Earphone EOG Wearable

Technology Reports

Special Articles on User Interface Research —New Interface Design of Mobile Phones—

Using Earphones to Perform Gaze Detection for Wearable Interfaces

*With the arrival of the WALKMAN®*1, listening to music through earphones became a commonplace everyday activity. Portable music players are often operated by means of remote controls, but this can sometimes be difficult if, for example, the user is carrying luggage in both hands. We have therefore experimented with the use of earphones that can also be used as an input device that detects the user's eye movements, and we have made a prototype to verify the feasibility of this idea. Using these earphones, it should be possible to achieve hands-free and voice-free input in situations where the user's hands and voice cannot be used.*

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1. Introduction

Gaze direction and eye movements (i.e., temporal changes in the gaze direction) offer an effective interface that can be used in everyday activities. For example, they can be used to implement hands-free input devices and gaze-based pointing devices. However, conventional systems that use gaze direction as an input interface have so far been concerned with a limited range of applications such as disabled users.

Although conventional gaze measuring devices are capable of accurate measurements, they have various drawbacks such as restricting the user's movement, covering the user's face, and partially obscuring the user's field of view. In everyday applications, high measurement precision is considered less important than the ability to wear the device comfortably.

We have already shown that it is possible to detect the user's gaze direction with large-scale headphones [1]. If it is possible to detect gaze directions with a wide range of different headphones, then the users will choose headphones that are suitable for their own purposes. So in this study, we attempted to detect gaze directions with earphones.

In this article we show that it is possible to perform Electrooculogram (EOG) measurements from the ear canals and their surroundings, and that Kalman filter*2 is an effective way of reducing drift in these signals. Next, we construct a prototype to show that it is possible to generate input just by moving the eyes.

*1 **WALKMAN®**: A registered trademark of Sony Corporation.

*2 **Kalman filter**: A technique for estimating the true state of a system from observed values that contain noise.

2. Conventional Technologies

2.1 Gaze Detection Methods

Gaze detection methods are known to include optical, physical and electrical methods. Optical methods such as the corneal reflection method[*3] and limbus tracking method[*4] are widely used, but impose constraints on the locations where they can be used, and obscure part of the user's field of view. Physical methods such as the search coil method[*5] place a large burden on the user.

On the other hand, electrical methods estimate the gaze direction by using electrodes attached near the eye to detect the corneal-retinal potential (the electrical potential at the retina is negative, positive at the cornea). The principle of this technique—which is called EOG method—is shown in **Figure 1**. This is a schematic illustration of the user's eyes as seen from above, showing the electrodes positioned at the left and right ears, and the changes in potential that occur when the eyes move. When the user is looking straight ahead, no potential difference occurs between electrodes A and B (Fig. 1(a)). When looking to the left, the corneas move to the left and the retinas move to the right, and as a result electrode A has a positive potential with respect to electrode B (Fig. 1(b)). When looking to the right, the opposite situation arises (Fig. 1(c)). By detecting the potential difference between the left and right electrodes, it is therefore possible to measure the gaze direction. Since the potential difference corresponds directly to the gaze direction, a DC amplifier is normally used. The vertical component of the gaze direction can be obtained by placing electrodes above and below the eyes. Also, although Fig. 1 only shows two electrodes, a separate earth electrode is also required for differential amplification.

Since EOG methods are relatively simple to implement and have a wide measurement range, they are mainly used in medical fields. They also have the advantage of not obscuring the user's field of view. But in ordinary EOG methods, electrodes have to be attached above, below, and to the left and right of the user's eyes. As a result, these methods are not suitable for everyday use.

2.2 EOG Measurements via Headphones

In EOG methods, electrodes are attached next to the eyes in order to obtain EOG corresponding to the horizontal and vertical components of the user's eye movements with a high SNR. But if good quality EOG signals can be obtained from electrodes attached further away from the eyes, then it should be possible to detect the gaze direction without having to cover the user's face with electrodes.

We have therefore proposed a gaze input interface that uses headphones [1]. This interface attempts to detect the gaze direction solely by means of electrodes situated around the user's ears. With the proposed method, a user only needs to wear a pair of headphones to perform tasks such as operating a music player with eye movements and reading visual tags by gazing at them. Our prototype device is shown in **Photo 1**.

3. Using Earphones to Measure the Gaze Direction from the Ear Canals

3.1 EOG Measurement Tests

If it is possible to detect the gaze

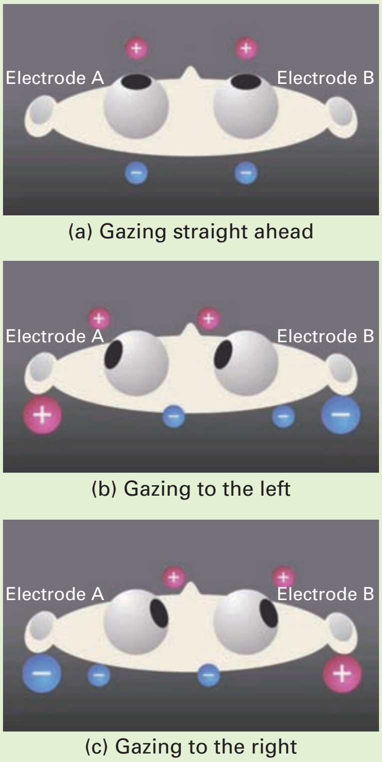

Figure 1 Principle of EOG method

*3 **Corneal reflection method**: A gaze measurement technique that involves shining near-infrared light at the cornea and detecting the reflected light (Purkinje effect).

*4 **Limbus tracking method**: A gaze measurement technique that uses reflected near-infrared light to detect the boundary between the cornea and sclera.

*5 **Search coil method**: A gaze measurement technique that involves fitting a coil to the cornea.

direction by using a more compact form of headphones such as earphones, then it will be possible to offer users a broader range of equipment to choose from. Using earphones to perform gaze measurements can be problematic because the electrodes are situated further away from the eyes.

To clarify these issues, we first performed EOG measurements from the ear canals and their surroundings. Since the skin surfaces surrounding the ear canal have a complex shape, it is not possible to use ordinary electrodes. We therefore developed an auricular electrode coated with AgCl ink in four locations matching the shape of a test subject's ear (**Photo 2**). **Figure 2** shows the EOGs obtained with auricular electrodes in the left and right ears while moving the test subject's gaze (hereinafter referred to as "earphone EOG"). This shows the results of EOG measurements performed while the test subject's gaze was moved to the extreme right and left positions, after which the test subject's gaze was directed at a series of seven targets arranged horizontally at 15° intervals. The amplitude of the EOG was approximately 120 μV when the gaze was moved to the extreme positions. This value is about the same as when the electrodes are placed on the earlobes, but is attenuated compared with the values of approximately 1,300 μV obtained with ordinary EOG, and approximately 650 μV obtained with electrodes mounted on larger headphones. On the other hand, when the gaze is moved vertically, the change in potential was so weak that it was difficult to measure. This is because it is not possible to place electrodes at positions where they are able to detect the vertical component.

Photo 1 Large-scale prototype headphones

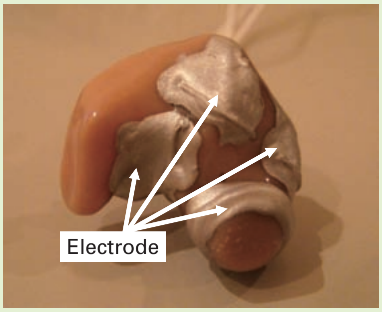

Photo 2 Auricular electrode for right ear

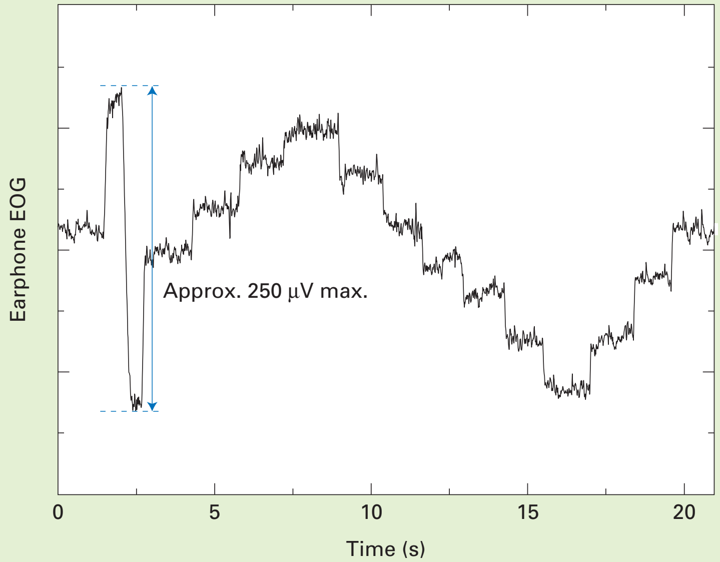

Figure 2 Measured earphone EOG

The black lines in **Figure 3** show how the DC level changes (drifts) in the earphone EOG as time passes. These lines show the EOGs obtained when the test subject's gaze was moved to the right and left extremes, then directed at a target situated directly in front of the test subject for approximately four minutes, and then moved to the right and left extremes again. The auricular electrodes we produced were provided with three conducting electrodes for each of the left and right ears, and four electrodes for the right ear also included an earth electrode as shown in Photo 2. As

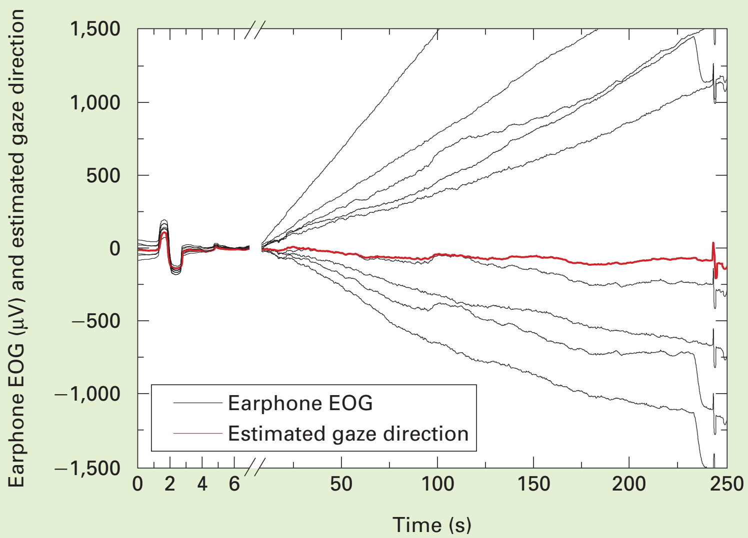

Figure 3 Earphone EOGs and estimated gaze direction when gazing at a fixed point

a result, Fig. 3 contains a total of nine earphone EOGs corresponding to the 3 × 3=9 electrode pairs.

As can be seen from the region where the test subject is gazing at a single point, there is a considerable amount of drift in the EOGs, and each signal exhibits a different magnitude and direction. But in most cases the effects of drift are large, with the change in the DC level that takes place over a few tens of seconds being roughly equal to the change that occurs when the gaze is moved to the extreme limit.

3.2 Issues Associated with Gaze Estimation

These results show that although it is possible to perform EOG measurements from earphone-mounted electrodes, the small signal amplitude means that signal drift has a correspondingly larger effect.

Since the main cause of drift is thought to be the polarizing characteristics of the electrodes and electrode potentials, it is difficult to remove only the drift components of these signals. One way of addressing this issue is to apply high-pass filtering to the signals, but this would result in smooth pursuit eye movements[*6] being eliminated together with the drift components. Another approach is to periodically calibrate the DC level, but this would require the user to carry around a display to present a gaze target for use in calibration, which would be difficult to do in everyday situations. Also, as Fig. 3 shows, some of the earphone EOG signals have smaller amounts of drift. One might consider selecting these EOG signals and using them directly. However, it is not possible to make this selection based solely on the magnitude of the measured values because the measured values are the sum of drift and changes associated with eye movements.

3.3 Drift Reduction Methods

To address this issue, we propose a method in which a Kalman filter is applied to multiple EOGs obtained with multiple electrodes. The signals $EOG_i(t)$ obtained from a single pair of electrodes can be expressed as shown by the following equation, where x(t) is a two-dimensional vector representing the gaze direction, Z_i is a transformation matrix that transforms the gaze direction into an EOG, and e(t) is a noise component that includes the drift:

$$EOG_i(t) = Z_i \cdot x(t) + e(t) \qquad (1)$$

If $\Delta EOG_i(t) = EOG_i(t)\text{-}EOG_i(t\text{-}1)$, and $\Delta EOG(t) = \{\Delta EOG_1(t), ..., \Delta EOG_n(t)\}^T$, then

$$\Delta EOG(t) = Z \cdot \Delta x(t) + \Delta e(t) \qquad (2)$$

Using the Kalman filter, we can obtain Δx(t) from the observed values ΔEOG(t). The gaze direction x(t) can be obtained by adding together Δx(t). When we applied this method to the large headphone prototype of Photo 1, we were able to reduce the drift and separate the horizontal and vertical

*6 **Smooth pursuit eye movement**: Smooth eye movement that occurs when gazing at a moving object. Normally the eyes move by repeated jerky movements called saccades, such as when reading.

components of the gaze direction.

By applying this method, it should be possible to reduce the amount of drift even in earphone EOG signals. We did this by transforming x(t) into a one-dimensional vector for just the horizontal component of the gaze direction.

The gaze estimation results are shown by the red line in Fig. 3. Since the gaze direction is normalized to the range from -1 to +1 when using this technique, the estimation results are shown at roughly the same amplitude as the earphone EOGs. The reduction in drift shows that this technique is also useful for earphone EOGs. We were also able to confirm that it is able to detect smooth changes in the gaze direction, such as smooth pursuit eye movements.

4. Applications for Gaze Input via Earphones

4.1 Prototype Earphones

Based on these results where we were able to reduce drift by applying a Kalman filter, we built a pair of earphone-shaped prototype (**Photo 3**). These earphones have Ag/AgCl electrodes positioned around the outside, and have an EOG preamplifier and speaker incorporated inside the outer enclosure. Of the three electrodes, two are used for EOG outputs (the other is used as an earth or as a reference electrode). The outputs from the earphones are amplified by an external DC amplifier and are then processed by a PC.

4.2 Study of Applications

With the earlier headphone prototype, we were able to use the estimated gaze direction and images taken with a camera to perform tasks such as identifying which object the user is looking at [1]. However, the earphone prototype does not detect the vertical component of the gaze direction and is incapable of being fitted with a camera, so it would be difficult to implement similar applications with this prototype.

On the other hand, it is also possible to consider these earphones as an output device (providing information to the user) to which have been added the functions of an input device (detecting the user's intentions). Simply by wearing these earphones, a user can complete a series of input/output operations, so it is possible to implement completely new types of application.

We built a demonstration system that allows users to operate devices such as music players and mobile terminals by eye movements. We presented this system at various exhibitions, including CEATEC JAPAN 2009 and the Mobile World Congress 2010. In this demonstration system, specific eye movements such as movements from left to right and from left to straight ahead are assigned to specific operations, allowing roughly ten different hands-free operations to be performed. This system can be used in a wide variety of everyday situations, but is particularly effective when the user's hands are unavailable, e.g., when carrying luggage in both hands, or when the user's hands are dirty. The allocation of eye movements to operating commands can be freely set by the user.

This system can also be applied to purposes such as providing hands-free input in noisy environments where speech recognition is impossible, and hiding input operations (taking advan-

Photo 3 Earphone-shaped prototype

tage of the fact that eye movements can still be detected even when the eyes are closed). It should also provide a useful input/output interface for technologies such as Augmented Reality (AR), which has become a hot topic in recent years.

5. Conclusion

With the aim of introducing a gaze input interface for use in everyday activities, we have experimented with the use of earphones to perform gaze detection. Based on EOGs obtained from the earphones, it is possible to estimate the horizontal component of the user's gaze direction. Drift can be reduced by applying a Kalman filter to multiple EOGs. Furthermore, we have demonstrated the hands-free operation of music players based on the eye movements of users wearing these earphones.

Our prototype earphones were made using disc-shaped electrodes mounted at fixed positions. This makes them unable to adapt to users with different ear shapes, so only a limited range of users are able to use them. Also, even with users for which measurements were possible, it was difficult to achieve stable skin contact with multiple electrodes. In the future, we intend to revise the electrode structure (e.g., by adding a spring mechanism), and to find ways of introducing gaze input interfaces into various everyday activities.

Reference

[1] H. Manabe and M. Fukumoto: "Full-time Wearable Headphone-Type Gaze Detector," Extended abstracts of CHI 2006, pp. 1073-1078, Apr. 2006.