A Smartphone-Based System for Improving Pedestrian Safety

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***Abstract*—With the prevalence of smartphones, pedestrians and joggers today often walk or run while listening to music. Since they are deprived of their auditory senses that would have provided important cues to dangers, they are at a much greater risk of being hit by cars or other vehicles. In this article, we present PAWS, a smartphone platform that utilizes an embedded wearable headset system mounted with an array of MEMS microphones to help detect, localize, and warn pedestrians of the imminent dangers of approaching cars.**

***Index Terms*—mobile computing, wearables, pedestrian safety**

I. Introduction

Smartphones provide us with many conveniences that a normal computer or laptop gives us, except in hand-held form. We can now listen to music, check emails, and go on social media almost anytime and anywhere. Pedestrians have been engaging more in their phones as they walk. This places themselves at risk because they tune out the traffic, visual, and auditory cues around them [4]. We have seen a large increase in injuries and deaths from incidents involving smartphone usage and distracted driving in recent years. A study by Injury Prevention and CNN has shown that the number of serious injuries and deaths of pedestrians who were walking with headsets has tripled in the last few years in the United States [3]. Our goal is to develop sensing technologies and intelligent wearable systems to address this devastating phenomenon.

In this article we present PAWS, a smartphone platform + headset wearable system that *detects* and localizes oncoming dangers, such as approaching cars, and *warns* pedestrians of these dangers in real-time. The system, based on our previous work [1] published in the Third Conference on Internet of Things Design and Implementation (IoTDI 2018), is intended to act as a second pair of ears for pedestrians whose senses are preoccupied by other tasks and is part of our vision for the next generation of intelligent and safety-aware IoT applications.

II. Other Smartphone Applications

There are other smartphone-based pedestrian safety systems, such as systems that leverage shoe sensors to detect when a pedestrian is crossing the street [2] and completely smartphone-based approaches [5]. However, both approaches are unable to localize oncoming dangers with fine granularity, or do not detect oncoming cars, such as the case of [2]. Our solution leverages two commonly used personal devices, headsets and smartphones, to localize cars and provide alerts.

Fig. 1. Left: UI of PAWS. When a car is detected, a dot corresponding to the relative position (direction and distance) of the car is shown in the graph highlighted in red. Right: low-power embedded headset, introduced in [1], that is used for car direction estimation.

III. Features

PAWS consists of a smartphone application and an optional low-power embedded wearable headset mounted with an array of MEMS microphones for localization. The headset and smartphone application are shown in Figure 1. The system pipeline of PAWS is shown in Figure 2. First, the smartphone application samples a window of audio and executes the first module: car detection. If a car is detected, then PAWS executes the second module: localization. To localize a car, we need to obtain its direction and distance, both of which are represented as submodules within the localization module. The third module: alerts, warns the user of the detected and localized car. The rest of the section details these three modules that make up the PAWS smartphone application.

A. Car Detection

The first module of PAWS samples a channel of audio from the microphone, extracts features from the audio samples, and runs a Random Forest classifier for car detection. Mel-Frequency Cepstral Coefficients (MFCC) are commonly used acoustic features because they closely model how people hear sounds. However, we show in [1] that car engine and tire sounds exhibit noise-like characteristics that MFCCs are unable to distinguish from non-car noise, and we propose a new feature, Non-Uniform Binned Integral Periodogram (NBIP), that is able to better separate car sounds from non-car noise. We adopt NBIP as the feature of choice for car detection in PAWS.

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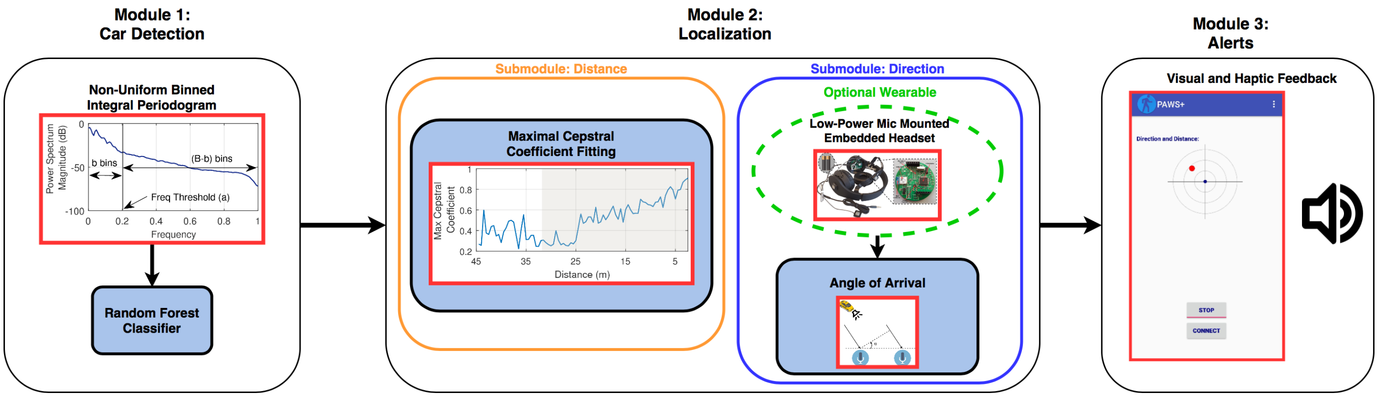

Fig. 2. Data pipeline of PAWS. PAWS runs the car detection module first. If a car is detected, the localization and alerts modules are then executed.

B. Car Localization

1) Direction: Common methods for sound source direction estimation involve computing the time difference of arrival (TDOA) between individual microphones of a microphone array and require at least three microphones for 360 degree coverage. Some smartphones have two microphones at different locations on the device, so systems like [5] have leveraged these features for car localization. However, users must keep the phone oriented properly and using less than three microphones prevents them from localizing cars 360 degrees around the pedestrian. Instead, we leverage a low-power embedded headset, introduced in [1], mounted with an array of four microphones that transmits TDOA measurements to the smartphone for direction estimation. In [1], we pass these TDOA measurements into a machine learning classifier to classify cars into one of eight directions. In this work, we directly compute the angle of arrival for finer granularity.

The wearable headset is required for obtaining accurate and fine-grained direction estimations, but is not required for car distance and detection. To get the full benefit of PAWS, users should still use the smartphone application in conjunction with the headset, but even without the headset, PAWS is still able to provide detection and distance alerts and becomes similar in functionality to works like [5].

2) Distance: People judge the distance of sound sources based on their perceived loudness. As such, we adopt a similar approach. In [1], we found that the maximal cepstral coefficients computed from our smartphone audio stream follows a linear pattern with distance up to 30m away. Past 30m, we are unable to achieve fine-grained distance estimation. In [1], we first trained a machine learning classifier using signal energy features such as relative power between microphones to detect if the car is within 30m; if the car is within 30m, we estimated fine-grained distance by mapping the maximal cepstral coefficient onto a distance using regression.

In this work, we recognize that past 30m, the energy of the car sound is below the noise floor. Using this observation we only employ the regression model for both coarse and fine-grained distance estimation because PAWS's cepstral coefficient regression model both coarsely classifies cars into two distance categories (past 30m if below the noise floor and within 30m otherwises) and provides fine-grained distance estimations if the car is within 30m.

C. Alerts

Once a car is detected and the location is estimated, the smartphone application alerts the user through haptic feedback, sound, and displays the direction and distance of the detected car on the UI of the application.

IV. Conclusion

In this article, we presented PAWS, a smartphone-based platform for pedestrian safety. PAWS provides a second pair of ears for pedestrians to detect and localize oncoming cars. This application is a step towards our vision of future smart cities and devices playing an active role in the safety of society.

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