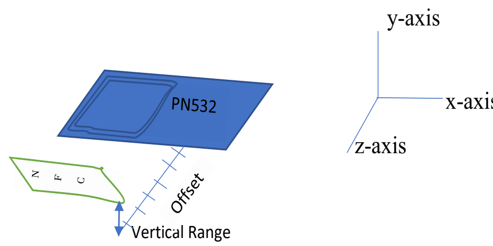


Fig. 6. Experiment at an offset from the NFC chip.

from NXP and communicates at 13.56 MHz frequency. The chip communicates in an active mode during communication with the MIFARE Classic card, MIFARE Classic coil, and NTAG 21x card at a bit rate of 106 kbit/s. The NFC chip can establish connection with different cards following protocols such as ISO/IEC 18092, ISO/IEC 21481, ISO/IEC 14443 A/B, the NFC Forum, and MIFARE and feliCA type of cards. The NFC chip can be used in three different modes, such as read/write, peer-to-peer, and card emulation mode. It requires 3.3V to work and its 13.56 MHz tuned antenna is itched on the breakout board. The NFC chip embedded on the breakout board can communicate with a micro-controller using UART, SPI, or I2C bus protocol. By powering the chip using micro-controller gives three benifits to the setup:

1) puts the NFC chip in different modes depending on the requirement. For instance, whether the communication is with a smartphone (active device) or with a passive tag, an appropriate mode must be chosen for communication.
2) sets the appropriate library settings required to successfully communicate with the NFC cards of different technologies, such as MIFARE Classic (NXP's proprietary cards, ISO/IEC 14443 Type A compliant) and NTAG 21x (NFC Forum and ISO/IEC compliant).
3) captures the date read by the chip when it communicates with a passive card, as well as in the card emulation mode with a smartphone. Because the chip does not have any memory of its own, only way to test the reception of data is to look at the serial monitor on PC.

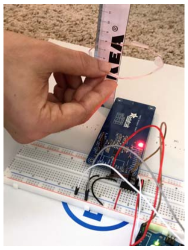
All these experiments are performed in three different orientations, which can be briefly explained as below:

a) The MIFARE coil with its axis in an alignment with the NFC chip's coil (referred as "from-above" orientation);
b) The MIFARE coil at the edge of the NFC chip, with its virtual axis orthogonal to the transceiver coil's axis (referred as "from-edge" orientation);
c) The MIFARE coil on the side of the NFC chip, with the orientation of the axes as in the "from-edge" orientation (referred as "from-sideways" orientation).

These orientations can be seen in Fig. 5. Also, sideways orientation gives the impression of how far a near field communication works at an offset from the NFC chip's coil. That is why experiments are done in the sideways orientation and the position of the NFC coil receiver is varied with respect to the NFC chip in an interval of one centimeter and the maximum vertical range was recorded (see Fig. 6).

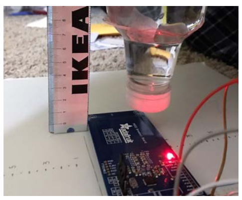
Also, an android app is written to accomplish the NFC communication in different NDEF payload types, such as a) TNF 01, Well-Known "U" type record b) TNF 02, MIME record c) TNF 01- Well-Known type "Smart poster" record and d) TNF- 04 External type "Android application" record. The app prompts its users to choose an appropriate payload type to be written to their card. Communication between the smartphone and the NFC chip is successfully tested in the card emulation mode, in which the NFC chip receives the data in a passive mode, and the smartphone sends the data in an active mode.

Different NFC receivers that are used in different experiments are: smartphone, MIFARE classic coil, MIFARE classic card (tag), NTAG 213 card, and NTAG 216. Readings are taken using a measuring scale, and photographs are taken during the measurement for a persistent and error-free reading. Communication between the smartphone and the NFC chip in the card emulation mode is also included in experimentation. Using two MIFARE coils and other NFC cards during experimentation has helped in reducing the errors in the

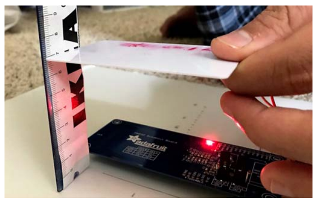


(a) Coil

(b) Smartphone



(c) Water



(d) NFC Card

Fig. 7. Different receivers (other than human arm) used in experimentation.

measurement and reaching to a reliable conclusion.

B. *Experiment 1: Air-channel communication*

This is the most popular media in which NFC technology works. All familiar applications of the NFC, such as mobile payment in a shopping mall, or a gate-access to the building, works having the carrier signal propagating in the air. In this experiment, various NFC receivers are tested, such as a smartphone, a card, or a coil, as shown in Fig. 7. For all the receivers' readings recorded in the above orientation, the maximum range has been recorded in comparison to the other two, edge and sideways orientations. The maximum flux links with the receiver in the line-in-sight orientation resulting in the increased communication range. Also, distances for the NTAG216 card are greater when compared to MIFARE classic cardboth cards have similar card dimensions. Because the NTAG cards are the latest cards compared to the MIFARE classic, so they are built around the more advanced technology compared to the MIFARE classic. The smartphone (Samsung's Galaxy SIII) has lesser distances in all orientations compared to both the cards because the NFC antenna, which is embedded in the phones battery, and has smaller dimensions in comparison to both the cards. The readings for all the receivers in the air channel have been recorded in a tabular form in Table I

TABLE I
READINGS FOR DIFFERENT RECEIVERS MEASURED IN DIFFERENT ORIENTATIONS IN THE AIR MEDIUM AS A COMMUNICATION CHANNEL

Receiver	From-above(cm)	From-edge(cm)	From-sideways(cm)
Coil (Avg.)	7.5	2.5	3.75
MIFARE	7	4	3.5
NTAG216	9.5	4.2	4.2
Smartphone	6.2		3.2

C. *Experiment 2: Water-channel communication*

In this experiment, the coil was placed around the neck of the bottle and fixed using an adhesive tape (see Figure). Unlike the air medium, the only NFC receiver used in this experiment is the MIFARE coil. A bottle of appropriate size must be chosen, so that it is neither too tight or too loose for placing a coil on it. Similarly, as for the air-channel, distances for different orientations as well as the vertical range as a function of offset from the NFC chip are calculated. Later, same experiment was repeated for the concentrated salt water in order to closely match the conductivity of the human body. A similar trend to the air-channel has been observed when the communication in the water channel; however, distances in all three orientations are lesser compared to the former. The water medium attenuates the magnetic field, that's why the communication range is reduced compared to the air medium (see Table II)

TABLE II
READINGS FOR BOTH COILS C1, AND C2, MEASURED IN DIFFERENT ORIENTATIONS IN THE WATER MEDIUM AS A COMMUNICATION CHANNEL

Receiver	From-above(cm)	From-edge(cm)	From-sideways(cm)
Coil C1	6.5	2.5	3.5
Coil C2	4.5	1.5	3
Coil (Avg.)	5.5	2	3.25

D. *Experiment 3: Human body communication*

To determine how NFC is affected in human proximity, as well as how the communication range is effected when the communication channel is the human body, this experiment has a critical significance. To achieve a communication in human proximity, a coil is worn around the human arm. The magnetic field's path of travel is mostly through the human arm in this communication. Two experiments—as done for the air and the water channel—are done for the human arm as a communication channel. First, coil's placement on the arm is varied and vertical readings in the sideways orientation are taken as a function of offset from the NFC chip. The experiment is done for the three different positions of the MIFARE coil on the arm—at 0, 7, and 13 cm—as shown in Fig. 8. To test the human body channel, most of the magnetic field should be linked through the body. At 13 cm, measuring from 0 cm as a start reading—on the author's arm—the air-gap is negligible; whereas, at an intermediate distance of 7 cm, the air-gap exists, but is minimal (see Figure 26). The vertical range is greater when there is no air-gap between the coil and the arm (see Figure 24). Also, the communication dropped relatively faster for the 0-cm placement of the coil around the arm compared to the 7 and 13-cm placement (see Figure 25). It can be seen that when most of the magnetic flux link through the human body, communication is improved.

The Table III shows the results for different coils C1 and C2 in the human body channel. The average distance of both the coils is greater in the human channel medium experiment in all the orientations. Also, for the above and edge orientation,

TABLE III
READINGS FOR BOTH COILS C1, AND C2, MEASURED IN DIFFERENT ORIENTATIONS IN THE HUMAN BODY MEDIUM AS A COMMUNICATION CHANNEL

Receiver	From-above(cm)	From-edge(cm)	From-sideways(cm)
Coil C1	10	6	4
Coil C2	8	4.5	3
Coil (Avg.)	9	5.25	3.5

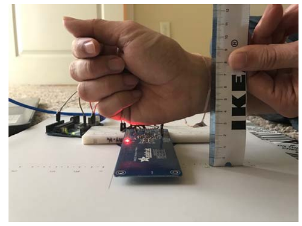
the average distance is greater for the human body medium in comparison to the reading in the air medium experiment. All the communication media have comparable readings in the sideways orientation. It can be inferred from the readings in this experiment that the NFC technology performs effectively in the human body medium, as the communication is not affected in the human body, when compared to the air and the water medium. In fact, for the line-of-sight communication (above orientation), an improved distance was measured in this experiment in comparison to the previous experiments performed in the air and water channels in similar orientations setting.

E. Evaluation

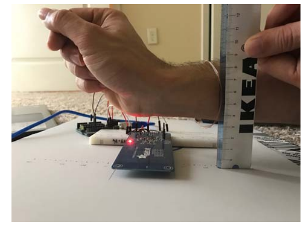
It can be evaluated from both the graphs in Fig. 10 that the maximum flux is linked when 1) the circular coil is used, 2) both coils' axes are aligned to each other, i.e. in the above orientation.That is why, range distance is greater in the above orientation in comparison to the remaining two. Thus, a line-in-sight communication usually results in a higher efficiency compared to other orientations. A range distance of 10 cm is recorded in the human body channel for one of the coils, which is the maximum theoretical range that can be achieved using the a coil of approximately 6 cm diameter. This also validates the fact that not only does the human body has a similar characteristics to the air in terms of fields attenuation, but it channels the field from the receiver to the transmitter. Also, the shape of the coil affects the range of communication too. The range distance of the MIFARE coil is greater compared to the rectangular MIFARE classic card. Thus, keeping the shape of the proposed bracelet circular, communication range can be improved for the same energy input. Also, for the experiments performed for the maximum vertical range as a function of offset from the NFC chip, it has been concluded from the readings that the field strength rapidly drops off from the chip-coil with the increase in an offset distance. This trend is shown in the graph in Fig. 11. This distance is even lesser when the communication channel is through the human arm, which naturally improves the security at the hardware level and so the efforts in developing a complex crytographic algorithm will be minimized for a general application (see Fig. 9).

IV. CONCLUSION

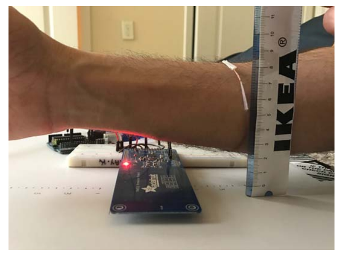
In this paper, we propose to develop a low-cost wearable device that combines the advantages of HBC and NFC. Our system brings enhancements to both technologies: a) NFC-the proposed wristband has a support for multiple applications in NFC, and b) HBC-magnetic field technology has a simpler setup and lower power consumption compared to the electrostatic field technology. We evaluated the system via multiple experiments in different orientation settings and in different communication media. The results demonstrated that the human body is the most effective channel for short-range NFC in comparison to other channels such as air and water. The range of communication of our bracelet improved



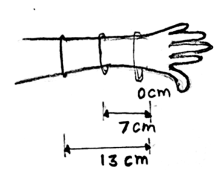
(a) 0 cm placement



(b) 7 cm placement



(c) 13 cm placement



(d) Diagram depiction

Fig. 8. Variation of the coil on the human arm.

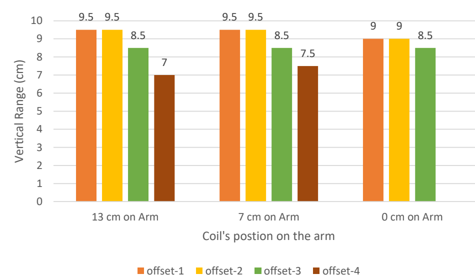
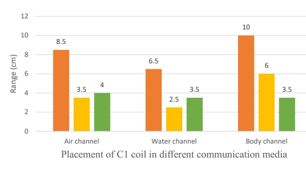
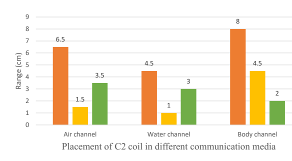


Fig. 9. Vertical range measured for different coil position on the arm as a function of offset from the NFC chip.



(a) Graph for coil C1



(b) Graph for coil C2

Fig. 10. Range vs orientation graph for three different communication media.

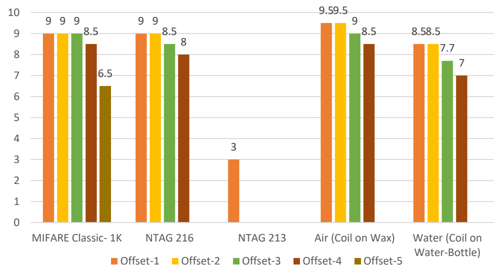


Fig. 11. Vertical range measured for different NFC receivers as a function of offset from the NFC chip.

when compared with conventional NFC. The proposed system is very flexible with a longer communication range than normal NFC and achieves better physical-level security. It is also compatible with existing NFC readers and systems. Like NFC, this technology can easily be accommodated in a) public spheres, such as with public transportation, and for commercial payments; and b) a private sphere for personal use, such as in wearables for sharing of personal information, and controlling other NFC-enabled gadgets at home or at work. New application scenarios and communication patterns can be generated as well. For example, exchanging contact information with a handshake when both the participants are wearing our NFC-enabled bracelet.

V. Future Work

Future work will focus on developing a wristband prototype working in an active mode, such that communication is through the human body (human arm), and the development of applications around it. Two crucial applications for this technology are development of the hardware and software modules for secure mobile payment and the secure sharing of information with a handshake. These two applications are in the early stages of development and require a high measure of security, which makes them highly prospective technologies for developers.

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