sensing,
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perception lab

Department of Computer Science, ETH Zürich

Semester Project

Development of a replica of ElectroRing based on active electrical sensing

Fabio Bazzi

1st supervisor

Prof. Dr. Christian Holz
Sensing, Interaction & Perception Lab
ETH Zürich

2nd supervisor

Paul Streli
Sensing, Interaction & Perception Lab
ETH Zürich

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Fabio Bazzi
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Supervisors: Prof. Dr. Christian Holz and Paul Streli

ETH Zürich
Department of Computer Science, ETH Zürich
Universitätstrasse 6
8092 Zürich

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Fabio Bazzi
Sensing, Interaction & Perception Lab
Department of Computer Science, ETH Zürich
bazzif@ethz.ch

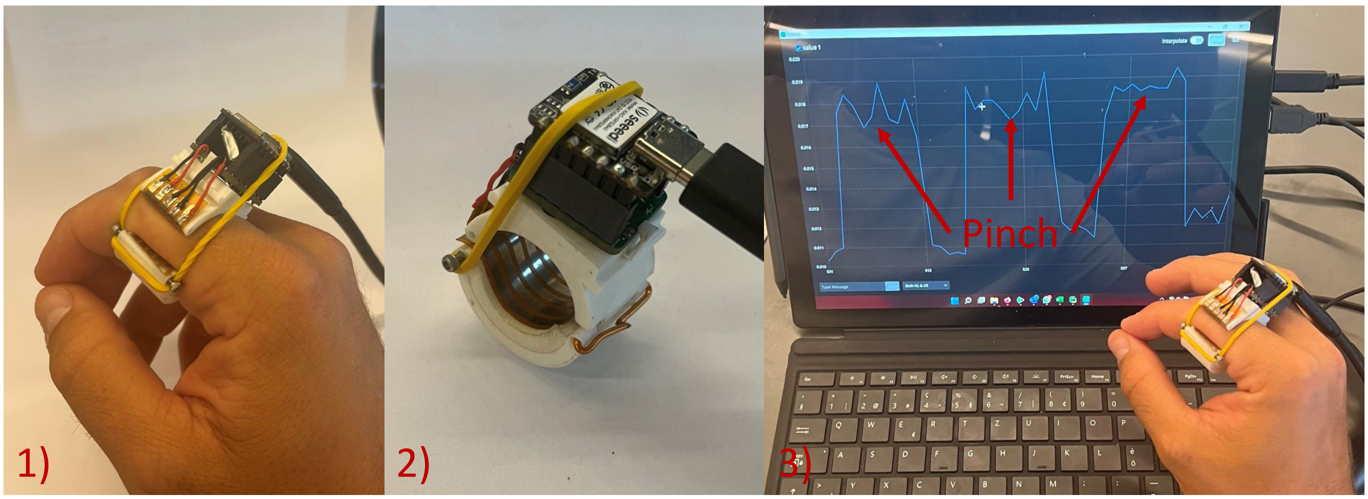

Figure 1. 1) Replica of the ElectroRing worn on the index finger, 2) 3-D printed case with PCB mounted and flexPCB attached on the inside with a rubber band closure, and 3) Raw Real-time data from measured pinches.

ABSTRACT

As part of the semester project, a replica of the *ElectroRing* presented in the work of Kienzle et al. [1] was developed. The technology is based on electrically active sensing and is used to detect the creation of touches and the release of touches on the own body.

As part of the project, a printed circuit board (PCB) was developed that enables electronic active sensing. With a *Seeed XAIO BLE* the signal of the PCB was measured and processed with the discrete Fourier transform (DFT). Using a threshold, the signal is converted into a pinch state. This state is then sent to a peripheral device via BLE. All parts are held together by a 3D printed housing that can be attached to the index finger.

The replica of the *ElectroRing* was further tested for signal to noise ratio (SNR) with an average of 25 dB and an average latency of 130 ms. As an application example, the ring was configured to use a pinch as a mouse click input on the computer.

The documentation of the project is available at the following Github repository

Keywords

Touch and pinch detection; mixed reality.

INTRODUCTION

Computers play an essential role in human interaction. Since the development of the personal computer, several waves of computer innovation have advanced computer technology. A new wave of innovation that integrate virtual reality (VR) and augmented reality (AR) into human daily life is emerging. [3]

Already today there are various devices that visualize VR and AR in high resolution, but the input devices that simplify interaction with VR and AR are not yet as advanced. [2]

The *ElectroRing* is an example of a VR and AR wearable interaction device. It can be used to detect pinching and touching the body as well as its release. This is especially useful in AR applications because it is difficult to detect touches with head mounted cameras when the fingers hover above the surface.

ElectroRing can therefore be used in AR applications. For example, a button can be projected on the human body and the pressing of the button can be measured with the *ElectroRing*.

The *ElectorRing* can not only be used for VR and AR applications, but it is also possible to use it with a personal computer to provide a new interaction experience for the user.

This technology has many application potentials, which makes the *ElectroRing* interesting for the research group *SIP* of the

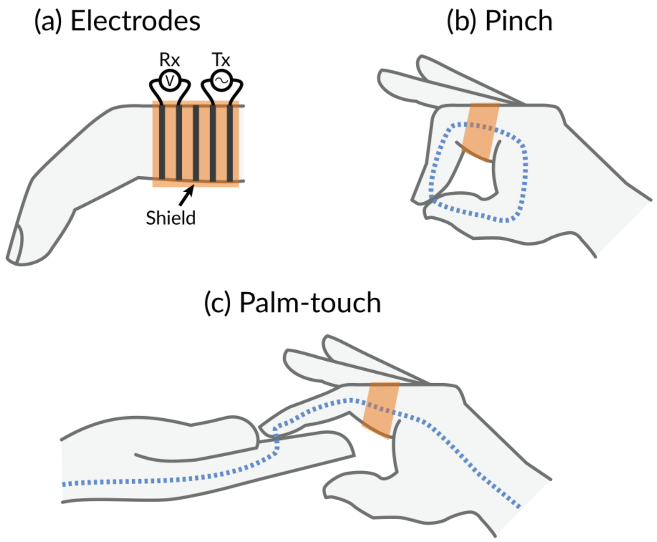

Figure 2. "(a) ElectroRing uses five electrodes: two transmit electrodes (closest to the palm) differentially couple the AC signal to the finger, the middle electrode shields direct coupling between the Tx and Rx electrodes, two receive electrodes (distal) measure the gradient of the signal along the finger. (b) During a pinch, the signal travels through the thumb and galvanically back to the transmit electrode. (c) Touching the opposing palm creates a galvanic path through the body back to the proximal transmit electrode. " [1]

ETH Zurich and therefore a replica of the *ElectroRing* was created in this project.

Theory of Operation

In Figure 2 the theory of operation of *ElectroRing* is shown. In summary, the ring works by coupling a 10.7 MHz square wave of 3.3 volts with two transmitting electrodes on the body. When no galvanic contact between the transmitter and the receiver (e.g. Pinch or Palm-touch) exists most of the signal flows between the two transmitter electrodes. An electrical shield in the middle prevents the transmitter to directly couple with the receiver. When a galvanic path is closed by a pinch, the two receiver electrodes measure the gradient of the signal along the finger.

For more and deeper explanation on the principle of effect, the work of Kienzle et al. [1] is recommended.

RELATED WORK

There are already various systems for segmenting touches, with an electro active sensing system. The work of Kienzle et al. [1] is about the *ElectroRing* which served as a basis to create a replica in this semester project. In another work of Zahng et al. [5] a bracelet is used, called *ActiTouch*. The *ElectroRing* is based on the *ActiTouch*, but it has an electrical shield between the receiver and the transmitter. Therefore the *ElectroRing* simplifies instrumentation by requiring only one instrumentation location instead of two as the *ActiTouch* does.

ElectroRing

The paper describes the principle of operation, the production of the *ElectroRing* and measurement results. In addition, the ring described in the paper has an integrated IMU-2-D tracking system, with which they concluded that the sensing technology is largely independent of gestures velocity or the mechanical action at contact with a 25 dBV SNR. They have also shown in further work that there is a potential to use the *ElectroRing* to detect various electrically conductive materials by touch. [1]

ActiTouch

With *ActiTouch*, the transmitter electrodes are attached to a wristband and receiver electrodes are attached to a head-mounted display. *ActiTouch*, unlike *ElectroRing*, does not include an active shield. This causes the receiver electrode to become saturated when the transmitter and receiver electrodes are close together, resulting in poor sensitivity to touch. This makes it impossible to incorporate active electronic sensing technology in a single small device. According to their paper, the best material for the electrodes is silver fabric which are galvanically arranged longitudinally to each other. Further they have shown with a frequency swept that the best signal to noise results are reached at the frequency 10.5 MHz. Also they have not found negative health effects on the human body using this measurement principle. [5]

IMPLEMENTATION

Hardware and software was developed for the replica of *ElectroRing*. In order for the replica of *ElectroRing* to measure signals and communicate with peripheral devices, a micro controller was used. Further, a printed circuit board (PCB) was designed, which contains signal generation, the electrical shield and a measurement gain. In addition, a ring was designed to hold all the parts together and to attach the system to the finger in a portable way. The hardware was then programmed which allows to measure a pinch state and to send it to a peripheral device. Finally, an application example was created to demonstrate the potential of the replica of *ElectroRing* and measure latency. 4

Hardware

Electronics

The electronics of the replica of *ElectroRing* consist of a PCB and a *Seeed XIAO BLE*. The PCB is used for signal generation and amplification and the *Seeed XIAO BLE* is used for measurement and communication. The PCB contains a transmitter, receiver and a shield. The transmitter generates a 3.3V 10.7 MHz rectangular signal that is then coupled to the body over electrodes. The receiver is an instrumentation amplifier with a gain of 30 and with electrodes contacted to the body. Located between receiver and transmitter is the shield electrode with a potential of 1.65 volt. The electronics are powered by a 3.7 V battery with 40 mAh. The current for the operation was measured with a *Fluke 115* and is 60 mA, therefore the replica of *ElectroRing* can be theoretically be powered for 40 minutes.

Housing

The housing to hold and attach the PCB to the finger is 3-D printed with PLA. A flexPCB with a conductor width of 2 mm and a distance of 1 mm between the conductor paths is used to connect the receiver, transmitter and shield to the finger. A sealing material is glued inside the ring to ensure the contact of the conductive lines with the finger and to increase the wearing

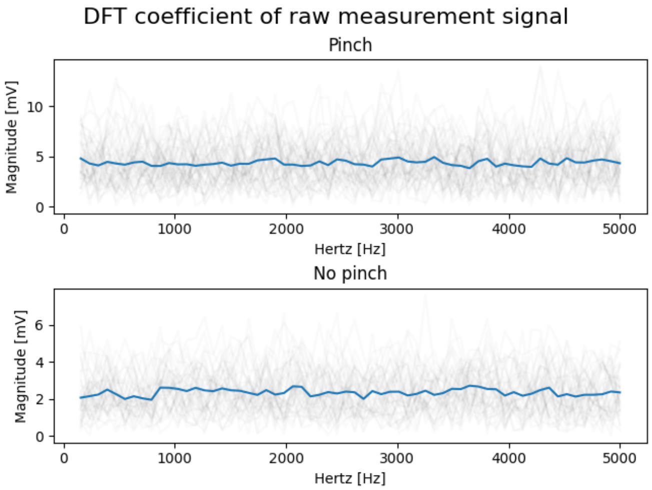

Figure 3. The blue line is the mean value of the DFT coefficient for multiple measurement bins, while the black lines are the DFT coefficients for consecutive bins of 128 samples, the signal was sampled at 10 kHz.

comfort. With double sided tape the flexPCB is attached to the seal. The ring is closed by means of a rubber band.

Software

The signal of the receiver is undersampled with the *Seeed XIAO BLE*'s maximum standard sampling rate of 10 kHz. The original intention was to calculate the DFT coefficients by using 128 samples to determine a frequency range that rises during pinching, and then to use a Goertzel filter to filter the frequency associated with the pinch. However, when evaluating the DFT coefficients, no particular frequency could be found which increased alone when the galvanic path was closed. It was found that all coefficients except the first coefficient, which belongs to the DC current, changed significantly when pinched, as one can see in Figure 3. For this reason, the average of the DFT coefficients, except the first coefficient, was calculated. When the average of the DFT coefficients exceeded a medium threshold with hysteresis, a pinch state is detected. If this is undershot, a pinch release is detected. However, these values do not work unconditionally for every user and the replica of the *ElectroRing* must be recalibrated after the user changes.

EVALUATION

Two evaluations were performed using the replica of the *ElectroRing*.

1. Latency measurement
2. Signal to noise ratio (SNR) measurement

Apparatus for latency

To measure the latency, the ring was attached to the index finger. In the front of a screen of the computer with a visible running power point presentation, the index finger was filmed with an *iPhone 12 Pro* in slow motion with 240 FPS. By pinching the finger the *Seeed XIAO BLE* detected the pinch and sent it a via BLE to a second *Seeed XIAO BLE* connected to the Computer. The second microcontroller connected to the computer generated a mouse click. Thus a change of slides was triggered. The latency can be calculated by the frame rate and counting the number of frames that elapse between the pinch and the slide change.

Test subject	Threshold [mV]	Hysteresis [mv]
1	0.016	0.003
2	0.011	0.02
3	0.013	0.002

Table 1. Threshold and hysteresis values for the three test subjects

Test subject	mean	SD
1	15.81 dB	0.40
2	29.72 dB	0.39
3	28.73 dB	0.47

Table 2. Mean and SD of SNR for all test subjects

Apparatus for SNR

The SNR was measured for 3 different people with the *ElectroRing* attached to the index finger. The *ElectroRing* was initially calibrated for each person connected to the computer. The ring is calibrated by considering the signal described in subsection 3.2 for pinch and no pinch for a given person, then both middle threshold and hysteresis are set empirically. The values can be seen in Table 1. The three different test subjects had to switch five times between pinch and non-pinch state. The signal from subsection 3.2 was recorded and saved with *PuTTY* to the disk and the SNR was calculated according the equation Equation 1.

$$\mathrm{SNR} = 20log_{10}\left(\frac{\mathrm{mean}(v_{touch}) - \mathrm{mean}(v_{no-touch})}{\mathrm{SD}(v_{noise})}\right) \quad (1)$$

"v_{touch} are samples from a touch segment, $v_{no-touch}$ are samples from a non-touch segment, and v_{noise} are samples from the preceding non-touch segment."[1].

RESULTS

The data generated from the replica of the *ElectroRing* evaluation was processed in *Python*, using the packages *Pandas*, *Scipy* and *Matplotlib*.

Latency

The result of the latency measurement is shown in Figure 4 as a box plot. On average the latency is 130 milliseconds (ms) (SD = 21 ms) to detect a pinch, send it to a second device and execute an input action on a personal computer.

Signal to Noise

The results of the SNR measurements are shown in Figure 5. The mean and SD are summarized in Table 2.

Every pinch was detected correctly, so the precision given Equation 2 and recall given Equation 3 were perfect.

$$\mathrm{precision} = \frac{\mathrm{TP}}{\mathrm{TP} + \mathrm{FP}} \quad (2)$$

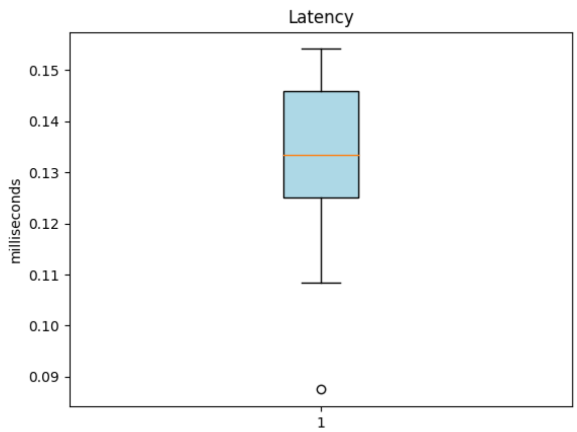

Figure 4. Measured latency due to pinch to trigger an action on the personal computer

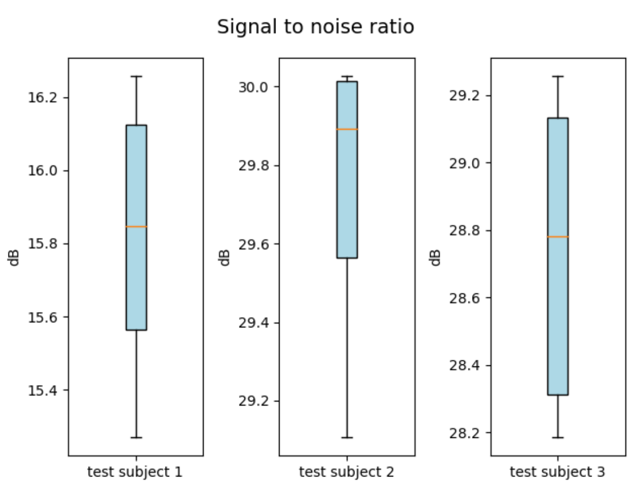

Figure 5. Caption

$$\text{precision} = \frac{\text{TP}}{\text{TP} + \text{FN}} \tag{3}$$

With:

true positive (TP) : Pinch correctly detected

false positive (FP) : Pinch falsely detected

false negative (FN) : Pinch not detected

DISCUSSION

In this project, a replica of *ElectroRing* was built to detect touch. The viability of the ring was validated in two experiments. With a latency of 130 ms (SD = 21ms), the latency is acceptable based on the work of Ritter et al. [4]. Furthermore, the SNR of over 15 dB provides a sufficiently robust touch detection with a perfect recall and precision. However, it must be taken into account that the threshold and hysteresis must be individually tuned to detect touch.

Both latency and SNR can be further optimized by improving the software of the replica of *ElectroRing*. Instead of calculating the average of all DFT coefficients except the first, it could be more useful to determine the exact frequency band that rises during pinching and then to filter it with an appropriate bandpass filter. This partially reduces the computation time of the code and improves latency. It also improves the robustness. If all DFT coefficients except the first are considered, other signals with a different operating frequency than the *ElectroRing* that are coupled to the body can also have an influence. This on the other hand simplifies the tuning of the ring and makes it even more robust and user-friendly. One approach could be to increase the sampling rate when reading the signal to determine a unique frequency and then filter it with a Gortzel filter to detect touch.

If the replica of the *ElectroRing* is operated by the computer there are no misdetections of a pinch. When powered only by the battery and not connected to the computer, misdetections occur but only rarely. This may be due to the fact that the ring is powered by 5 volts when connected to the computer, and 3.7 volts when powered by the battery. To see how the behaviour of the ring changes when powered by the battery, the next step should be to transmit not only the pinch state via BLE, but also the signal described in subsection 3.2.

CONCLUSION

During the semester project, a Working MVP of the *ElectroRing* was developed based on the work of Kienzle et al. [1]. With the evaluation it was shown that the SNR is sufficient to detect the pinch state reliably. Further, with a low latency it was shown that the responsiveness of the ring is sufficient to ensure a acceptable human computer interaction.

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