Poster: Distracted Driving Detection By Sensing The Hand Gripping Of The Phone

Ruxin Wang, Long Huang, Chen Wang
School of Electrical Engineering and Computer Science,Louisiana State University
Baton Rouge, LA 70820, USA
rwang31@lsu.edu,lhuan45@lsu.edu,chenwang1@lsu.edu

Abstract

Phone usage while driving is unanimously considered a really dangerous habit due to a strong correlation with road accidents. This paper proposes a phone-use monitoring system that detects the driver's handheld phone use and eliminates the distraction at once. Specifically, the proposed system emits periodic ultrasonic pulses to sense if the phone is being held in hand or placed on support surfaces (e.g., seat and cup holder) by capturing the unique signal interference resulted from the contact object's damping, reflection and refraction. We derive the short-time Fourier transform from the microphone data to describe such impacts and develop a CNN-based binary classifier to discriminate the phone use between the handheld and the handsfree status. Additionally, we design a classification error correction filter to correct the classification errors during the monitoring. The experiments with six people, one phone and one car model show that our system achieves 99% accuracy in recognizing handheld phone-use activities.

Keywords: Driver Safety, Phone-use Monitoring, Acoustic Sensing

ACM Reference Format:
Ruxin Wang, Long Huang, Chen Wang, . 2022. Poster: Distracted Driving Detection By Sensing The Hand Gripping Of The Phone . In *The 27th Annual International Conference on Mobile Computing and Networking (ACM MobiCom '21), January 31–February 4, 2022, New Orleans, LA, USA*. ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/3447993.3482861

1 Introduction

Using a handheld device while driving is a dangerous behavior. The driver can be impacted by all three types of distractions from the phone (i.e., visual, manual, and cognitive), which increases the risk of crashing by up to 23 times [2]. Though law enforcement and insurance penalty policies help raise public awareness and lower car accidents, they achieve limited effects. More efforts are still urgently needed to reduce the driver's handheld phone use to improve traffic safety. There has been active work on using the smartphone itself to prevent distractions. By recognizing when the phone user is driving, the smartphone could automatically turn on the do-not-disturb mode and prohibit the phone use. For example, the cellphone handovers and signal strength variations can be used to recognize a phone in a moving car. However, most users refuse to disable phone services completely while driving though acknowledging the dangers. They may have concerns about missing important notifications and calls during driving. Thus, knowing when a driver holds the phone and take measures immediately is more practical and effective than disabling all phone services for an entire trip. Toward this end, some researchers explore monitoring the driver's phone use, mainly monitoring the display on/off, the phone lifting action [3], and the phone dynamics related to distracting phone activities (e.g., texting and calling) [1]. But these methods have limited abilities to cover the diverse phone distraction scenarios, and they are not robust in the noisy in-vehicle environment.

Figure 1. Illustration of the acoustic signal interacting with the driver's hand.

In this work, we develop a continuous phone-use monitoring system based on acoustic sensing, which starts to work when the phone user has been identified as the driver by

---

ACM MobiCom '21, January 31–February 4, 2022, New Orleans, LA, USA

ACM ISBN 978-1-4503-8342-4/22/01…$15.00
https://doi.org/10.1145/3447993.3482861

existing methods [4]. The system can monitor the driver's phone use between the handheld and the handsfree status by directly sensing the gripping hand, to eliminate the distraction or reduce the impact at once. Figure 1 illustrates how the acoustic signal interacts with the driver's hand. The smartphone's speaker emits ultrasonic pulses periodically to sample the phone-use status. The acoustic signals traveling on the device surface could be uniquely damped, reflected and refracted by a gripping hand. The resulting signals reaching the smartphone microphones are different from the scenarios when the phone is placed on a seat, cup holder, center console, pocket or phone mount, due to their unique materials and contact areas. Furthermore, our system can detect when the driver grabs/holds/drops the phone accurately. Because no additional hardware is required, users of our system can continue to use their existing cars without technological restrictions.

Our contributions can be summarized as:

- This work proposes a continuous phone-use monitoring system to eliminate the driver's handheld device distraction. The proposed system leverages active acoustic sensing to detect when the phone is held by the driver's hand and take safety-enhancing measures immediately.
- We derive the short-time Fourier transform from the sensing sound to describe the phone's contacting surface and develop a CNN-based algorithm to discriminate the handheld phone use from various handsfree scenarios.
- We design a classification error correction filter to process the phone-use sampling results and facilitate capturing each complete handheld phone-use activity accurately in noisy in-vehicle environments.

2 System Design

The architecture of our system is shown in Figure 2, which takes the smartphone microphone recording as the input. The *Data Preprocessing* is performed first to prepare the data for analysis. It applies a bandpass filter to remove the noises outside the sensing signal frequency range and synchronizes the data by referring to the original audio. Based on that, we can find the start and end of the pulse signal to obtain the pulse segment, which contains information about the phone contacting surface. After that, the *Phone-use Status Recognition* processes the pulse sound and recognizes the phone-use status at the current sampling point. Based on a series of the most recent phone-use status samples, the system outputs the final decision of driving status.

2.1 Acoustic Sensing Signal Design

The signal we designed is sweeping from 18kHz to 22kHz to leverage the rich frequency information, which facilitates capturing more characteristics of the object in contact with the phone. Besides, this high-frequency range is not impacted much by the in-vehicle noises, mainly on lower frequencies. Moreover, the signal lasts for a short period (i.e., 25ms), and every two pulses are separated by a stop period (i.e., 75ms). The aim is to reduce the impact of the strong echo effect in the in-vehicle environment and the interference between adjacent pulses. Only the 25ms pulse sound is used for analysis. Furthermore, we use the two mics to independently sense the contacting surface and integrate their results to make a decision, which reduces the errors of every single mic and is robust in in-vehicle environments.

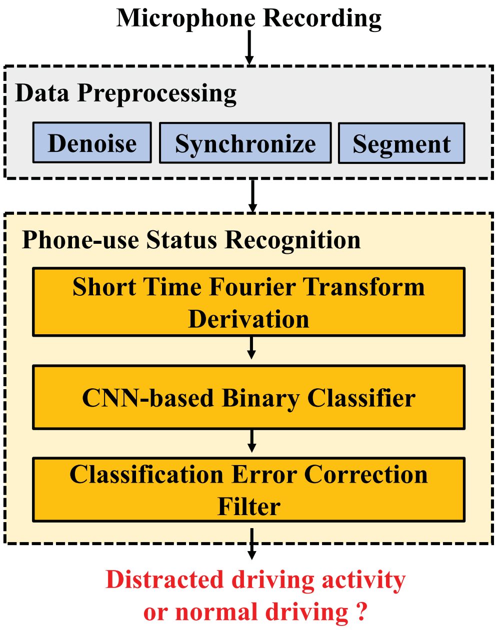

Figure 2. The architecture of our system.

2.2 Data Preprocessing

After obtaining the data from the microphone buffer, we first pre-process it for denoising, synchronization, and segmentation. In particular, we design a bandpass filter with the 18kHz-to-22kHz passband to reduce the noises outside of the sensing signal's frequency range. For example, the noises from the engine, road, and wind can be removed, which are mainly on frequencies below 6kHz. After denoising, we can focus better on the sensing signal changes caused by different contacting surface. Next, we run a synchronization scheme to precisely locate the pulse signal in the microphone data and then segment and normalize it.

2.3 Phone-use Status Recognition

We derive the Short-Time Fourier Transform (STFT) from the pulse sound to describe the time-frequency characteristics of the contacting surface in the acoustic domain. The 2D STFT is input to the CNN-based binary classifier to discriminate the phone-use status between handheld and handsfree. The CNN-based algorithm consists of two phases. During the training phase, we involve a number of people to collect the handheld and handsfree phone-use activities. Moreover,

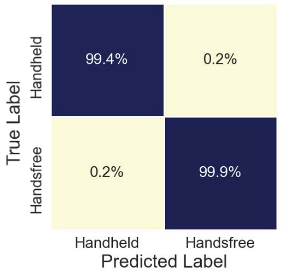

Figure 3. Binary classification (Handheld *vs* Handsfree).

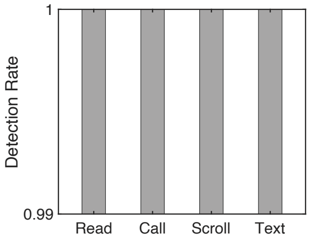

Figure 4. Handheld phone distraction detection rate.

the various handheld phone-use activities are considered in order to cover the various scenarios when the user holds the phone still, tap/swipe on the phone screen, and hold the phone close to face (e.g., making phone calls). Additionally, we separately train two CNN models for the phone's Mic 1 and Mic 2, which analyze the contacting surface from two acoustic channels. During the testing phase, the 2D STFT of the testing pulse sound is input to the two CNN models to process independently. The CNN scores of the two models are integrated to make the classification decision. The accurate classification of each pulse sound is the basis for getting the handheld phone use status. But monitoring the handheld phone use in practical in-vehicle scenarios is more challenging, as even the classification error of a single sample could come at a tremendous cost. Therefore, we design a classification error correction filter to correct the errors from the CNN-based binary classifier that do not make sense in actual driving situations. Specifically, the classification results after the classifier is a sequence of labels between handheld and handsfree based on which the system decides whether the user is being distracted by the phone or driving normally. The filter further corrects the errors in label sequence based on the fact that the phone-use status can not be toggled too quickly by human activities.

3 Preliminary Experiments

To evaluate our system, we develop an experimental platform based on Android, which periodically sends ultrasonic pulse signals and records the stereo sounds simultaneously. We recruit six participants (3 males and 3 females) for experiment and collect data from one smartphone model (Samsung Galaxy S8), in one vehicle model (Nissan Rogue SV). The phone runs Android 9.0, and the microphone sampling rate is set to 48kHz. Each participant was asked to use the phone in four handheld phone uses (i.e., holding the phone still or reading, scrolling, texting and calling) and six handsfree scenarios (i.e., in a pocket, cup holder, center console, phone mount, phone charging on phone mount and seat) in the city-driving environment. For each scenario, the participant was asked to re-grab or reposition the phone 40 times, which involves behavioral inconsistency and phone location differences. For safety reasons, the experiments are performed by a passenger. We apply half data for training and half for testing.

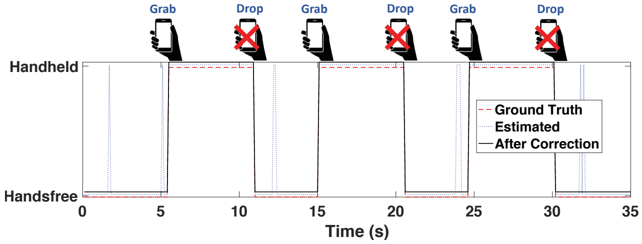

Figure 5. The phone-use status monitoring.

Phone-use Status Recognition The confusion matrix of Handheld and Handsfree classification of our system is presented in Figure 3. We find the system achieves 99% accuracy to discriminate *handheld* from *handsfree*. The result is very promising as the system correctly recognizes the handheld and handsfree scenarios, regardless of how the driver uses the phone and who holds the phone. Next, we investigate how the system discriminates each of the four Phone-use status between handheld and handsfree. Figure 4 presents handheld Detection Rate (DR) in four handheld scenarios. We observe that our system performs well for all four scenarios with a 100% DR. The results indicate that our system successfully detects the phone-use scenarios based on its contact with a hand.

Phone-use Monitoring Case Study. Lastly, we conducted a case study to monitor one participant's phone-use status during city-driving and detect once distracted driving happens. Figure 5 illustrates the results of phone-use status monitoring when the driver uses the handheld phone three times. We observe that though some samples are mistakenly classified, they can be corrected by our classification error correction filter. The resulted phone-use status sequence is close to the ground truth curve. Based on the monitoring results, we can further determine the start, end, and duration of each complete distracted driving activity.

Acknowledgment. This work was partially supported by LEQSF(2020-23)-RD-A-11.

References

[1] Ahmed, K. B., Goel, B., Bharti, P., Chellappan, S., and Bouhorma, M. Leveraging smartphone sensors to detect distracted driving activities. *IEEE Transactions on Intelligent Transportation Systems 20*, 9 (2018), 3303–3312.

[2] Lee, V. K., Champagne, C. R., and Francescutti, L. H. Fatal distraction: Cell phone use while driving. *Canadian Family Physician 59*, 7 (2013), 723–725.

[3] Lee, W.-H., Liu, X., Shen, Y., Jin, H., and Lee, R. B. Secure pick up: Implicit authentication when you start using the smartphone. In *Proceedings of the 22nd ACM on Symposium on Access Control Models and Technologies* (2017), pp. 67–78.

[4] Wang, Y., Chen, Y. J., Yang, J., Gruteser, M., Martin, R. P., Liu, H., Liu, L., and Karatas, C. Determining driver phone use by exploiting smartphone integrated sensors. *IEEE Transactions on Mobile Computing 15*, 8 (2015), 1965–1981.