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ABAid: Navigation Aid for Blind People Using Acoustic Signal

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Abstract—**Blind mobility aid is a primary part in the daily life of blind people. Although plenty of systems or devices are invented to make the navigation of blind people easier, those are generally expensive and hardly affordable for them. To solve these issues, we introduce ABAid, a novel system designed for blind or visually impaired people to navigate, with commercial off-the-shelf (COTS) mobile devices. Based on in-depth acoustic localization and gyroscope techniques, this system is not only the means of huge convenience to carry, but also capable of detecting obstacles before reaching them. In our experiments designed to detect the distance of wall, the proposed system achieves 3.24% average error rate. It can further measure the direction of wall, and the average error is $2.73°$. With high accuracy and stable measurement, ABAid is able to help blind people move independently in fairly uncomplicated scenarios.**

I. INTRODUCTION

According to World Health Organization (WHO), 285 million people are estimated to be visually impaired worldwide, about 90% of whom live under low-income settings [1]. Most of the visually impaired people are likely to use a long white cane or guide dog. However, those only provide short range information. Moreover, none of them are convenient to be carried all the time. Nowadays, technology is developing so rapidly that we cannot render visually impaired people trapped with a blind cane forever. Smart phones are so widely prevalent that it becomes reasonable for visually impaired people to carry a smart phone for emergency situations. Therefore, this paper aims to design a navigation aid on a smart phone.

The underlying principle of this system is to utilize smart phone in emitting and collecting near-ultrasonic waves concurrently. After acoustic waves are emitted, objects surrounding the user reflect part of the waves, which together with noise are collected by the microphone and time lags are calculated. From the product of the time lag and the velocity of sound, we can infer the distance between the visually impaired people and the obstacle.

However, developing such a system is not as straightforward as what we thought. The first challenge is how to distinguish the reflection of interest from the acoustic waves of other obstacles. Besides our object of interest, there are countless other objects that communicate over acoustic waves. For this reason, we need to evaluate the similarity of the collected audio data with the signal that our system emits. By doing this, we are able to recognize each reflection when a peak of similarity has been seen. Then, the compact description of the surrounding environments can be achieved and delivered to the user.

To summarize, the major contributions of this paper can be concluded as follows.

- To the best of our knowledge, ABAid is the first attempt to implement blind mobility aid on COTS mobile devices without customizing or integrating any other devices.
- ABAid can become the pioneer work for acoustic commercial blind mobility aid, and be easily implemented in various commercial devices. For instance, most Virtual Reality (VR) devices block users' vision, and this can be mitigated by integrating such simple navigation feature for the sake of safety.

The rest of this paper is organized as follows. In Section II, we review the existing works in this context. In Section III, we provide an overview of ABAid system. Section IV illustrates how ABAid is designed in detail. In Section V, we design intensive experiments and evaluate our system thoroughly. Section VI concludes this paper.

II. RELATED WORK

This section provides the state-of-the-art works that deal with the mobility aid of visually impaired people. The work mainly falls into three categories as follows.

Acoustic-based Aid: By mimicking bats, [2] designed a pair of spectacles, which are composed of one transmitter and two receivers, in order to guide blind people. [3], [4] design the state-of-the-art cane by integrating ultrasonic sensors in order to construct a sub-map of obstacles or move the guide wheels sideways to avoid obstacles. To help visually impaired people in freeing their hands, [5] proposed an idea of equipping them with a NavBelt, which is also highly customized.

Camera-based Aid: Authors of [6] developed a system with a vision sensor mounted headgear. [7] proved the feasibility of a low-cost system that preserves much visual information in the generated sound system and that involves a special purpose computer connected to a standard television camera.

Robotic Aid: Evaluated in [8], a robot is attached to the handrail of disabled persons to provide physical support and a joystick which indicates the intentions of users. The authors in [9] also introduced a robotic system, which combines vision-based localization techniques as well as acoustic sensors.

III. SYSTEM OVERVIEW

First, we can have a brief view of how ABAid works. All the devices that ABAid needs are a speaker, a microphone

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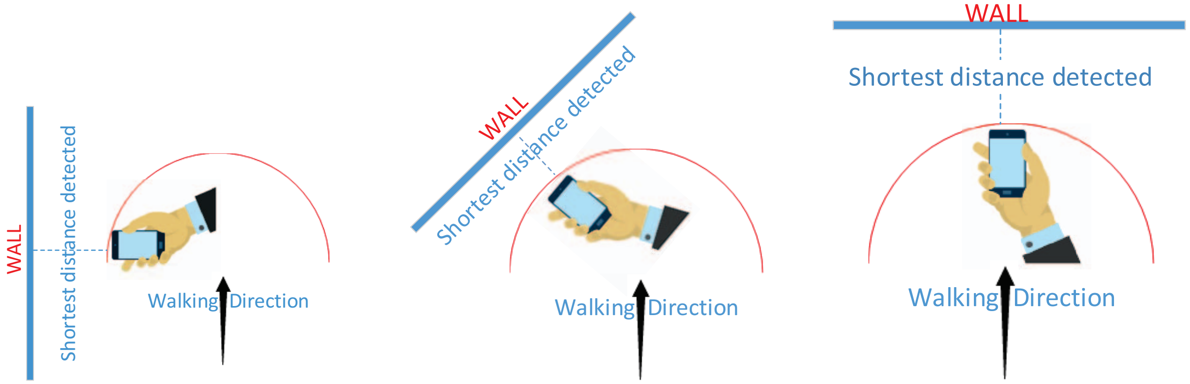


(a) the wall is parallel to the walking direction. (b) the wall is forming an angle with walking direction. (c) the wall is perpendicular to the walking direction.

Fig. 1: Three typical scenarios of detecting wall using ABAid: (a) the wall is parallel to the walking direction; (b) the wall is forming an angle with walking direction (c) the wall is perpendicular to the walking direction.

and a gyroscope, which are prevalent on most of the modern mobile devices. A speaker and a microphone are used for detecting the distances of obstacles to our device. Combined with gyroscope, the direction of obstacle can be determined by signal processing. Consequently, the location of obstacle can be detected with our prevalent modern device.

In order to build a proper model for ABAid, we chose commercial mobile devices that have a microphone and a speaker, which are closely located. In such setup, we can assume that the microphone has the same distance towards the object of reflection as the speaker does. Since a mobile device sends chirps periodically and records consistently, we are able to calculate the cross-correlation value and measure the distance towards obstacle periodically. If there is no obstacle in the near front, users can walk casually while carrying the smart device. If the distance is less than 2m, the smart device gives the user an alert message. In this way, the user knows if he/she is approaching the wall. Now, the question is how to detect the direction towards which the wall is located. For this purpose, intuitively, we can hold and move the device to draw a half circle. When the device is held perpendicularly towards the wall, the shortest wall distance is detected. Moreover, if the speaker and microphone are in the same side of the device, the strongest reflection is received perpendicularly from the wall. Then, the gyroscope on the phone is used to calculate the angle by which the phone is rotated to obtain the shortest distance and strongest reflection. Since the wall behind the user is not in our concern, drawing a half circle is adequate to detect nearby obstacles.

A sample scenario is provided in Fig. 1. Note that since cross-correlation calculation of the received signal is required, the movement should be relatively slow so that the signal shape is not corrupted due to *Doppler Effect*.

IV. SYSTEM DESIGN

In this section, we give detailed introduction to the specific design of each part in the system, mainly including signal design, distance measurement and orientation estimation.

A. Signal Design

There are two considerations to be taken into account when designing such a system, namely, less interruption to others and better navigation performance. To achieve these two goals, we carefully design the signals from two aspects, e.g., *signal frequency* and *modulation scheme*.

As for frequency selection, we choose frequency to be above 18kHz, intending not to cause any interruption for users. Although near-infrasonic wave is also nearly inaudible [10], this sound band is filled with surrounding noises. Meanwhile, the upper bound of frequency is around 22kHz, since the sampling frequency of most audio interfaces is 44.1kHz, according to Nyquist-Shannon sampling theorem.

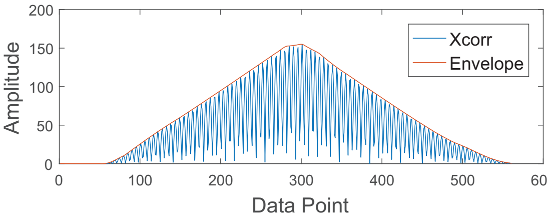
Typically, there are two forms of the source signal: pure tone (single frequency) and chirp (various frequencies). If the pure tone is chosen, the delay estimation via the cross-correlation metric is likely to be inaccurate since other peaks may be easily corrupted due to the residue from the previous peaks [11]. The better choice of acoustic signal is chirp. With the chirp, no two parts of the signal are the same, which leads to a much sharper peak in the cross correlation function and further leads to the possibility of detecting closer lags. Comparison of these two forms is shown in Fig. 2.

In ABAid, we choose the periodic acoustic signal apart by 0.5s, which is 1ms linear up-chirp (from 18kHz to 20kHz) with 499ms silence period. Fig. 3 illustrates a sample set of periodic chirps, and the spectrogram of one sample chirp.

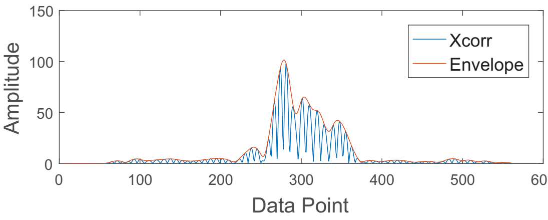
B. Distance Measurement

In this part, we introduce the core component of ABAid, that is, distance measurement with acoustic signals.

In order to remove the negative effect of noise, before any further signal processing, we first apply a 3-order bandpass Butterworth filter with a passband of [18000-100, 20000+100] Hz. The rationale of setting the passband is that, since the



(a) Cross-correlation in the case of pure tone signals.



(b) Cross-correlation in the case of linear chirp signals.

Fig. 2: Cross-correlations of modulated emitted signals and recorded signals

emitted signal sweeping from 18kHz to 20kHz, the reflected echo still preserves such a frequency property. Additionally, in order to avoid the fringe effect caused by filtering, we slightly relax the passband beyond [18, 20] kHz by 100 Hz.

After denoising, distance traveling by echo reflected from the wall is to be estimated. In principle, to obtain the traveling distance of the echo, it is required to obtain the time of flight (ToF) that this echo travels from the transmitter (speaker) to receiver (microphone). To solve this, we apply cross-correlation, which is a measure of similarity of two series as a function of the displacement of one relative to the other. In [12], for discrete functions *f[n]* and *g[n]*, the cross-correlation is defined as

$$\text{Xcorr}(f,g)[n] \overset{def}{=\!=} \sum_{m=0}^{N-1} f[m]g[m+n]. \tag{1}$$

Cross-correlation metric is useful for determining the time delay between two signals, which is also useful for localization. In practice, we calculate the cross-correlation values of the recorded signal and the chirp signal for detecting delayed signals. For the sake of easiness in analysis, we implement the Hilbert Transform of the cross-correlation value to get the envelope. For instance, when the user is about 1m far away from the wall, the corresponding recorded signal is shown in Fig. 4. The highest peak of the envelope corresponds to the acoustic signal that passes through the direct path, which is directly from the speaker to the microphone and has the least attenuation. From Fig. 4, we can see that the peak of the reflection of wall is highly recognizable since the large area of wall reflects much more acoustic waves than other obstacles with similar distance. Thus, a distinct peak appears at around 6ms lag, which is due to the propagation of acoustic signal.

In order to detect the peak of wall automatically, we further design a simple scheme. When a user walks towards a wall, ABAid can easily detect the location of that wall by comparing the signals obtained at different time instants as shown in Fig. 5. The cross-correlation peak of a wall is usually stronger while the corresponding time lag is smaller. However, the reflection from the floor, ceiling or the user is relatively static. For being considered in the same scale, we calculate the normalized cross-correlation value for each period of signal separately. Amplitude threshold and time lag threshold are set to filter out peaks with tiny amplitudes or huge time lags. Moreover, the shift of time lag is no larger than 5ms compared to the corresponding pre-period peak, according to the walking speed of 96.5 meter/min [13].

C. Orientation Estimation

Once the peak of wall is found, ABAid gives user alert message when the user is within 2m far away from the wall. Then, the user can hold the device to draw a half circle for determining the direction of wall. At this point, ABAid tells the user about the approximated physical angle between the wall and his/her initial position. For this, the user is recommended to draw a half circle from his/her left or right side. This is because the time lag of peak of wall remains consistent if the distance towards the wall does not change.

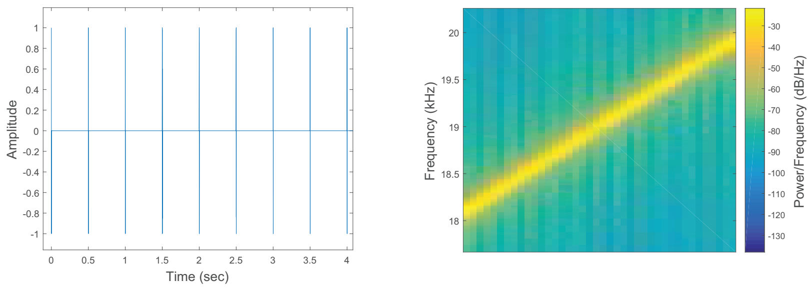
Gyroscopes are known to be immune to external accelerations and magnetic interference. By solely exploiting gyroscope, we could calculate angle with no larger than 6% error rate from actual rotated values [14]. As the experiments conducted in [15], the gyroscope can track very accurate attitude in short time periods (within 10s). In our system, only the change of measured attitude over the short period of time is needed.

When the drawing operation is in process, the direction of wall is detected in the domain of cross-correlation values by shortest time lag from wall as well as the strongest peak value. Then, according to the time duration from the initiation of movement until pointing perpendicularly towards the wall, we are able to locate the corresponding gyroscope data. The entire function is possible due to the simultaneous operation of the microphone and gyroscope in the setting of our application.

V. PERFORMANCE EVALUATION

In this section, we evaluate the performance of our system in terms of the accuracy in detecting the distance towards wall and detecting the orientation of wall.

We implement our system with an off-the-shelf Android device, MEIZU PRO 5. This device has a speaker and a microphone, which are closely located on the same side. We have developed an Android application to collect ambient sound (microphone), emit modulated signals (speaker) and obtain angular data (gyroscope). Since these functions are implemented on the same device, it is easy to synchronize three modules and start working together. As for microphone, the sampling rate is set to 44100Hz, while the sampling rate of gyroscope is 100Hz. Android device is able to collect data and further process data at real time. Thus, when a user is



(a) Emitted Chirps

(b) Spectrogram of Each Chirp

Fig. 3: An illustration of produced chirps.

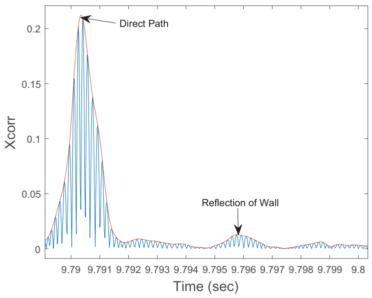


Fig. 4: Variation of cross-correlation of received signal with time.

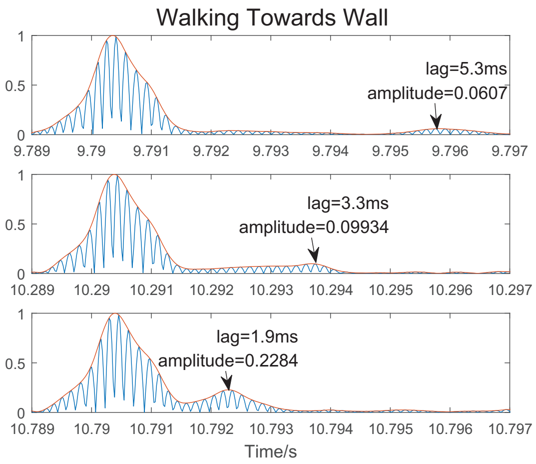


Fig. 5: Variation of time lag and amplitude of received signal while walking.

TABLE I: Average error rates over different users and scenarios.

Outdoor		Scenarios		Overall
User 1	3.46%	Outdoor-glass	3.35%	3.24%
User 2	2.90%	Indoor-glass	1.99%	
User 3	2.94%	Indoor-stone	2.27%	
User 4	3.15%	With noise	4.78%	
User 5	4.94%	Without noise	3.05%	
User 6	2.72%			

holding device while walking towards the wall, the device will be able to alert user when he/she is within 2m from the obstacle, by sound alert and vibration alert. Then user will obtain the orientation of obstacle by drawing half a circle using the device. And device will indicate the orientation by sound and vibration.

6 participants were recruited to conduct intensive experiments for evaluation of this system, both indoors and outdoors. And they were facing different obstacles, like glass wall, hanging TV and stone wall. All participants wore blindfolds to simulate the behaviors of blind people, during experiments. We design our experiments in mainly two parts: measuring distance and measuring orientation. When measuring distance of obstacle, participants can hold the mobile device in hand causally as they like; when measuring orientation of obstacle, participant will draw half a circle using device.

A. Overall Accuracy of Distance Measurement

We first evaluate how accurate and robust ABAid can detect the distance between the wall and user. Experiments were conducted in three scenarios, specifically, facing a wall of glass for outdoors, facing a wall of stone for indoors and facing a huge hanging TV made of glass for indoors. For the former two scenarios, the distances between the obstacle and the participants are changing from 6m to 60cm (with 60cm interval). For the last scenario, the distances are changing from 3 m to 60cm (with 60cm interval), since the space outside the elevator is usually not large. For detecting distance, users only need to hold the device in hand and switch on ABAid to emit chirps and collect acoustic data. As we can see from Table I, there is no obvious difference between different users. Considering the factor of multipath, we can clearly see that whether in indoor or outdoor environment, the estimated distance is very close to the groundtruth with a maximum error rate of 1.99% and 3.35%, respectively. It demonstrates that ABAid is highly robust to multipath effect. The higher outdoor error rate may merely because of the outdoor uncontrollable noises. As for the effect of wall material, the distance error rates for a glass wall and stone wall are 1.99% and 2.27% respectively in indoor environment. As for the performance in noisy environment, we can see that noisy environments would not obviously affect the performance of ABAid, because most of the daily noises are not near-ultrasonic and will be filtered out. The above results prove that for detecting distance, ABAid is quite accurate as well as stable. Even when the scenarios are different, accuracies are not affected significantly. The average error rate of all scenarios is 3.24%.

B. Accuracy of Detecting the Direction of Wall

First, we verify the error rate of gyroscope could be within 6% (Fig. 6). Then, since we are drawing half a circle to detect the direction of wall, not only the distance is changing, but also the angle between the device and obstacle. Thus, Further experiments were conducted to see how the amplitude of cross-

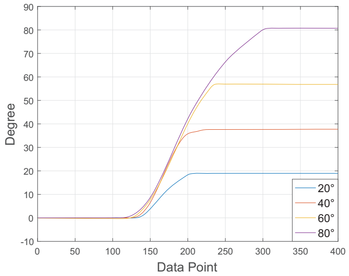


Fig. 6: Measured angle by gyroscope.

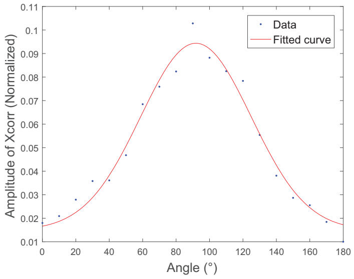


Fig. 7: Relationship between cross-correlation amplitude and angle of device.

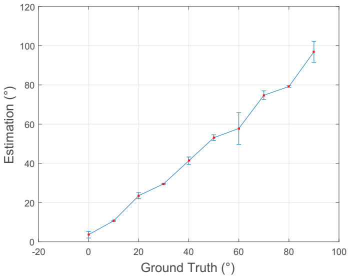


Fig. 8: Comparison between measured and actual direction.

correlation was affected by the angle of device. With the fixed distance, we held the device with various angles. The distance was first set to 1m. The time lags were considerably stable and accurate while the amplitude was affected. This is because the propagation of sound waves is directional due to the hardware structure of the speaker or the microphone. The corresponding results of these experiments are shown in Fig. 7. Each time period to calculate the cross-correlation has been normalized so the results are under the same scale. It is evident that when the device is pointed perpendicularly towards the wall (90°), the strongest amplitude is obtained.

In the above experiments, angles are changing with fixed distance. And strongest reflection can be obtained when pointing perpendicularly. Therefore, when drawing half a circle, shortest distance is formed when perpendicularly, compared with other angles. So strongest reflection should also be obtained when perpendicularly, during the drawing procedure.

After evaluating how accurately ABAid is able to detect the direction of wall, the results are shown in Fig. 8, in the form of error bar (with standard deviation). The achieved average error is 2.73°. Although this accuracy is adequate since people are not sensitive to tiny variation of angle, the accuracy could be further improved by simply adjusting the chirp interval to be shorter as well as drawing the half circle more slowly to obtain data with higher resolution.

VI. CONCLUSION

In this paper, we designed and provided implementation detail of ABAid on commercial mobile device, which helps visually impaired people in detecting large obstacles while navigation. The deployment and implementation of ABAid require one device with a speaker (that emits chirps), a microphone (that collects reflected chirps) and a gyroscope (that obtains angular data). Cross-correlation and angular integral of the received acoustic signal are essential in order to make ABAid works.

VII. ACKNOWLEDGMENT

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