

Through-body Capacitive Touch Communication

Hoang Truong
University of Colorado Boulder
Hoang.Truong@colorado.edu

Mohamed Ibrahim
WINLAB, Rutgers University
mibrahim@winlab.rutgers.edu

Phuc Nguyen
University of Colorado Boulder
vp.nguyen@colorado.edu

Richard Howard
WINLAB, Rutgers University
reh@winlab.rutgers.edu

Viet Nguyen
WINLAB, Rutgers University
vietnh@winlab.rutgers.edu

Marco Gruteser
WINLAB, Rutgers University
gruteser@winlab.rutgers.edu

Tam Vu
University of Colorado Boulder
tam.vu@colorado.edu

ABSTRACT

To overcome the drawbacks and security issues of traditional wireless and RF-based communication techniques, multiple alternative "wireless" communication methods have been investigated. Among them, capacitive touch communication which utilizes the touch-screen process as communication channel has been proposed with the promising future since capacitive touchscreen has been widely known as an important component of pervasive touch-enabled smart devices. In this paper, we present for the first time the indirect method of capacitive touch communication that allows the users to transmit their information from the wearable devices to the touch-enabled devices using human body as a medium. The key idea is to modulate the signal emitted from a wearable device propagating through user's body. These signal can be decoded to extract the transmitted data when the user touch to the touch-surface. In particular, we show a system design of through-body capacitive touch communication channel together with the circuit model analysis. We present our preliminary results of our system, and identify possible challenges for future research and development.

KEYWORDS

capacitive touch communication; through-body communication

1 INTRODUCTION

Near-field communication has been attracted researchers and engineers in recent years. Alternative forms of "wireless" communication which utilized vibration [3], light [2], capacitive sensing [5], have been proposed with the goals of ensuring more secure communication channel and enabling better human-computer interaction.

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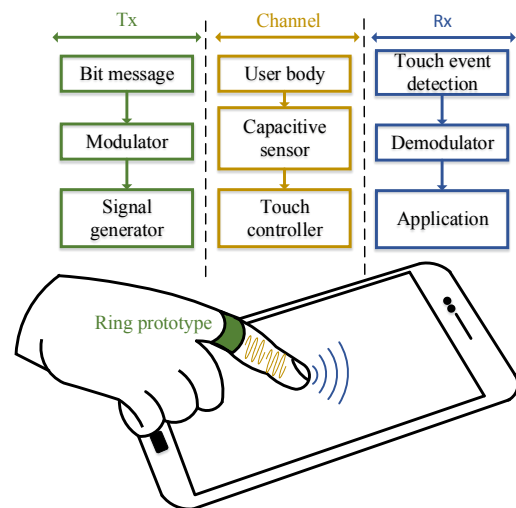


Figure 1: System overview

Along with the overgrowth of touch-enabled devices (i.e. mobile phone, tablet, tabletop, touch surfaces and etc) on which users rely most of their daily activities such as social network, email, online payment, privacy information storage and etc; secured user identification and authentication process must be ensured for the safe of users. Popular and traditional authentication ways include password input and fingerprint verification which are still cumbersome and not fit to the scenario of seamlessly authentication for shared devices [1].

Upon our prior works, capacitive touch communication has been proposed [5] to enable user identification by utilizing the capacitive touchscreen of commercialized-off-the-shelf (COTS) devices as receivers for identification messages transmitted from user side via a customized hardware token. Nguyen et al. [1] also utilize this communication channel to enable interaction between object token and capacitive touch-enabled devices. Overall, in order to enable the communication, users need to touch the surface of token directly onto the touchscreen. However, this *direct* method for capacitive touch communication maintains the limitation of non-smooth usage due to the need of switching between using finger (touching normally) and using token (touching for identification). In addition, low data rate might lead to the security risk in identification and authentication process.

In this paper, we survey the preliminary study on different method of capacitive touch communication, i.e. *indirect/through-body* other than previous work which utilizes direct communication. We propose a hardware system to enable this communication modality with a detail analysis and theory of its corresponding circuit model. Finally, we evaluate the proposed system to show the feasibility of solving the stated challenges in capacitive touch communication. In this work, we have met the following key challenges:

- The behavior of data transmitted in capacitive through-body communication is unpredictable. There have been many researches on modeling signal for intrabody communication. However, our system has different receiver (i.e touch-enabled devices) from traditional intrabody communication.
- Our system model is the combination of both intrabody communication and capacitive touch communication model. Thus, a detail circuit model must be derived in order to precisely predict the response of the communication channel.
- We work with COTS touch-enabled devices with the constrain of the unmodified touch sensing hardware and the variation in capacitive touch sensor mechanisms from different manufacturers.

2 CHALLENGE APPROACH

The new in through-body capacitive touch communication. Capacitive touch communication scheme has been proposed as a classical communication system with a transmitter, a receiver and together with a complex channel. In previous system, the transmitter is a wearable battery-powered hardware token with a simple processor that modulates pre-defined bit sequences and generates corresponding signal. The receiver is based on the manipulation of touch events which are generated on screen of COTS devices during the transmission process, in which the touchscreen is spoofed by output signal from stated tokens. The channel between transmitter and receiver is considered to be the combination of all hardware and software components of capacitive touchscreen (i.e. the touchscreen panel, capacitive sensors and sensing circuit underneath the screen, and the software that control the touch IC). In *indirect* communication method that we are investigating here, the transmitter and receiver concepts remain the same. However, the signal path through human body is the new element of communication channel. This addition brings in the challenge of more complicated communication channels, the difficulty in controlling the output of transmitter side and the unusual behavior of the input to receiver side. To overcome this, we aim to analyze our system model with respect to the combination of both intrabody communication and direct capacitive touch communication.

The need of general circuit of touch screen mechanism. Since the natural constrain for our system is the limitation to hardware modification and non-disclosure information of COTS touch device, in order to provide a reliable solution that will be able to operate on various touch-enabled devices, we derive the most common pattern of the underlying touch sensing mechanism. Most common parts of the sensing circuit consist of a driving source, a sensor capacitor, an integration capacitor, a bleeding resistor and a comparator [4]. Fig. 2 shows the general capacitive sensing circuit

and the corresponding current flow during its operation stages to determine the excitation at the sensor capacitor. The source usually drive voltage to charge the sensor capacitor up to certain threshold during the closing period of switch S_1 . Next, the integration capacitor and bleeding resistor exist to discharge the sensor capacitor while switch S_2 is closed. Finally, a comparator which is connected to ADC component of MCU will transfer the comparison of parameters observed on bleeding resistor (i.e. voltage, voltage difference or frequency changing) to process further in order to give the decision of capacitive sensor measurement.

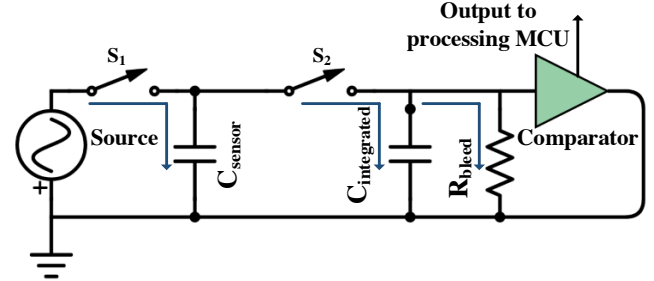


Figure 2: General capacitive sensing circuit

The myth of real common ground. Common ground traditionally refers to a common potential to which all of the elements surrounding the system are refereed to. This shared reference enables the operation of capacitive sensor by completing the circuit loop and current flow. In most cases, this common ground refers to Earth ground or the nearest floor which provide strong electrical coupled potential. However, in our system as depicted in Fig. 1, the ground potential might not essentially the floor or the Earth, but just a local common reference such as the human body itself, or the case of the touch device or the ground plate of the wearable hardware. Because the role of ground is vital to the operation of capacitive sensing systems, one of our missions is to identify the *real* common ground in our proposed system.

3 SYSTEM AND EVALUATION

Custom hardware setup. We generate signal from a signal generator which is controlled by a battery-powered ARM-based PC. We have full control over the generator with the precision up to milliseconds. We use a transformer to boost up the output signal that is injected into human body. This signal is in high voltage range of 40-240V (based on frequency of input signal) but is still the low current (under 1mA) and in the safe range for human body. The reason that we need such high voltage is that the amplitude of final output signal at the finger tip was measured to be two to three orders lower than the one injected to human body. If the output signal at finger tip is too low, it will not be able to spoof the artificial touch on the touchscreen because its effect on screen is ignored by the filtering mechanism of the device's touch sensing process itself. With adequate output signal amplitude, whenever the modulated signal is transmitted from the signal generator, the touchscreen is affected and touch events are generated corresponding to the period when generator is turned on. This hardware setup has the advantages of isolating the earth ground and minimizing

the unnecessary coupling effect between different elements of the system.

Circuit diagram analysis. In order to overcome the challenge of the unpredictable intrabody signal and the complex system model which combines both intrabody and capacitive touch communication model, we derive the detail circuit model (Fig. 3) for the overall system which takes into account all the possible electrically coupling effect from elements that are relevant to the system. The possible elements that cause coupling effect in our system are call *terminals*, which include positive and negative output pins of transformer, users' finger (human body), screen of touch device and the real common ground. Let p, n, b, s, g be the abbreviation of those terminals correspondingly, and C_{ij} be the coupling capacitance between any two terminals i and j . The magnitude of those coupling capacitances can be estimated using Zimmerman's method [6].

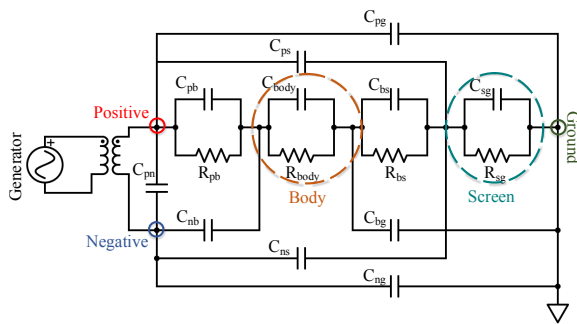


Figure 3: Circuit model

Preliminary evaluation. We use our customized hardware as a transmitter and the touchscreen of Samsung Galaxy S5 as a receiver; and evaluate the overall system which is shown in Fig. 1 in order to show the feasibility of achieving reliable communication with our proposed system. Fig. 4 shows the average number of generated touch events using current prototype with respect to different intervals of turning the signal generator on. An intuitive way to embed data is to use On-Off Keying in which signal generator is turned on to transmit bit 1 and turned off to transmit bit 0. The receiver demodulates bit sequence based on the detection that whether there is touch events generated during pre-defined period. We use a start bit and end bit for every transmitted message. With this simple message separation, the receiver differentiates messages and segments the symbols from event stream with the fixed timestamp threshold based-on the knowledge of pre-defined on/off interval of the signal generator. By counting the number of touch events from each segment, receiver can validate the receiving of bit 1 or bit 0 and finally recover the original data sequence. We observe that the smallest interval between two consecutive generated touch events at the touchscreen of Samsung Galaxy S5 is 17ms. Thus, we can reliably differentiate the on/off pattern upto the on/off intervals of 50/200ms. The detection rate (i.e. correctly decode data message with OOK demodulation) is up to 95.3% which implies the feasibility of our proposed system to achieve a reliable communication. The average number of generated touch events and reliable on/off interval infers the limitation of COTS devices where most of current touchscreen theoretically has the scan rate ranging from 60Hz to 120Hz (i.e. the minimum interval between 2 consecutive touch events is in range of 8.3 ms to 16.7 ms).

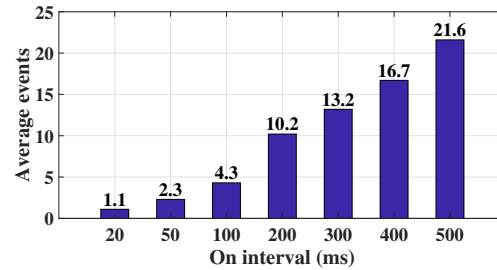


Figure 4: Average event numbers

4 CONCLUSION AND FUTURE WORK

We have presented the first study of indirect/through-body method for capacitive touch communication. We showed the preliminary results of the system obtained with a COTS device. We are implementing the remaining components and aim to improve the data rate in order to adapt this method with following improvements:

Per-touch authentication application. Our final goal is to integrate this technique into authentication process for COTS touch-enabled devices, where each touch of user is augmented with their ID and authentication protocol. This application enables a more intuitive and seamlessly way for interaction between human and smart devices (e.g. one touch authentication applies for every action yet still satisfies high security level), between users on shared devices (e.g. different users' touch will open different sessions on the same application based on their IDs) or simultaneously multi-user activities on a same devices (e.g. multiplayer games, collaboration works and etc).

Data rate improvement. Current data rate is suitable for user identification scheme, in which a known message is transmitted repeatedly. In order to reach our final goal of per-touch authentication application, we aim to achieve a better communication rate which is expected to reach around 60bps which is feasibility even with the limitation of touch scanning rate on current COTS devices as stated before (Section 1).

Hardware and software optimization. Current customized hardware has many space for enhancement with the goal of having a small wearable prototype (wristband or ring form) with low power consumption. Due to the variety of COTS touchscreen hardware and controller (i.e. different manufacturers and flagships has different touch ICs and hardware which evolve rapidly). Thus, an extension of evaluation on wider ranges of COTS touch-enabled devices will be conducted in order to adapt our proposed system to multiple touch-enabled device models.

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