Towards Non-Distracting Smartphone Interaction While Biking Using Capacitive Sensing as Input Device

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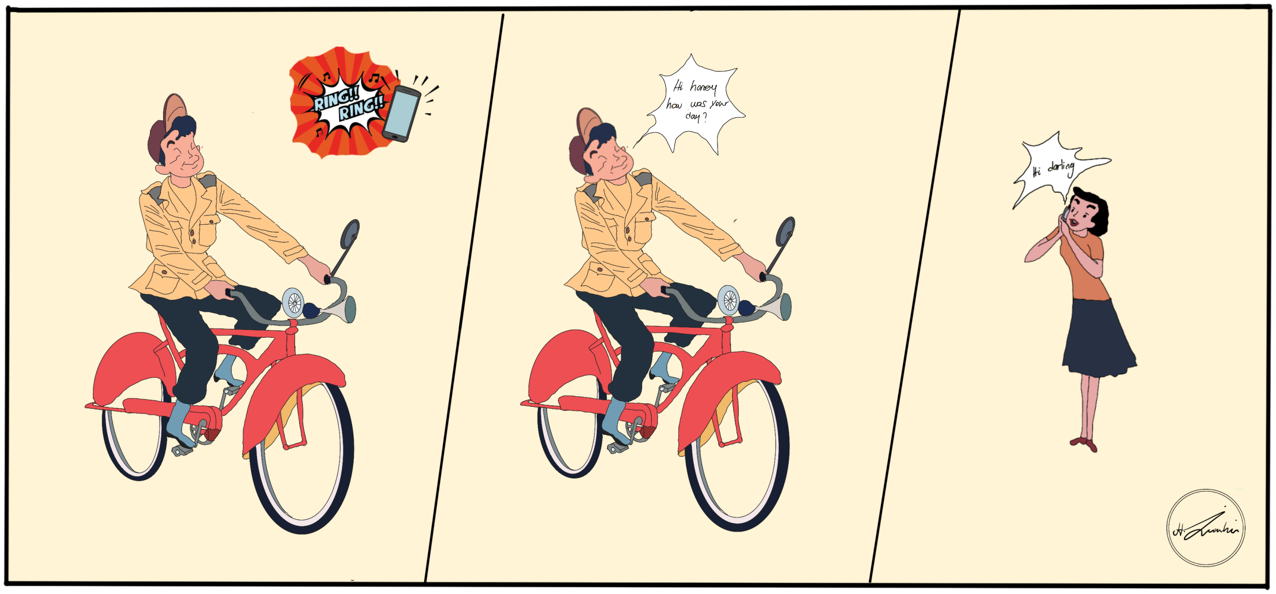


Figure 1: Exemplary sketch for hands- and eyes-free smartphone interaction while biking: Utilizing the capacitive sensing shoulder cover as input device to accept a phone call through shoulder tapping.

ABSTRACT

The rising cycling trend in recent years has highlighted the need for enhanced safety, especially with increasing cyclist numbers and changing infrastructure dynamics. Fueled by the increasing smartphone usage, distracted riding due to digital devices remains a critical concern. In this work, we propose a system utilizing capacitive sensing for hands- and eyes-free interaction, designed to improve safety while maintaining digital connectivity. Our system employs capacitive shoulder covers that detect shoulder tap gestures with the user's cheeks, allowing cyclists to interact with their smartphones without removing their hands from the handlebars or diverting their gaze from the road. A mobile application deployed on Android forms the interface to detect gestures through a Convolutional Neural Network and link them with appropriate smartphone features. Potential use cases include phone call management, media player control, navigation confirmation, and broader integration towards cyclist communication and safety in swarm cycling scenarios.

UbiComp Companion '24, October 5–9, 2024, Melbourne, VIC, Australia

ACM ISBN 979-8-4007-1058-2/24/10
https://doi.org/10.1145/3675094.3677544

CCS CONCEPTS

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

KEYWORDS

Bike Interaction, Bike Safety, Gesture Recognition, Capacitive Sensing

ACM Reference Format:

Daniel Geißler, Bo Zhou, Hamraz Javaheri, Esther Zahn, Emil Woop, Stefan Schaffer, Paul Lukowicz, and Jakob Karolus. 2024. Towards Non-Distracting Smartphone Interaction While Biking Using Capacitive Sensing as Input Device. In *Companion of the 2024 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp Companion '24), October 5–9, 2024, Melbourne, VIC, Australia.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3675094.3677544

1 INTRODUCTION

With the rising popularity of cycling fueled by the pandemic, bike and cyclist safety move more into focus, especially since cyclist numbers remain high [12]. Infrastructure changes, such as pop-up bike lanes, provide safe space for cyclists during traffic [19]. Yet, while environmental safety is increasing, many riders still drive carelessly and are distracted by digital devices. The Netherlands even prohibited phone usage during cycling in 2019 [5].

While there is an increasing demand for digital connectivity while "on-the-road", we argue that current interaction methods often overlook safety concerns favoring rich interaction bandwidths instead of limited — but safe — interaction. Interacting with one's smartphone through touch on a wobbly holder attached to the handlebar is bound to cause critical situations. Here, related works have looked into two aspects of ensuring safer interaction: hands-free [13] and eyes-free interaction [18].

In this work, we present a system based on capacitive sensing, combining both hands- and eye-free interaction. Through a capacitive shoulder cover, users are able to execute two rudimentary gestures by performing shoulder taps (Figure 2) [6]. Our system does not require the riders to remove their hands from the handlebar, nor do they have to divert their gaze from the road. Through an iterative evolution of our prototype, we achieved an unobtrusive form factor and high detection rates of up to 97%. Further, the system integrates into Android-based phone applications through Bluetooth Low Energy (BLE), allowing ubiquitous access to the user's input.

Our work on capacitive wearables highlights that smart garments are a promising research direction to ensure the safety of cyclists when interacting with digital devices while on the go and can serve as a natural driving extension.

2 SYSTEM DESIGN AND EVALUATION

Our system's technology utilizes capacitive sensing as a core modality to detect shoulder taps. Various works, especially in the wearable sensing area have proven the usability of capacitive sensing for detecting motions and gestures for human activity recognition (HAR) [4, 8, 17, 20].

Through previous work, we identified shoulder tapping as a robust and reliable solution to detect a set of gestures for bike interaction through [6]. Inspired by established tap gestures from in-ear headphones, two strategically placed conductive textile patches on the user's shoulder mimic the option of tapping left and right with the user's cheeks.

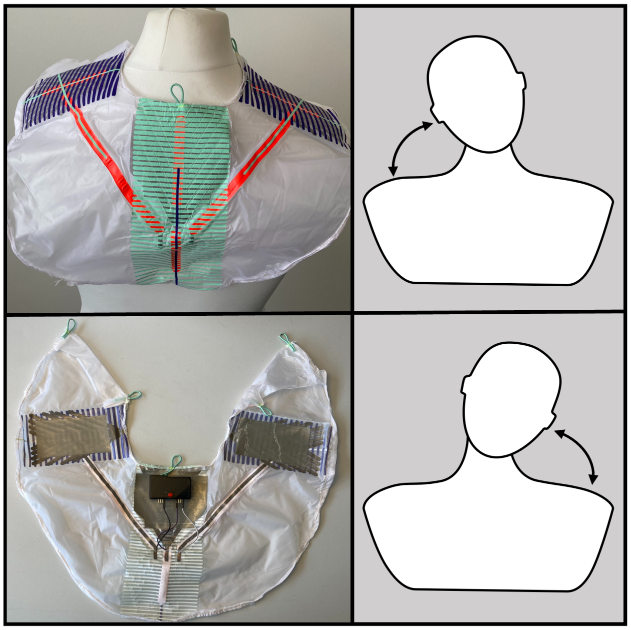


Figure 2: The design and technical implementation of capacitive sensing in wearable fabrics and the schematic representation of possible left and right tap gestures.

Through multiple iterations of prototypes with research on integrating functionality, robustness and design elements in smart wearable garments [7], we eventually designed a shoulder cover as shown in Figure 2 . It can be worn as an additional layer, independent of the user's clothing choice and is unaffected by upper body and arm movements. The conductive patches form the main interaction component, producing robust and clean signals when being touched with the wearer's cheek. The Data Acquisition Unit (DAU) was added to the backside of the shoulder cover and connected to the left and right patches. The gathered data is sent to a smartphone via BLE to store it as a formatted dataset for each participant.

Our evaluation served the purpose of gathering real-world data from participants in order to validate our approach. We conducted an in-the-wild experiment with 22 participants (14 male and 8 female) with bike riding experience to generate a representative dataset as presented in [6]. Each participant was asked to cycle for approximately 15 minutes and executed a random pattern of left or right taps repeatedly with an interval of 10 seconds. The experiment was conducted in a closed-up area to supervise the experiment within a safe and non-traffic environment. We also tested different clothing choices and helmets without recognizable effects on data quality. Due to the slim dual channel setup of our prototype and the clear signal when touching the patches, a small classifier based on the common Convolutional Neural Network

Figure 3: A participant of our data collection experiment executing a gesture by tapping the shoulder patch with his cheek while biking.

(CNN) architecture was able to yield up to 97% average accuracy validated through leave-one-participant-out cross-validation.

After confirming the feasibility of our approach, we implemented an Android-based system leveraging our trained model that allows run-time mapping of the detected gesture with common smartphone features, realizing a real-world Human-Interface Device (HID) [11].

3 IMPLEMENTATION

In order to map the capacitive sensing signal to digital smartphone features, we implemented a mobile Android application based on Apache Cordova 12.0.0 [15]. The app, currently tested on Android 13, connects to the DAU from the shoulder cover via the classic BLE protocol to receive the continuous capacitive signals from both shoulder patches as shown in Figure 4. A screenshot of the app is shown in Figure 5, explaining the user interface with the implemented functionality.

We deploy a simple yet efficient pipeline within the app to propagate the signal through the model and link it with a feature execution. The capacitive time series data is obtained with a frequency of 30 Hertz and a sliding window mechanism. As an initial step, we normalize the raw signal stream into the range of 0 to 1 to remove the operation frequency of each capacitive channel. The CNN architecture was adjusted to meet the input size of 30 samples, representing a one-second data sequence. We run the model pre-trained on the full dataset from the previous experiment within the ONNX environment to embed the runtime inference into the Cordova app [1]. We adjusted the training of the CNN through hyper parameter optimization to maximize the performance while minimizing the architecture and therefore the energy-footprint [9]. A stride of 15 samples or 0.5 seconds results in two model evaluations per second with half a window overlap. The model inference runs asynchronously apart from the BLE data receiving. Running on a Google Pixel 3 XL, we measured an inference time of only 50 milliseconds for the full pipeline from raw data to predicted class, mainly due to the slim architecture of the CNN. The low latency allows model inference to obtain sufficient performance to meet the required data throughput for stable and continuous evaluation without causing delay or buffering.

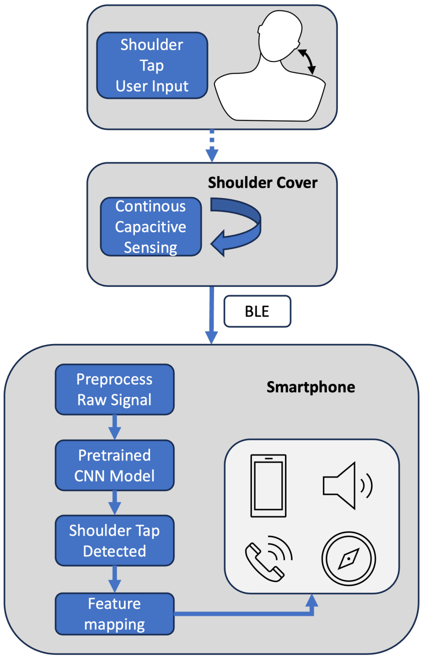


Figure 4: The system's pipeline to process a shoulder tap until the final execution of mapped smartphone features.

The user is able to customize the feature mapping for the left and right shoulder tap gestures in the app. The tap duration during our experiments was less than a second on average. Consequently, we implemented a blocking period of two inference steps after a detected shoulder gesture to prevent multiple executions through the same tap.

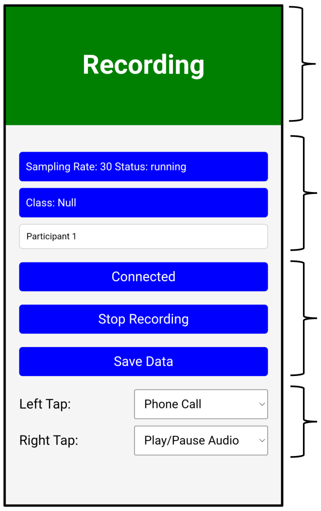
4 USE CASES

Having confirmed the detection capabilities of our system, we demonstrate potential use cases during cycling. These range from the aforementioned integration into phone applications as part of bike-related HID features to extended mappings serving as a driving extension. Here, we showcase how the system can serve as a real driving extension, particularly in bike swarm scenarios. Currently, we link those features through our Android App as shown in Figure 5, implemented through two simple drop-down menus to select the feature.

4.1 Integration in Smartphone Applications

As depicted in Figure 4, our system readily integrates into most phone applications. As such, shoulder taps can be mapped to a variety of functions. We do note that the purpose of this work is to focus on a limited set, ensuring safety while cycling. Possible interactions include:

Communication: A quick shoulder tap allows you to answer and decline incoming calls while on the bike, without the need to divert



Sampling Rate: 30 Status: running

Class: Null

Participant 1

Left Tap: Phone Call

Right Tap: Play/Pause Audio

Status Bar with visual (green, yellow, red) and audio (Warning sound) output to notify user in case of system issues.

Monitor the system BLE and ONNX model and set the participants name.

Button controls to connect the shoulder cover, start recording/evaluating and possibly saving data.

Dropdown menu to map detected taps to smartphone features

Figure 5: Screenshot of the Android-based app, connected to the shoulder cover, hosting the ONNX model and mapping detected shoulder taps to smartphone features.

attention from the road. This example is depicted in our teaser figure (Figure 1). This feature is implemented through a third-party Cordova Plugin [14]. Likewise, as meetings on the move are gaining popularity [10], straightforward mute and unmute via shoulder taps in meetings during riding greatly improves usability compared to tapping buttons on one's headphones.

Media Player Control: Shoulder taps can be mapped to individual controls of a media player. Cordova integrates the media control directly. One shoulder tap can be linked to play, pause, next song, volume up or volume down.

Navigation: While ongoing navigation usually does not require any active user input, the shoulder taps are implemented to confirm navigation choices or alternatives offered. For this feature, we utilize a workaround through Android notifications to integrate an input in common navigation apps.

4.2 Smart Garments as Driving Extension

Apart from integration into phone applications, we demonstrate how our system can integrate into the cycling process and augment it.

Turn Taking. Left and right shoulder taps provide natural mappings for turn taking. Integrated with a visible actuator, e.g. on the rider's back as shown in Figure 6, this method allows for safer turn taking without the need for extended hand signs and offers high visibility (cf. [3]). A quick tap to the right allows the rider to signal their turning intention to other road users. Especially in dense traffic, this hands-free method enables full control over the bike at all times.

Swarm Hazard Warnings. Apart from single-rider extensions, we draw inspiration from bike swarm scenarios [16]. A common challenge in swarm riding is reduced visibility for individual cyclists, as riders are close together [2]. Hence, obstacles and hazards cannot be recognized well in advance, leading to dangerous evasive maneuvers. Using shoulder taps, the lead cyclist can quickly propagate hazard warnings throughout the swarm. A display device as shown in Figure 6 allows propagation in real-time and warns following cyclists of the hazards. Our system interaction naturally aligns with indicating the position of potential hazards, taping left or right for the respective position, confirming well with a natural mapping of this movement.

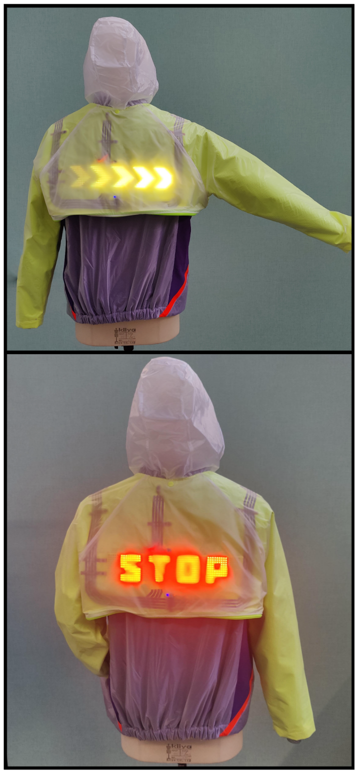


Figure 6: LED matrix attached to the rider's back as a visible actuator to utilize shoulder tap input as an output to warn following cyclists.

5 CONCLUSION

We contribute an alternative interaction method with digital devices while cycling leveraging capacitive sensing technology. Our system allows hands- and eyes-free interaction, focusing on safe riding. We deliberately focused on a limited set of gestures, yet sufficient for common phone interaction tasks. Our gesture set also serves as a possible driving extension, naturally combining left and right movements with respective hazard warnings or turn taking. The unobtrusive form factor of our prototype increases wardrobe freedom for the rider and showcases the potential for smart garments for bike interaction.

For the future, we aim to extend the available feature mappings to address more complex smartphone interactions, for instance through the support of digital voice assistants, while keeping the simplicity of shoulder tapping. Such extensions may also implement the support of double tap gestures for investigating the user experience of double head movements.

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