Enable Touch-based Communication between Laptop and Smartwatch

Dian Ding
dingdian94@sjtu.edu.cn
Shanghai Jiao Tong University
Shanghai, China

Yijie Li
yijieli@sjtu.edu.cn
Shanghai Jiao Tong University
Shanghai, China

Hao Pan
panhao@microsoft.com
Microsoft Research Asia
Shanghai, China

Yu Lu
yulu01@sjtu.edu.cn
Shanghai Jiao Tong University
Shanghai, China

Yi-Chao Chen
yichao@sjtu.edu.cn
Shanghai Jiao Tong University
Shanghai, China

Guangtao Xue
gt_xue@sjtu.edu.cn
Shanghai Jiao Tong University
Shanghai, China

ABSTRACT

Wearable devices, including smartwatches, are increasingly popular among consumers due to their user-friendly services. However, transmitting sensitive data like social media messages and payment QR codes via commonly used low-power Bluetooth exposes users to privacy breaches and financial losses. This study introduces *TouchHBC*, a secure and reliable communication scheme leveraging a smartwatch's built-in electrodes. This system establishes a touch-based human communication system utilizing a laptop's leakage current. As the transmitting device, the laptop modulates this current via the CPU. Simultaneously, the smartwatch, equipped with built-in electrodes, captures the current traversing the human body and decodes it. The modulation and decoding processes involve techniques such as amplitude modulation, spectral subtraction, channel estimation, and retransmission mechanisms. *TouchHBC* facilitates communication between laptops and smartwatches. Real-world tests demonstrate that our prototype achieves a throughput of 19.83*bps*. Moreover, *TouchHBC* offers the potential for enhanced interaction, including improved gaming experiences through vibration feedback and secure touch login for smartwatch applications by synchronizing with a laptop.

CCS CONCEPTS

• **Human-centered computing → Ubiquitous and mobile devices**.

KEYWORDS

Human Body Communication, Leakage Current, Laptop, Smart Watch

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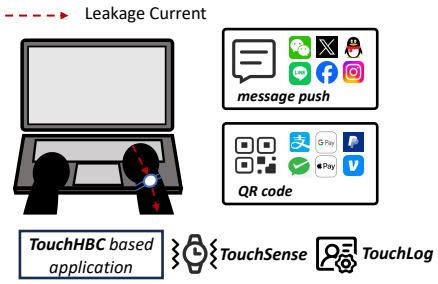


Figure 1: Human body communication of *TouchHBC*.

1 INTRODUCTION

Smartwatches, renowned for user-friendly services like health monitoring and sports management, saw global spending reach 31.3 billion in 2022 [12]. However, these devices predominantly rely on limited communication methods, with low-power Bluetooth being the most common. This protocol is vulnerable as attackers can simulate low-volume devices to circumvent its encryption and authentication processes, potentially leading to information theft [18]. Although some models support cellular networks, they tend to be more costly.

Unlike devices such as smartphones, smartwatches typically receive smaller texts, such as prompting messages from social software logged into other devices. In addition, with the growing popularity of mobile payments, smartwatches can synchronize QR codes from payment software for transactions. While these transmissions do not demand high communication rates, communication security is critical. Information leakage will bring non-negligible risks to the user's financial security and personal privacy.

This paper focuses on ***developing a secure and efficient communication system utilizing smartwatch's inherent components***. Based on this, we propose a new smartwatch communication solution, *TouchHBC*, facilitating a touch-based human body communication system using the leakage current of a laptop. As shown in Fig. 1, a user simply needs to touch the metal casing of the laptop with his hand, enabling the smartwatch's built-in electrodes to capture the leakage current flowing through the human body.

This system can synchronize social media messages, and authenticate information like accounts, passwords, and payment QR codes without hindering the laptop's normal functions.

The leakage current, serving as the communication medium, originates from a safety capacitor in the laptop's adapter [5, 7] and varies with the laptop's operation [3, 10]. By modulating high-consumption components of the laptop such as the CPU, the system can modulate the spectral characteristics of the leakage current for data transmission.

In this study, we introduce a touch-based human body communication system *TouchHBC* that consists of two components: a transmitter and a receiver. The transmitter modulates the leakage current through the power consumption of the laptop CPU and employs a retransmission mechanism to improve the reliability of the communication. The receiver consists of leakage current pre-processing and decoding.

2 RELATED WORKS

Recent researchers have developed numerous communication methods using various media to establish different communication systems based on bypass signals.

2.0.1 Acoustic Communication. MUDIS [9] enabled multi-user audible acoustic directional communication based on the parametric array and acoustic metasurface. Endophasia [21] implemented silent speech commands on the smartphone using GSM signals. MagicInput [14] achieved handwriting recognition based on 1-dimensional tracking using acoustic signals.

2.0.2 Magnetic Communication. MagneComm [13, 20] regulated the magnetic induction signal from the CPU and enabled near-field communication via magnetometer sensing on the device. MagView [21] achieved magnetic communication by changing the video packet type and reducing the quantization parameter to effectively control the CPU utilization of video decoding.

2.0.3 Vibration Communication. Ripple [15] explored the possibility of using physical vibrations as a mode of wireless communication. VibWriter [4, 6] used the built-in accelerometer of the smartphone to identify the handwriting on the same table.

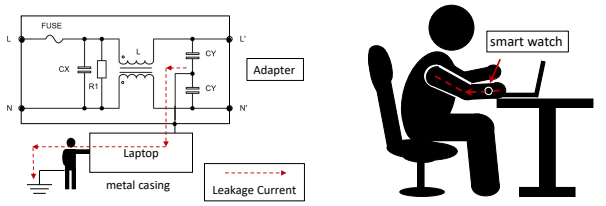
3 BACKGROUND

3.1 Leakage Current

As a laptop with a metal casing (such as a MacBook) is connected to a power source, the metal casing of the laptop carries the leakage current from the adapter [7]. The leakage current comes from the Y-capacitor (safety capacitor) of the adapter and is usually configured on both the high and low-voltage sides of the SMPS. As a common mode capacitor, grounding of the Y capacitor generates the leakage current [5, 19]:

$$I = 2\pi f C_h U_h + k C_l U_l + I_{cmi} \quad (1)$$

where the leakage current in the high voltage side is $2\pi f C_h U_h$. f refers to the mains frequency, C_h indicates the size of the capacitor, and U_h indicates the voltage. On the low-voltage side, k is the leakage current constant (about 0.01 to 0.03 depending on the manufacturer), C_l and U_l denote the corresponding Y capacitor and voltage. The Y capacitors used in laptop adapters are typically around $5nF$. I_{cmi} represents the common mode interference (high-frequency harmonics) in the SMPS and contains a disturbance signal generated by the fluctuations of loading states [10], such as the high computing rate of the CPU. Therefore, a laptop powered by the $220V/50Hz$ mains generates roughly $0.3mA$ of leakage current at the casing ($U_l = 12V$).



(a) The leakage current from the adapter. (b) The electrode-based system.

Figure 2: Fundamental principle of leakage current.

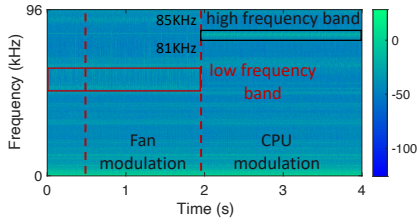


Figure 3: Leakage current as CPU power consumption increases.

3.2 Feasibility of *TouchHBC*

When using the laptop naturally, the user's hand is placed on the laptop in contact with the metal casing, and the feet are placed on the ground. The leakage current flows from the laptop through the human body and eventually into the ground, as shown in Fig. 2(a). The electrodes on the skin can perceive weak current flowing through the human body [11, 16, 17]. We therefore use the built-in electrode of the smartwatch to capture the leakage current (Fig. 2(b)).

As the leakage current is related to the working state of the laptop [10], we modulated the fan and CPU separately. The leakage currents collected by the built-in electrode are shown in Fig. 3, we calculated the spectrogram of the leakage current using Short-Time Fourier Transform (STFT). It can be seen that the leakage current is significantly enhanced when modulating the CPU to high power consumption. Furthermore, the CPU can be easily controlled by *loop* and *sleep* commands, which are available for most programming languages and operating systems.

It can be seen that the signal in the high-frequency band (black box in Fig. 3) of the leakage current is significantly increased (concentrated between $82KHZ$ and $84KHz$) when the CPU is at high power consumption. There is a corresponding attenuation of the signal in the low-frequency band (red box in Fig. 3).

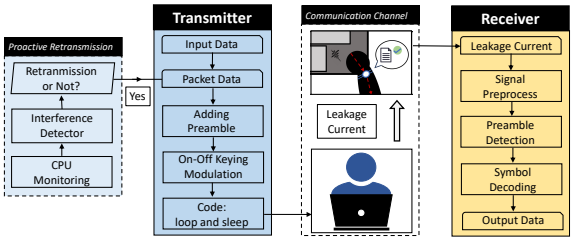


Figure 4: System architecture of the *TouchHBC* system.

4 SYSTEM

4.1 Transmitter Design

4.1.1 Preamble. *TouchHBC* sets a unique pattern of the leakage current for the preamble at the start of each data packet so that the system can use cross-correlation to locate the start time of the transmission. Moreover, the system can perform an initial estimation of the channel using the preamble.

4.1.2 Modulation. We chose On-Off Keying for the modulation of the data bits. The choice of transmission rate depends on the precision of the leakage current control. The control precision is defined as $P_{control} = \frac{1}{n}\sum_{i=1}^{n}(U_{real_i} - U_{desired_i})^2$, where $U_{desired}$ is the desired leakage current amplitude and U_{real} is the actual amplitude. We test the control accuracy of the electrode-based system at different transmission rates and a lower value for $P_{control}$ means that we can control the leakage current more precisely.

4.1.3 Proactive Retransmission. After a data packet has been sent, we determine whether there is interference during transmission by monitoring the CPU. If the usage of two or more non-transmitter CPU cores exceeds 30%, the transmitter will determine that there is interference with the symbol currently being sent. The transmitter will re-transmit the entire data packet if there is a corrupted symbol in the packet.

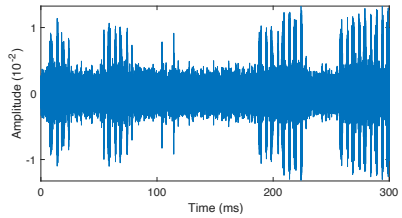
4.2 Receiver Design

4.2.1 Signal Preprocessing. The modulation of leakage current with the CPU is mainly reflected in specific frequency bands, as shown in Fig. 3. Therefore, we use a band-pass filter to extract the signal in this band of the leakage current. Considering the noise present in the leakage current, we denoise the signal using spectral subtraction [8] based on the noise samples taken at idle moments as follows:

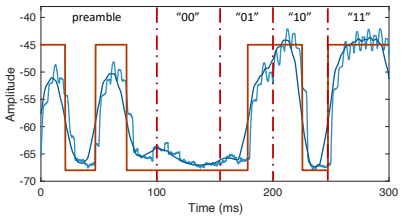
$$\|Y(k)\|^2 = \|S(k)\|^2 - \alpha\|N(k)\|^2 \tag{2}$$

where k represents the frequency range of the band, $S(k)$ and $N(k)$ represent filtered signal and noise signal respectively. α is the ratio of the signal strength of each frequency corresponding to symbol 0 in the current channel to the signal strength of the noise sample. To reduce the effect of signal fluctuations, we set a processing window of $0.02s$ and calculate the logarithmic short-time energy (log-STE) of the processing window as follows:

$$E(j) = 10\ log \sum_{i=j}^{j+0.02\times F_s} y(i)^2 \tag{3}$$



(a) Modulate the leakage current with the preamble and the binary sequence.



(b) Preprocess and decode the leakage current.

Figure 5: Transmission example: Fig. 5(a) Modulate the leakage current at the transmitter; Fig. 5(b) Preprocess and decode the leakage current at the receiver.

where $y(i)$ represents the leakage current signal and F_s represents the sampling rate of the receiver. To further smooth out the fluctuations in the signal, the signal was processed with a mean window of $0.02s$ in duration.

4.2.2 Signal Decoding. After pre-processing, we can identify the symbols corresponding to different signal segments. We detect the preamble to synchronize the transmitter and receiver and calculate the signal amplitude corresponding to different symbols. Then, we validated the system by two-bit binary coding. We added the preamble at the beginning of the example and modulated the leakage current for communication. The received leakage current is shown in Fig. 5(a), and the leakage current is preprocessed and decoded as shown in Fig. 5(b).

5 EVALUATION

5.1 Evaluational Setup

The prototype of *TouchHBC* is adopted on a laptop (MacBook Pro) as a transmitter as shown in Fig. 6. The laptop is placed on the desk and kept in charge. We collected the leakage current using the built-in electrodes of the smartwatch (Apple Watch S6), which is worn on the left wrist, as shown in Fig. 6. Due to sensor permission issues, we used the AD2 [1] to collect data. The user can communicate with the smartwatch by touching the metal casing of the laptop.

5.2 Micro Benchmark

5.2.1 Sampling Rate. In the feasibility experiment, the sampling rate of the AD2 was set to $192KHz$ and we were able to use the leakage current of the laptop for communication. We seek to sample the leakage current based on the aliasing effect [2], thus reducing the limitation of the sampling rate. In this experiment, we evaluate the throughput and signal-to-noise ratio of *TouchHBC* in two environments at various sampling rates from $48KHz$ to $192KHz$. We

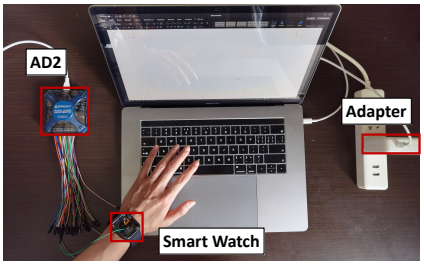
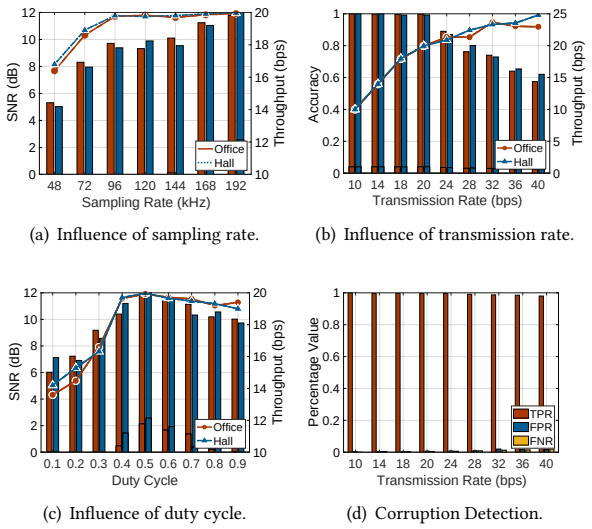


Figure 6: Evaluational Setup of the *TouchHBC* system.



(a) Influence of sampling rate.

(b) Influence of transmission rate.

(c) Influence of duty cycle.

(d) Corruption Detection.

Figure 7: Evaluation of the *TouchHBC* system.

keep the transmission rate and duty cycle as 20*bps* and 0.5, and the performance of the system is shown in Fig. 7(a).

5.2.2 Transmission Rate. We adjust the transmission rate of the leakage current to test the transmission rate of the system. We increased the transmission rate from 10*bps* to 40*bps* and measured the accuracy and throughput of the communication. As shown in Fig. 7(b), the transmission rate is increased from 10*bps* to 20*bps* and the communication accuracy remains above 99.1%. When the transmission rate is higher than 20*bps*, the communication accuracy decreases significantly, and the low accuracy may seriously affect the reliability of the communication system.

5.2.3 Duty Cycle. We increase the duty cycle from 0.1 to 0.9 and keep the sampling rate and transmission rate at 192*KHz* and 20*bps* in the process. As shown in Fig. 7(c), with a duty cycle of 0.5, the system can achieve the maximum throughput and SNR. As the duty cycle increases or decreases, both throughout and SNR decrease, especially as the duty cycle decreases.

5.2.4 Corruption Detection. To further guarantee the reliability of *TouchHBC*, one-way communication requires the transmitter to accurately detect and retransmit the data bits. We increased the transmission rate from 10*bps* to 40*bps*, the results are shown in Fig. 7(d). At transmission rates below 20*bps*, the TPR is 99.5% or higher, while the FNR is 0.05% or lower, indicating that our corruption detection algorithm on the transmitter can correctly detect corrupted symbols.

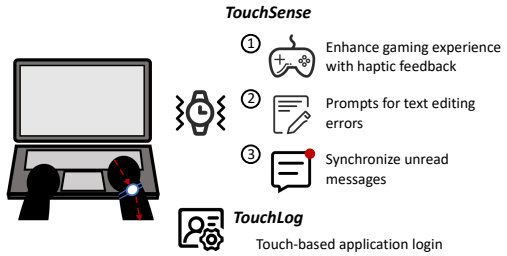


Figure 8: Extended applications of *TouchHBC*.

6 APPLICATION

6.1 TouchSense

Vibration feedback is now widely used in smartphones, switch consoles, and other devices to provide more realistic and interesting interactions while playing games. However, it is difficult for laptops to provide electronic components such as motors for vibration feedback. With the built-in motors in smartwatches, we can expand smartwatches into vibration feedback modules for laptops.

The smartwatch can extract the data embedded in the leakage current and define different vibration methods to achieve different feedback. As shown in Fig. 8, *TouchSense* can achieve real vibration feedback in the process of playing games, prompting typos during text editing, as well as prompting messages without affecting the screen display when watching videos on full screen.

6.2 TouchLog

As the hardware performance of smartwatches improves, the types of services they support and the number of apps they offer show explosive growth. It is difficult for users to directly manage the numerous accounts and passwords, and these may contain private information such as payment software and social software. Inspired by the Chrome browser to manage accounts and passwords for multiple websites, we can use a laptop to manage account passwords for different APPs in smartwatches and embed the information into leakage currents to log into different APPs in smartwatches and transmit information such as payment QR codes.

7 CONCLUSION

In this paper, we build a touch-based human communication system using the built-in electrodes of a smartwatch. The proposed system embeds information into the leakage current of a laptop to achieve communication. *TouchHBC* implements the communication between a laptop and a smartwatch with a throughput of 19.83*bps*. Furthermore, rich interaction extensions such as vibration feedback, account management, etc. can be implemented on smartwatches based on the proposed system.

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