

# Transforming Eyeglass Rim into Touch Panel Using Piezoelectric Sensors

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## ABSTRACT

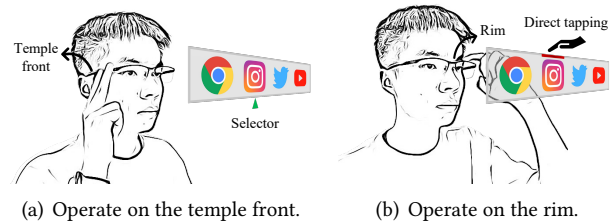
The traditional interaction method for smart eyewear is by touching a control panel located at the temple front of the eyeglass. This method can be unnatural since the control panel and the display are not within the same plane. In this paper, we propose a new and natural interaction technology for smart eyewear that allows users to interact with the rim of the eyeglass without adding additional hardware to the rim. This design is based on an observation that a finger touch would slightly alter the channel frequency response (CFR) of the eyeglass. We use one pair of piezoelectric (PZT) transducers to measure the CFR, and we recognize the tiny CFR changes by analyzing the complex representation of the CFR. The system detects five touch locations using a deep learning classifier. We recruit ten subjects to evaluate the system and the result shows that the system can recognize the five touch locations with an F1 score of 0.91.

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## 1 INTRODUCTION

Smart eyewear (e.g., AR glasses) is an emerging type of wearable device that displays information alongside the wearer's eyesight. The interaction of state-of-the-art smart eyewear mostly relies on touch panels [1, 2, 4, 6]. However, the touch panels of these products are generally located at the temple



**Figure 1: Interaction with smart eyewear. (a) The standard method. (b) The proposed method.**

front (see Fig. 1(a)). This design has the following two problems. The first problem is that since the display and the touch panel are perpendicular with each other, there is no natural mapping between the input gesture and the object being manipulated. To move the content on the display left or right, a user needs to perform a forward or backward sliding gesture on the touch panel. The mapping between the move-right or move-left on the display and slide-back or slight-forward on the touch panel has to be memorized by the user. The second problem is that the manipulation method of virtual objects is indirect. Unlike a touch screen where a user can open an app by directly tapping on the app's icon, the standard way to open an app on an smart eyewear is to use a selector. Through sliding forward and backward on the touch panel, the selector can be moved to the target app and open it with other pre-defined gestures. This indirect manipulation is not as natural as direct manipulation.

In this work, we seek to enable interaction on the outer rim of smart eyewear (see Fig. 1(b)). The advantages of this design are that, on one hand, since the rim of eyewear is within the same plane as the display, the controlling gestures and the manipulated objects can form a natural mapping (e.g., a left slide moves the content leftward). On the other hand, because the display is surrounded by the rim, direct manipulation of the virtual object on the display can be designed (shown in Fig. 1(b)). A straight-forward hardware configuration of this design is to install a glass-shaped touch panel on the rim. However, this is not feasible because a touch panel is usually large compared to the thin rim. Also, this solution does not fit for half-rim and rimless glasses.

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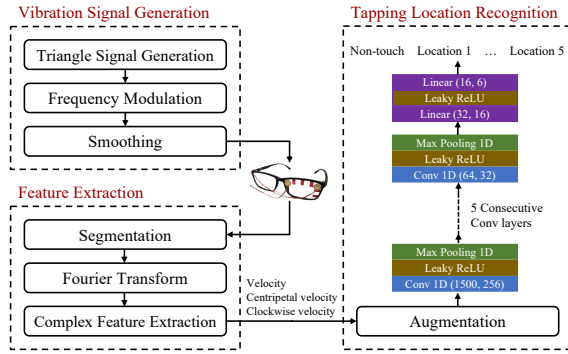


Figure 2: System design.

Inspired by previous work [5], we propose to put two PZT transducers, one for generating vibration and the other one for receiving, on the glass to sense touch gestures (see Fig. 5(a)). The rationale behind this design is that the two sensors and the eyeglass form a vibration system, and the CFR is altered if the user’s finger is touching the rim. By recognizing the CFR characteristics, the performed touching gestures can be detected. In this work, our system detects five click locations on the rim (see Fig. 5(a)).

There are two challenges in designing such a system. The first challenge is to design the vibration pattern so that it contains rich frequency resources while not generating audible impulse noises. In our system, we design a chirp signal with no phase gaps between adjacent cycles to avoid impulse noise. The second challenge is that touch actions on the rim can be very gentle and that makes the change of CFR hard to discover. To resolve this challenge, we view CFR in the complex domain because we observe that CFR has clearer changing patterns in the complex domain. Also, we use a deep learning classifier to recognize the touch gesture.

## 2 SYSTEM DESIGN

The overview of our system is shown in Fig. 2. The proposed system consists of three modules. The Vibration Signal Generation module produces a specially designed vibration signal. The Feature Extraction Module derives useful features from the collected vibration signal. The Tapping Location Recognition module detects the tapping location using a deep learning classifier.

**Vibration Signal Design.** Following a previous work [5], we use chirp signals that sweep from  $20: 1$  to  $40: 1$  whose range is proven to be sufficient to characterize structural changes of the contacting object. However, to minimize the audible impulse noise caused by frequency gap, the chirp signal has to be damped at both ends of each cycle. In this way, information at the two ends are lost and only the middle frequency is well preserved. In the context of eyewear where

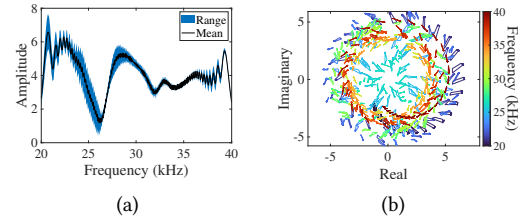


Figure 3: The CFR variation of clicking at location 1 in Fig. 5(a). (a) Amplitude. (b) Phase

a touch action can be gentle, the difference of CFRs caused by tapping is tiny. Hence, we shall make full use of the available bandwidth to characterize a touch event.

Our solution is to use a frequency-modulated signal whose frequency is linearly and periodically increased and decreased between  $20: 1$  and  $40: 1$ , i.e., the frequency is a triangular wave signal  $5^1 c^0$  with a cycle period of  $50 < B$ . Then, we use frequency modulation to generate our chirp signal as  $\sim 1^c = 2 > B^1 2 C 5_c c \sim 2 C \int_0^t 5^1 c^0 3 c^0$  where  $5_c$ , the central frequency, is  $30: 1$ . After the chirp signal is produced, we smooth the beginning and end of the entire signal by fading in and out to avoid audible noise at the two ends. The final signal is sent to one of the PZT transducers to vibrate the eyeglass. This vibration signal is not only inaudible to user’s ear but also imperceptible to user’s skin.

**Feature Extraction.** One PZT transducer collects the vibration pattern of the eyeglass. Since a finger touch changes the structural property of the vibration system, the information of this touch event is embedded in the collected vibration signal. This module tries to uncover features related to touch event from the received vibration signal.

After receiving the vibration signal, we first segment the entire signal so that each segment contains one up-chirp and one down-chirp. Then, we apply fast Fourier transform (FFT) on this segment to compute the CFR of this frame. In our design, the sampling frequency is  $96: 1$  and the CFR contains 2400 samples. The usable frequency range, i.e., the  $20\text{--}40: 1$  range, contains 500 samples.

Fig. 3(a) shows the amplitude of the CFR of a subjecting clicking the rim. The blue shadow indicates the range of variation at different frequencies. It is not difficult to observe that the variation of CFR amplitude is limited because the clicking is very gentle. However, if we see these frequency components in the complex domain as shown in Fig. 3(b), we can observe that each frequency component traverses through a clear trajectory in the plane. Note that these trajectories

