Lab-on-Phone: A Laboratory-on-Phone System

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***Abstract*—This paper presents a novel approach defined as "*Lab-on-Phone*" which is a new "*Dielectric Footprint Measure*" platform, specially for food quality control with storage and administration processes over the Internet. It can also be used for other types of products making minimal changes. A small acquisition device, with an inter-digitized capacitor sensor sends measurements to a smartphone via Near Field Communication (NFC) protocol. An Android application installed on the smartphone displays these measurements in a graph and sends them to a web server via Wi-Fi or cellphone network. For example, Lab-on-Phone allows users to know on site the food quality, and to companies, to have a quality control sensor network with a data base and a web server.**

Keywords*—*Near Field Communication (NFC); measurement platform; wireless measure; data acquisition; food quality control; ultralow power sensors; wireless sensors

I. Introduction

Near Field Communication (NFC) technology, is a wireless communication technology in the frequency range of 13.56 MHz. NFC can be used to transmit information between two NFC devices, to read/write a Radio Frequency IDentification (RFID) card or tag, or to both simulate them [1]. One of the main features of NFC technology is the less than 100 ms set up time, and there is no necessity of pairing. NFC have a communication range of 10 cm and a maximum data rate is 424 kbps.

There is a wide field of applications for the NFC technology in the fields of transport and payment; however, there are a lot of other applications involving NFC technology. American Thermal Instruments created an NFC tag capable of measuring temperature. The tag is read by an NFC-enabled phone with the LOG-IC Mobile App. The application allows monitoring the temperature anywhere and exporting data immediately to anyone via email or can be uploaded to the cloud. It also shows a report of temperatures measured including charts and graphs. The main goal, according to the manufacturer, is to be able to protect critical shipments all the way down to the last mile [2]. A final example of the wide range of NFC applications is SleepTrak, a combo device-application that uses an armband to track symptoms associated with inefficient sleep (recording how active you are during sleep, for example). The armband is read via NFC the next morning, and the app analyzes the data and provides suggestions for better sleep habits [3].

There are a lot of other examples showing that NFC technology is expanding all over the world. According to recent reports from Juniper Research about forecasts for the global NFC market, global NFC retail transaction values are expected to reach $110 bn in 2017 [4]; mobile NFC metro tickets are going to be used by 1 of 8 mobile users in the US and Western Europe by 2016 [5]; and 1 in 4 mobile users in the same region will pay in-store using NFC by 2017 [6]. An analysis made by Frost & Sullivan states that 53 % of phones are going to be NFC-enabled by 2015 [7]. London buses have added NFC technology to their card readers for a contactless payments with debit or credit cards. With a agreements between the bus system and the software industry will be possible to pay a bus ticket with a NFC-enable smartphone [8].

NFC will step smartphones to a new level of interaction and functionality, and will give the users the possibility to use its phones almost in every action that involves money, registration, identification, verification and much more other applications so that practically the only thing they will be carrying in their pockets will be the phone. For example, Google created the concept of an electronic wallet in which all credit and debit cards information are linked to the user Google account and can be accessed at anytime through a computer or a smart phone with Android OS and Google Wallet application. With Google Wallet users can use their NFC-enabled phones as a contactless payment card [9].

In the field of microsensors, there are a great variety and classifications. An alternative is the case of capacitive sensors, which can have a planar geometry based on parallel plates or inter-digitized plates. In this article inter-digitized capacitive sensors are described; they can be useful for measuring changes in the dielectric constant due to contact of any material with the sensor surface.

Inter-digitized electrode capacitive sensors have been used in numerous applications such as soil, grain, and paper moisture content monitoring; rain detection, proximity sensors, touch switches and biomedical sensors. Implementations have been made with several technologies and materials including sensors with printed circuit board technology [10]. The electrode overlapping area or the relative permittivity of the dielectric in the vicinity of the electrodes can be sensed by monitoring the changes in the structures capacitance [11].

Several investigations reported advances in the area of sensors, but left out the area of instrumentation. Most of the works that measure changes in capacitance use sophisticated equipment such as LCR-821 meter, impedance analyzer or similar, that are very expensive, bulky and complex to be used due to their variety of functions. This means that it is important to implement small systems with low cost even if they are designed for a reduced set of applications.

Having described the NFC protocol characteristics and the advantages and applications of capacitive sensors, this paper aims to develop a generic platform, which can be used in the field in a comfortable and complete way. This platform allows to take measurements with a capacitive sensor and communicate the results to a mobile device, such as a smartphone via NFC protocol. In the mobile platform, the measured data or historical data can be displayed and can be sent to a web server via Wireless Fidelity (Wi-Fi) protocol or General Packet Radio Service (GPRS), allowing multiple people to view the measurements for analysis and perform tracing procedures, almost in real time from any computer with Internet access.

There are previous studies about NFC implantable Medical Devices, which show that NFC technology can be used for data and power transmission to implantable devices without any health consequence [12]. For wireless measurement devices, NFC provides a noninvasive communication interface to smartphones in order to take advantage of their computation capacity and communication flexibility. For example, a generic NFC-enabled Measurement System for remote monitoring is described in [13]. This is a beneficial solution for low-power data acquisition in portable devices [14]. In the case of passive or semi-passive sensors, it is possible to use a batteryless acquisition system by feeding it with the power from the carrier signal of the NFC connection [15].

NFC-enabled phones provide long range Global System for Mobile Communications (GSM) and General Packet Radio Service (GPRS), services that can be used to establish a remote monitoring. Lab-on-Phone advantage is a novel portable platform of Dielectric Footprint Measure for food quality control providing storage and administration over the Internet, it is a small acquisition device with the size of a credit card, with a capacitor sensor that sends measurements to smartphones via NFC protocol. An Android application installed on the smartphone sends sensors information to a web server via Wi-Fi or cellphone network. Lab-on-Phone allows users to get to know on site the food quality, and companies to have a quality control sensor network with a data base and a web server.

In the next section, there will be a description of the system architecture and functionality. In Section III, early results are presented for a system validation based on commercial boards. Finally, Section IV summarizes the presented approach and future works.

II. Lab-on-Phone System Architecture

Figure 1 shows Lab-on-Phone system architecture, including a full chain of acquisition, processing, storage and analysis infrastructure. Lab-on-Phone is itself a multiuser and multipurpose system. The first layer of the system is based on a Measure Card, which is a small acquisition device, the size of a credit card, with a capacitor sensor. The Measure Card is enabled to send measurements to a smartphone via NFC protocol. An Android application installed on the smartphone processes the sensor measurements and gives an on-site result to the user. If the device has a data plan or Wi-Fi access, the measurements are send to a web server through this medium. The web server stores the measurements information from multiple smartphones and controls privacy. Lab-on-Phone also include a set of web applications, which allow accessing data from everywhere and any platform with Internet access.

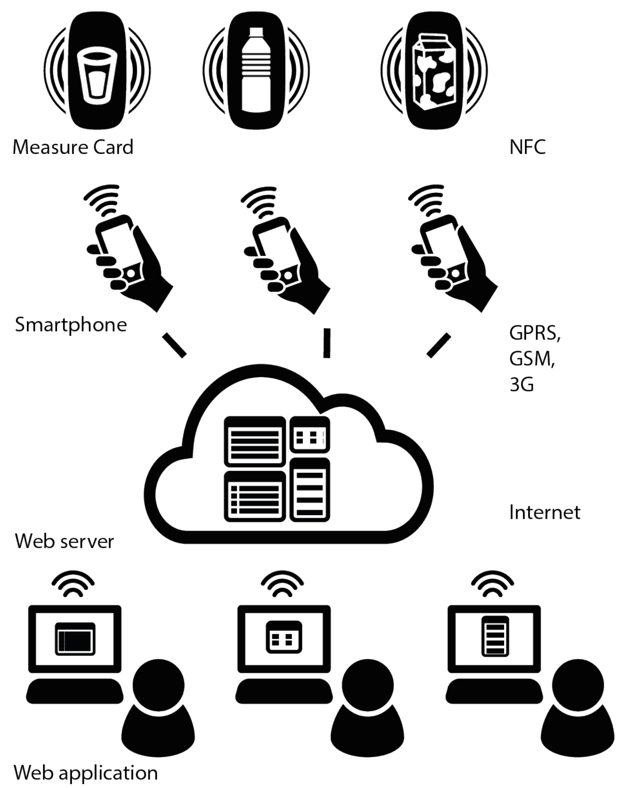

Fig. 1. System Architecture Diagram Block.

The Lab-on-Phone system helps people to have certainty about the quality of the product they buy and will also helps companies to avoid loses. For example, in Latin America, it is common to find adulterated liquors sold as original and there is not an onsite platform to ensure both consumers and authorities about the liquor quality. Although, this paper proposes Lab-on-Phone platform for food quality control; the tool can also be used to find out about the quality of almost any product for final consumers. The governments may take advantage of Lab-on-Phone to detect adulterated liquors suppliers or to have a record of the quality of food and beverages people are having.

A. *Measure Card: acquisition system and sensor*

The Measure Card is basically a small board with an Interdigitated Capacitor Sensor which sends measurements to a smartphone via NFC technology. An Interdigitated Capacitor Sensor can detect conductivity and dielectric constant of fluids. This type of sensor has a low-cost fabrication process and can be easily integrated with other sensing components. A low power microprocessor reads the sensor using a single slope Analog-to-Digital Converter (ADC) strategy. In other words, the microprocessor measures the discharger time of

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the Interdigitated capacitor. The measurement data is stored in a Dual Interface Electrically Erasable Programmable Read-Only Memory (EEPROM - M24LR16E), which is accessed by the microcontroller via Inter-Integrated Circuit (I2C) protocol. This EEPROM memory can also be accessed via NFC communication.

The Measure Card may have an LC sensor, which is a planar coil with an Interdigitated Capacitor, which uses the same strategy of detecting the conductivity and dielectric constant of fluids but it needs a different read strategy based on a self-resonant frequency, meaning the sensor may be wireless. These type of sensor is also inexpensive; so, it can be disposable as well.

The harvesting strategy is possible having a wireless powering via the carrier signal of the NFC technology, this way the proposed Measure Card is a low cost board with Interdigitated Capacitor and it could be batteryless or wireless powering.

The Measure Card implementation uses M24LR16E-A [16], which consist of a dual interface EEPROM connected to an I2C bus and a 20 mm x 40 mm 13.56 MHz etched Radio Frequency (RF) antenna (Figure 2). The integrated circuit (IC) can be feed with the RF energy field of the external device or with an external 1.8 to 5.5 Volts power source. The chip comes with the option of Energy Harvesting; so, the unused energy in the connection and in the command transmission in RF mode can be used to feed another electronic component like a Light-Emitting Diode (LED) or an IC. The RF interface works with the ISO 15693 protocol allowing an NFC device to be able to communicate with it. The minimum data rate is 6.62 kbits/s and the maximum is 52.97 kBits/s.

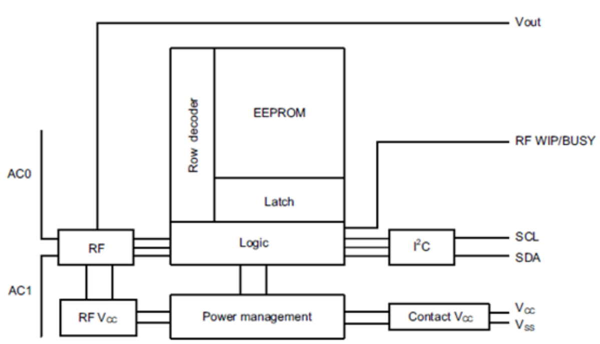


Fig. 2. M24LR16E-A Diagram Block [16]. In the middle can be seen the EEPROM component that can be accessed by an NFC device (left block) or a microcontroller by I2C protocol (right block).

In the Figure 3, the memory area set up is shown. The memory can be divided into the storing area and the configuration area.

The storing area is divided into 16 sectors of 32 blocks of 32 bits. Each sector can be read/write protected in RF or I2C modes with the corresponding Sector Security Status 5-bit registry or the Write Lock_bit registry respectively. In the configuration area, the passwords for read/write protection, the tag identifiers (UID, DSFID, AFI) and the configuration byte are stored.

Sector	Area	Sector security status
0	1 Kbit EEPROM sector	5 bits
1	1 Kbit EEPROM sector	5 bits
2	1 Kbit EEPROM sector	5 bits
3	1 Kbit EEPROM sector	5 bits
12	1 Kbit EEPROM sector	5 bits
13	1 Kbit EEPROM sector	5 bits
14	1 Kbit EEPROM sector	5 bits
15	1 Kbit EEPROM sector	5 bits
	I²C password	System
	RF password 1	System
	RF password 2	System
	RF password 3	System
	8-bit DSFID	System
	8-bit AFI	System
	64-bit UID	System
	8-bit configuration	System
	16-bit I²C Write Lock_bit	System
	80-bit SSS	System

Fig. 3. M24LR16E-A Memory Structure. The registers above represent the data memory divided in sectors. Each one can be write/read protected by its corresponding Sector Security Status (SSS) that can be set in the configuration area (bottom registers).

B. Comunication interfaces

NFC Forum is the world association that established all the set of specifications related with NFC Technology. The set of specifications includes the definition of the NFC Data Exchange Format (NDEF) [17], which defines a format for the exchange of information between NFC applications. There are also defined Record Type Definitions (RTD) that specify the types of the data that can be sent in a NDEF message. The Simple NDEF Exchange Protocol (SNEP) [18] is a high level protocol defined by the NFC Forum for the exchange of NDEF messages between applications. The SNEP works above the Logical Link Control Protocol (LLCP), which defines the way data transmission is made through the physical medium. The LLCP [19] allows two packets transmission modes (Payload Data Units - PDUs): connection-oriented and connectionless. Connection-oriented transport provides a data transmission service with sequenced and guaranteed delivery of service data units unlike connectionless transport, which provides an unacknowledged data transmission service with minimum protocol complexity. NFC Forum has created also specifications for four different tags types.

NFC devices can operate with RFID technologies like ISO/IEC 14443 (Type A and B) used by Mifare Type A (NXP smartcard technology), Calypso (European Cards) or EMV (Europay, Mastercard or Visa cards) cards; JIS6319-4 used by Felica Cards (Sony Smartcard System); ISO15693 used by RFID cards with a range up to 1.5 meters, obviously this will be reduced if the card is read with NFC technology; or ISODEP 14443-4 which is a transmission protocol used in proximity cards used for identification.

The dual interface Memory M24LR16E-A uses ISO15693 standard [16] which allows communication with more than one tag at the same time, but it is not going to be a common stage of our application. The protocol defines the structure of the requests made by the RFID device, as shown in Figure 4.

SOF	Flags	Command code	Parameters	Data	CRC	EOF

Fig. 4. ISO15693 Request Format.

The first field is the Start Of Frame (SOF), which indicates to the tag, the beginning of a new command. The 8-bit Request_ flags field indicates the tag features of the command and the communication like subcarrier mode, data rate or mode selection. The 8-bit command code field indicates the command to be executed on the tag as well. The parameters, data fields length and information depend on the command to be executed. The next field contains the Cyclic Redundancy Check 16-bit (CRC-16-bit) value, of the previous fields (without the SOF) for content verification at the reception. Finally, there is an End Of Frame (EOF) which indicates the tag the end of the request.

As in the previous case, the response starts and ends with an SOF and EOF frames respectively. The 8-bit Response_ flags field indicates if there was an error, if this is the case, the error information is given in the 8-bit parameters field. The data field carries information related to the request made by the RF device. Next to it, there is a 16-bit CRC for content verification at the RF device. In the Figure 5, the response format the tag sends to the RF device is shown.

SOF	Flags	Parameters	Data	CRC	EOF

Fig. 5. ISO15693 Response Format.

This protocol has defined a lot of commands for reading or writing individual or multiple blocks in the storing area and the configuration area. The main commands used in the application were the following: Read Single Block, Write Single Block, Get system Info, Write sector password, Present sector password, ReadCfg (for reading the configuration byte), WriteEHCfg (for writing the Energy Harvesting configuration), ReadEHCfg (for reading the Energy Harvesting configuration) and WriteDOCfg (for writing the configuration byte).

Data tag acquisition is included with any device with Android OS and NFC technology. The Android OS provides an API for NFC access from the applications [20]. When an NFC tag comes close to the RF radio of the NFC hardware, the operating system automatically parses it and notifies applications designed to manage NFC tags related to it. The API is specifically designed for operations with NFC tags; however, it also has support for other RFID protocols including ISO 15693. For this protocol, the API provides the following methods:

- close() Disable I/O operations to the tag from this TagTechnology object, and release resources.
- connect() Enable I/O operations to the tag from this TagTechnology object.
- get(Tag tag) Get an instance of NfcV for the given tag.
- getDsfId() Return the DSF ID bytes from tag discovery.
- getMaxTransceiveLength() Return the maximum number of bytes that can be sent with transceive(byte[]).
- getResponseFlags() Return the Response Flag bytes from tag discovery.
- getTag() Get the Tag object backing this TagTechnology object.
- isConnected() Helper to indicate if I/O operations should be possible.
- transceive(byte[] data) Send raw NFC-V commands to the tag and receive the response.

After the operating system notifies the application that an ISO 15693 tag has been discovered, the application connects to the tag via the connect() method and start sending commands via transceive() method which receives as input argument the command going to be sent as an array of bytes. This method returns the response given by the tag, after executing the request. For the development of the application, a library with all the commands in the ISO15693 protocol was built.

For sending information through the network the org.apache.http [21] packet available in the Android Development Environment was used. This packet provides the core interfaces and classes of the HTTP components, and deal with the fundamental requirements for using the HTTP protocol, such as representing a message including its headers and optional entity. In order to prepare messages before sending or after receiving them, there are interceptors for requests and responses. The more important classes for communication with a server are HTTPClient, HTTPPost, and HTTPGet. HTTPClient encapsulate a smorgasbord of objects required to execute HTTP requests while handling cookies, authentication, connection management, and other features. HTTPPost can be used to request that the origin server accept the entity enclosed in the request as a new subordinate of the resource identified by the Request-URI in the Request-Line. HttpGet is used to retrieve whatever information (in the form of an entity) is identified by the Request-URI.

In the application, after receiving the data of the measure from the tag an HTTP post request is created with this information. Then the request is executed via an HTTPClient, which sends it to the Internet Protocol (IP) server via internet. Access to the internet can be made via Wi-Fi or a mobile network (GPRS, GSM, 3G, 4G); in that case, if the smartphone has a data plan, the measurements can be sent to the server from anywhere with a mobile network access and can be tracked from any computer with internet almost in real-time. The measure information taken from the tag is stored in a Java Script Object Notation (JSON) object, and then put as an entity in the http request. JSON is a useful format for storing name-value pairs of any type. If the application does not have an available connection to the internet; then the applications waits until it is available to send it to the server.

C. *Data storage, information processing*

The information acquired from the sensor is stored in any type of external memory (SD Card typically, by default) or in the internal memory, if there is no external memory or if the user opts to store it there. Android provides a very practical set of functions to manage this process. On the other hand, the information send to the server via HTTPPost method is processed in the server side by a PHP algorithm and stored in a MySql database. The database can be viewed from a web page stored in the web server (the same with the PHP code).

D. *User interfaces and applications*

The platform has two types of user. The first user or field user is the one with the sensor and the phone in the field or site where the measurement is taken. The user puts the card with the sensor in the direct solution or surface where the measurement is desired to be made. Then the user must approach the phone to the sensor. When the phone approaches close enough for NFC communication, the application pop-ups automatically and begin to acquire the measurements from the sensor. The data transmission stops as soon as the user takes away the phone from the card. When the application receives a measurement, it append the actual phone's time and date, the exact position taken from the gps if available, or the approximate position from the local network, and the phone id (which must be registered in the server database). The Android application allows that the user visualize the data in a chart.

The other type of user is the one monitoring the measurements from the web application. It allows visualizing data in the database to different field users and also sending notifications to them. When a user sends data to the server via HTTPPost, it performs a user-password validation before storing data in the database. The web application can only be accessed by registered users.

III. RESULTS

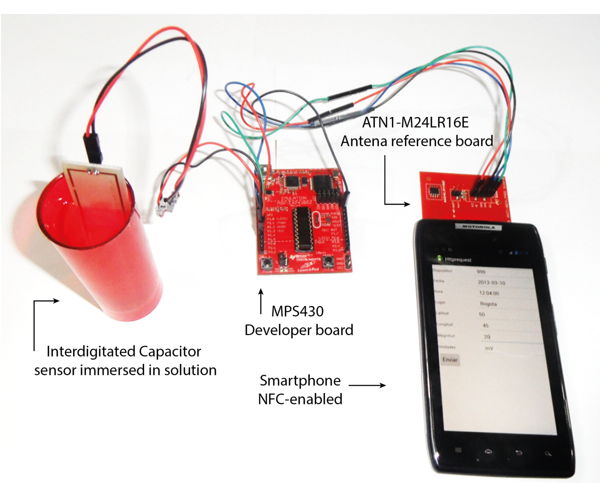
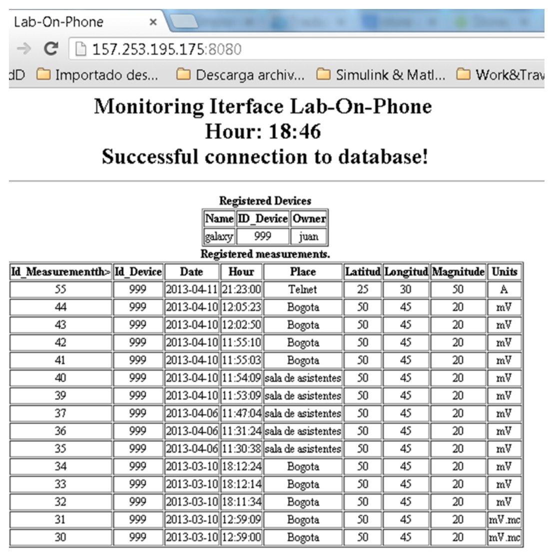


Fig. 6. Implemented acquisition system. From left to right we show the sensor (Interdigitated capacitance) immersed in a solution, a microcontroller and a dual interface EEPROM which is below the phone.

Figure 6 shows the implemented acquisition system using an ANT1-M24LR16E antenna STMicroelectronics reference board, including a MSP430G2553 on a LaunchPab board from Texas Instruments. The Interdigitated Capacitor Sensors was designed and manufactured on the Printed Circuits Board laboratory at Universidad de los Andes.

The Android Application was developed for Android 4.0.3 Version (Ice Cream Sandwich) and tested in a Sony Xperia Sola with the same version of OS, NFC technology, GPS, Wi-Fi, GSM, HSDPA, EDGE, GPRS, Dual-core 1 GHz Cortex-A9 and 512MB of RAM.

For the web server and the database, a LAMP Server was installed in an Ubuntu Server 12.04.1. The apache version of the web server is 2.2.22. The MySql version is 5.5.29. Figure 7 shows an example of web application screenshot where we can observe of measurements sent from the android application, after reading the card via Wi-Fi and 3G. The web application was programmed to update its information every 30 seconds; in no case the transmission overlaped this time, which showed monitoring the measurements made by field users can performed almost instantly.



Registered Devices

Name	ID_Device	Owner
galaxy	999	juan

Registered measurements.

Id_Measurementth>	Id_Device	Date	Hour	Place	Latitud	Longitud	Magnitude	Units
55	999	2013-04-11	21:23:00	Telnet	25	30	50	A
44	999	2013-04-10	12:05:23	Bogota	50	45	20	mV
43	999	2013-04-10	12:02:50	Bogota	50	45	20	mV
42	999	2013-04-10	11:55:10	Bogota	50	45	20	mV
41	999	2013-04-10	11:55:03	Bogota	50	45	20	mV
40	999	2013-04-10	11:54:09	sala de asistentes	50	45	20	mV
39	999	2013-04-10	11:53:09	sala de asistentes	50	45	20	mV
37	999	2013-04-06	11:47:04	sala de asistentes	50	45	20	mV
36	999	2013-04-06	11:31:24	sala de asistentes	50	45	20	mV
35	999	2013-04-06	11:30:38	sala de asistentes	50	45	20	mV
34	999	2013-03-10	18:12:24	Bogota	50	45	20	mV
33	999	2013-03-10	18:12:14	Bogota	50	45	20	mV
32	999	2013-03-10	18:11:34	Bogota	50	45	20	mV
31	999	2013-03-10	12:59:09	Bogota	50	45	20	mV.mc
30	999	2013-03-10	12:59:00	Bogota	50	45	20	mV.mc

Fig. 7. Web application interface. The measurements send by the phone with information of the place, time, date and device identification are showed in a table. There is also a table showing the registered devices that are allowed to send data to the server.

To validated de implementation we used ethanol (99 %), methanol (99 %) and a traditional Colombian Liqueur (Ethanol 27%) . The sensor was previously characterized using an impedance analyzer HP4194A in order to identify the solutions.

Finally, all the proposed system was tested. For this validation, the acquisition system measure capacitance sensor discharge time. As Table I shows, the system was able to determinate a difference between discharge time for each alcohol. The proposed system was able to successfully identify and differentiate each alcohol.

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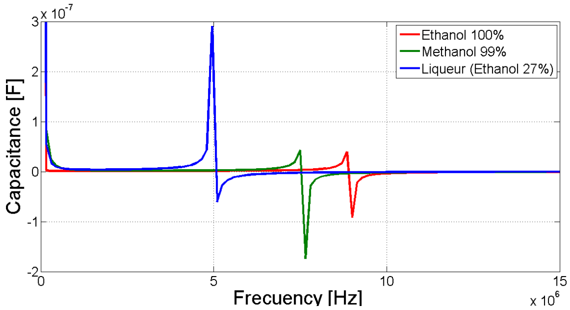

Fig. 8. Capacitance Measurements. The capacitance has a unique peak in a different frequency for each one of the solutions.

TABLE I
DISCHARGE TIMES

Alcohol	Discharge Time [ms]
Ethanol	64 $\pm$0.5
Colombian Liqueur	69 $\pm$0.5
Methanol	72 $\pm$0.5

IV. CONCLUSION AND FUTURE WORKS

This paper presented a novel approach defined as “Lab-on-Phone”, that is a new “Dielectric Footprint Measure” platform, specially for food quality control with storage and administration over the Internet. The platform uses the principle of inter-digitized capacitors as the sensor element. For the measurement with the sensor, the system uses the same energy generated by the device NFC component reading card.

The entire measurement chain has been tested in all its phases, including the sensor measurement, data adquision with NFC communication, the mobile application, sending data to the cloud and the application on the server.

The present work does not focus on the development of sensors, but in the development of a novel platform taking advantage of the smartphone benefits.

The stage was developed with NFC commercial kits. As future work, we propose the development of a smaller card that integrates a sensor capacitive coupling, a low-power microcontroller for acquisition and processing, and a dual interface memory that can be accessed by the microcontroller and NFC device. We also propose the use of other types of sensors, such as LC resonators.

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