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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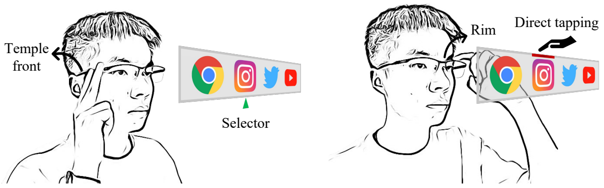
1 INTRODUCTION

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 locate at the temple 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.



(a) Operate on the temple front. (b) Operate on the rim.

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

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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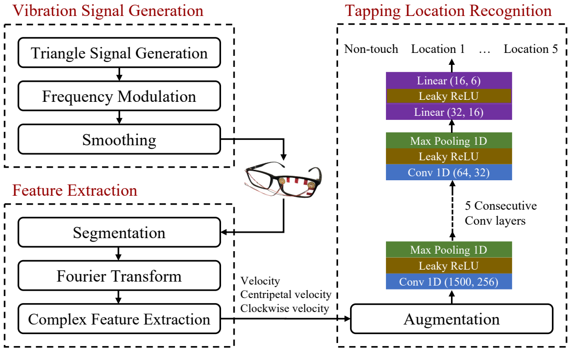


Figure 2: System design.

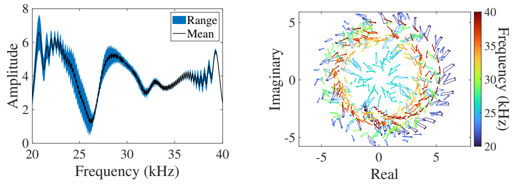
Inspired by previous work [5], we propose to put two PZT transducers, one for generating vibration and the other one for receiving, on the glass to sense touch gestures (see Fig. 5(a)). The rationale behind this design is that the two sensors and the eyeglass form a vibration system, and the CFR is altered 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 $20kHz$ to $40kHz$ 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 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.



(a) (b)

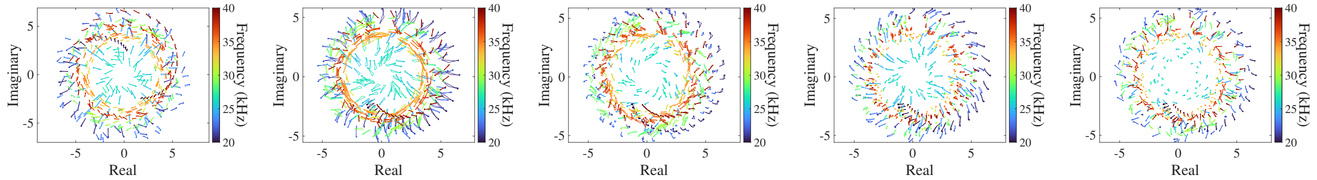
Figure 3: The CFR variation of clicking at location 1 in Fig. 5(a). (a) Amplitude. (b) Phase

Our solution is to use a frequency-modulated signal whose frequency is linearly and periodically increased and decreased between $20kHz$ and $40kHz$, *i.e.*, the frequency is a triangular wave signal. In this way, the phase at the ends of adjacent cycles are continuous and no impulse noise will be introduced. Specifically, we first generate a triangular wave signal $f(t)$ with a cycle period of $50ms$. Then, we use frequency modulation to generate our chirp signal as $y(t) = cos(2\pi f_c t + 2\pi \int_0^t f(t)dt)$ where f_c, the central frequency, is $30kHz$. 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 indaudible to user's ear but also inperceivable 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.

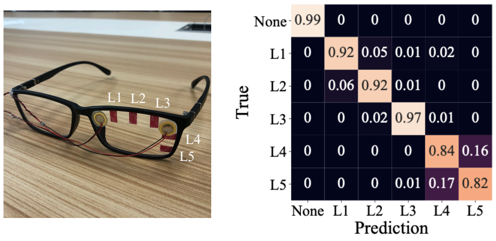
After receiving the vibration signal, we first segment the entire signal so that each segment contains one up-chirp and one down-chirp. Then, we apply fast Fourier transform (FFT) on this segment to compute the CFR of this frame. In our design, the sampling frequency is $96kHz$ and the CFR contains 2400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



(a) Location 1. (b) Location 2. (c) Location 3. (d) Location 4. (e) Location 5.

Figure 4: The complex representation of each frequency component of a subject clicking the 5 locations.



True \ Prediction	None	L1	L2	L3	L4	L5
None	0.99	0	0	0	0	0
L1	0	0.92	0.05	0.01	0.02	0
L2	0	0.06	0.92	0.01	0	0
L3	0	0	0.02	0.97	0.01	0
L4	0	0	0	0	0.84	0.16
L5	0	0	0	0.01	0.17	0.82

(a) Prototype. (b) Confusion matrix.

Figure 5: Preliminary evaluation (L: location).

show a similar round-trip pattern because the performed gesture is clicking which consists of two inverse actions - press and release. Therefore, by using the complex representation of CFR, we can detect tiny touch actions.

Fig. 4 shows the complex representation of CFR of five touching gestures. It is easy to observe that the complex vectors move in different velocities and directions when touching different locations. Therefore, we use the following three features to characterize the moving pattern of the complex vectors. (i) Velocity: the velocity measures the absolute displacement traversed by a complex vector in a given time. (ii) Centripetal velocity: the sub-component of the velocity in the centripetal direction. (iii) Clockwise velocity: the sub-component of the velocity in the clockwise direction.

Tapping Location Recognition. After the three features are extracted from the received vibration signal, our system uses a deep learning classifier to predict the touch gesture. The classifier takes a 1.5s of the three features as the input. In other word, the input size of the model is 1500×30. The architecture of this model consists of five consecutive 1D convolutional layers followed by two fully-connected layers (as shown in Fig. 2). The output layer has six units representing the five touching locations and a non-touch class.

3 PRELIMINARY EVALUATION

We implement the prototype of our system using two PZT transducers manufactured by PUIaudio [7], and a common pair of eyeglasses. We use Focusrite Scarlett 8i6 audio interface [3] to feed and receive signals. The prototype is shown in Fig. 5(a). We recruit ten subjects in the evaluation. We instruct each subject to click gently at the five target location sequentially and this process are repeated for 15 rounds. We have collected 910 samples in total (including non-touch samples), we augment the collected samples by shifting left and right along the time axis to form a dataset containing 4550 samples. We use leave-out-subject-out validation to evaluate the classification performance. The confusion matrix is shown in Fig. 5(b). The average F1-score is 0.91. Note that the five target locations are selected just to show the feasibility of the design and we believe more target locations can be achieved in the future.

4 CONCLUSION

This paper presents a new interaction technology for smart eyewear that transforms the rim of an eyeglass into an interactable touch panel using PZT transducers. The proposed technology uses a pair of PZT transducers to continuously sense the frequency response of the eyeglass. By analyzing the variation of the frequency response caused by finger touch and by using a deep learning classifier, the proposed system can recognize touch events on five target locations on the rim. Experiments with ten subjects show that the proposed system can achieve a mean F1-score of 0.91 in detecting these touch gestures.

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