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Sensing Vehicle Dynamics Using Drivers Smart Phone to Keep Away from Physical Damage

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ABSTRACT

This paper utilizes Smartphone sensing of vehicle dynamics to determine driver phone use, which can facilitate many traffic safety applications. Our system uses embedded sensors in smart phones, i.e., accelerometers and gyroscopes, to capture differences in centripetal acceleration due to vehicle dynamics These differences combined with angular speed can determine whether the phone is on the left or right side of the vehicle. Despite noisy sensor readings from Smartphone, our approach can achieve a classification accuracy of over 90 percent with a false positive rate of a few percent. We also find that by combining sensing results in a few turns, we can achieve better accuracy (e.g., 95 percent) with a lower false positive rate.

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1. INTRODUCTION

Distracted driving due to mobile devices contributes to nearly one thousand fatalities per year and is now receiving attention not only from government regulators but also within the highest executive levels of the mobile industry. Indeed, the National Transportation Safety Board has called for a Nationwide ban on mobile devices behind the wheel, while the mobile industry has adopted a subtler approach with apps that seek to manage distraction. The AT&T Drive Safe app for example, silences the phone for incoming text messages while in driving mode as Discussed in. Such approaches depend on the phone being able to sense when the user is driving, since experience with a phone's silent mode and instant message status has shown in Figure 1 that users are not very reliable at setting the status manually. Several know approaches exist for detecting whether a phone user is in a vehicle. More difficult, however, is determining whether a user is actually driving or is simply a passenger in the vehicle.

Figure 1. Setting the status manually

2. RELATED WORK

There has been active research work in detecting dangerous behaviour while operating an automobile especially for the driver distraction problem caused by hand-held devices. Some recent work dedicated to mitigate driver phone distraction includes Quiet Calls, Blind Sight, Negotiator, and Lindquist's systems. Furthermore, some apps are developed to block incoming or outgoing calls and texts for the phones inside a moving vehicle. Apps such as require special devices installed inside the vehicle to enable blocking cellular communications of a specific phone based on the readings from the vehicle's speedometer, or even rely on a radio jammer. These studies either require prior knowledge of the phone use by the driver (e.g., user activates the system indicating himself as the driver) or blindly block calls/text of the entire cell phones inside the vehicle. These solutions, however, cannot automatically distinguish a driver's cell phone from a passenger's. Sensor of diving phone as shown in Figure 2.

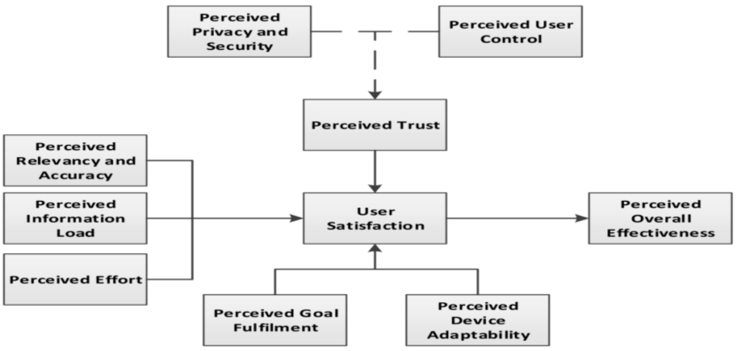

Figure 2. Sensor of diving phone

3. CHALLENGES AND GOALS

Building such a system involves a number of challenges in both design and implementation: Robustness to real-road driving environments. The centripetal acceleration is affected by a number of factors including the different size of turns, driving speed, and driving style. Furthermore, vibrations from the vehicle (e.g., a running engine) and environment (e.g., wind) all contribute to noisy sensor readings. Thus, the algorithm to obtain the centripetal acceleration has to be robust to deal with real road driving environments. Achieving single phone sensing. The approach should work even when only a single phone is present in the vehicle, since it is not always clear that this phone belongs to the driver. Determining the pose of the phone. The measured sensor readings from Smartphone cannot be directly applied to produce vehicle dynamics (e.g., centripetal acceleration) without knowing the pose of the phone inside the Vehicle. An effective re-orientation mechanism is needed to align the phone's pose with the vehicle's coordinate system.

Coordinate systems of a smart phone and a vehicle is shown in Figure 3.

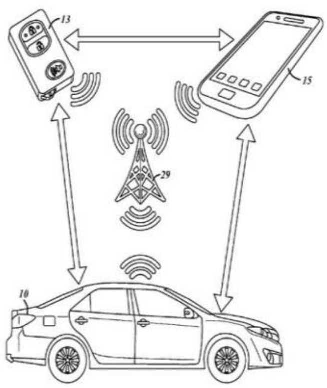

Figure 3. Coordinate systems of a smart phone and a vehicle

The phone further conducts calibration on the data collected by it as well as the data reported by the reference point. Our data calibration process includes three steps: Data Interpolation, Trace Synchronization, and Acceleration Adjustment, which aims to synchronize the traces from different sources and reduce the hardware bias caused by different phone models. Finally, Position Detection determines the phone's position in car leveraging the cumulative difference of centripetal acceleration (e.g., k samples around the maximum angular speed) and combining the turn direction determined from the sign of the angular speed. We next describe how to sense vehicle dynamics using Smartphone and present the core component, Detection Algorithm, in our system.

3.1. Sensing Vehicle Dynamics

Phone and vehicle alignment. We utilize the three-axis accelerometer and 3-axis gyroscope embedded in the Smartphone to obtain the centripetal acceleration while the vehicle makes a turn. There are two coordinate systems, one for the Smartphone (fXp; Yp; Zpg) and the other for the vehicle (fXc; Yc; Zcg), as illustrated in Figure. 3. To simplify the description of our approach, we assume the smart phone's coordinate system is already aligned with the vehicle's (i.e., aligned).

Deriving centripetal acceleration via accelerometers. The vehicle (i.e., opposite side of the driver). The X-axis acceleration reading on the phone reflects the centripetal acceleration (i.e., a) when the vehicle makes a turn. The X-axis reading is zero when the vehicle is driving along a straight line and reaches its positive or negative peak when the vehicle goes into the middle of a turn. The sign of the acceleration on the X-axis is determined by the turn direction due to that the centripetal acceleration is always pointing to the centre of a turn. Thus, the X-axis acceleration is negative when the vehicle is making a left turn, and vice versa. Additionally, the Yc points to the head of the vehicle. Thus, the Y -axis acceleration reading of the phone indicates the acceleration of the tangential speed (i.e., v) of the vehicle in a turn. Determining turn directions uses the gyroscope. To compare the centripetal acceleration at different positions inside the vehicle, we need to determine the turn direction, i.e., whether the vehicle is making a right turn or a left turn. The Z-axis gyroscope reading on the phone can be utilized to represent the vehicle angular speed of the turn. A counter clockwise rotation around Z-axis generates positive reading, which indicates the vehicle is making a left turn; otherwise, the gyroscope generates negative reading, indicating the vehicle is making a right turn.

4. TRACESYNCHRONIZE

This procedure is used to synchronize the sensor readings from the phone and the readings at the reference point (e.g., the cigarette lighter adapter or OBD-II port adapter) since these readings come from two sources with different clocks. In our approach, two types of reference data are involved, one is the centripetal acceleration of the vehicle (reference acceleration from the cigarette lighter adapter), and the other is the speed of the vehicle (reference speed from OBD-II port adapter). To synchronize the phone's centripetal acceleration readings with the ones from the reference acceleration we calculate the cross correlation between these two sequence of readings in time series. When the cross correlation reaches the maximum, these two sequence of readings are synchronized because both sequences reflect vehicle's movement. However, when the speed obtained from the OBD-II port adapter is used as the reference point, synchronization becomes more challenging. We develop a synchronization mechanism utilizing vehicle's acceleration, leveraging the change point in the tangential acceleration during normal driving, to synchronize the trace of reference speed from OBD-II with the acceleration reading trace from Smartphone in time series. The rationale behind this mechanism is that the time point that the vehicle changes from acceleration to deceleration during normal driving is the point that the vehicle reaches its maximum speed. Thus, for the reference speed trace (from OBD-II), we can perform synchronization by subtracting the time difference ðt2 _ t1Þ from all its time stamps.

5. ACCELERATION ADJUSTMENTS

Acceleration adjustment is used to reduce the bias caused by hardware differences in Smartphone through adjusting the centripetal because the centripetal acceleration only exists during a turn, the readings on the X-axis accelerometer of the phone should be zero when the vehicle is moving along a straight line. Nevertheless, the acceleration on the X-axis may have a constant value different from zero due to different hardware characteristics in different phone encountering traffic lights and stop sign). The gyroscope is used to determine whether the vehicle is driving straight (i.e., with zero rotation rate). We note the gravity component needs to be excluded because it distributes on all three axes of the phone when the phone's coordinate system is not aligned with the vehicles. Obtaining ^I. Since the coordinate system follows the right hand rule, we can determine the unit vector ^I ¼ ^j _ ^k ¼ ½xi; yes; zest .After obtaining the rotation matrix R, given the sensor reading vector in the phone's coordinate system s, we can obtain the rotated sensor reading vector s0 aligned with vehicle's coordinate system by applying a rotation matrix Raps: s0 ¼ s _ R. We note that there are existing studies utilizing the sensors embedded in Smartphone to calibrate the coordinate systems between the phone and the vehicle.

Different from the previous study, our coordinate alignment mechanism does not require working with the GPS on the phone, and thus is more accurate and energy efficient. When the coordinate realignment is needed? During driving, the phone's position may change due to unintentional body movements or intentionally moved by the user. So after the initial coordinate alignment performed when our system starts, tracking the phone's position change and performing realignment of the two coordinate systems is desired. To track the phone's position change, the centripetal acceleration of the phone (in the aligned coordinate system) is examined while driving straight. Under this case, the centripetal acceleration on the X-axis accelerometer of the phone should be zero. Thus, if the centripetal acceleration of the phone on the X-axis of phone's aligned coordinate system exceeds a threshold while the vehicle is running straight; our system determines that the phone's position is changed. Then a new rotation matrix will be generated by following the steps in the coordinate alignment method presented in Section 4.2.

6. POSITIONDETECTIONUSING MAGNETOMETERS

Based on the observation that different in-vehicle positrons have different distributions of EMF, we thus can compare the EMF distribution measured at the Smartphone to that of the reference point to detect driver phone use. We assume there is a low-cost cigarette lighter adapter installed in the middle of the vehicle, which has three-axis accelerometer and magnetometer. We also assume that Smartphone can obtain data from the adapter via Bluetooth. Given the collected EMF measurements, we first perform the Magnetometer Data Calibration to pre-process EMF data before performing Phone Position Detection. Position Detection Using Magnetometers based on the observation that different in-vehicle positrons have different distributions of EMF; we thus can compare the EMF distribution measured at the Smartphone to that of the reference point to detect driver phone use. We assume there is a low-cost cigarette lighter adapter installed in the middle of the vehicle, which has three-axis accelerometer and magnetometer. We also assume that Smartphone can obtain data from the adapter via Bluetooth. Given the collected EMF measurements, we first perform the Magnetometer Data Calibration to pre-process EMF data before performing Phone Position Detection.

7. EVALUATION USING DUAL PHONES

When there are passengers in the vehicle, our system can leverage a second phone instead of an adapter on the car to determine the driver phone. While we have not found any detailed statistics on driver versus passenger cell phone use in vehicles, a federal accident database (FARS) [34] reveals that about 38 percent of automobile trips include passengers. Basically, our system can directly compare the centripetal acceleration of these two phones to determine the one on the left side is the driver's phone. These two phones can exchange their centripetal acceleration via Bluetooth. To evaluate such an approach, we carry out a series of experiments by putting one phone at two driver's locations: driver's left pocket (position A), driver's right pocket (position B), and the other phone at two passenger's locations: passenger's left pocket (position C), and passenger's right pocket (positionD).

8. EVALUATIONUSING MAGNETOMETERS

We evaluate the effectiveness of the EMF based method with three different types of vehicles: a small size sedan (Toyota Corolla), a full size sedan (Honda Accord), and a SUV (Nissan Rogue). We conduct the real-driving experiments under two scenarios in NJ: one is driving on highway I-95 and the other is maintaining the vehicle stationary on urban streets. We first fix the moving time window to 35 s and compare the performance of our system in three different Impacts of the size of the moving time window. It presents the detection rate versus false positive rate of driver phone use detection in the Corolla when applying different size of moving time windows. We observe that with a 5 s moving time window, our system achieves more than 80 percent detection rate with a 10 percent false positive rate. In particular, comparing driving on the highway, the detection rate is higher when the vehicle is stationary, i.e., around 90 percent, suggesting that results from stationary case are more reliable than that of mobile case due to stationary case involves less dynamic changes of the magnetic environments. In addition, larger moving time window results in better performance. Specifically, the detection rate in both highway and stationary cases go up to more than 90 percent with a 10 percent false positive rate when the moving time window is 25 s. This indicates that our systemcan achieve high detection accuracy under a small system latency.

9. DISCUSSION

In this section, how this technique can be extended with front-rear detection based on acceleration forces created when the vehicle passes over bumps has been discussed. We then discuss our initial attempts and results towards a completely phone-based solution that is a solution that also eliminates the requirement for the plugin adapter. Finally, we speculate about other vehicle sensors that could be used as a reference point, when vehicles become a more open platform.

10. POWERCONSUMPTION

Our driver phone use detection system can be implemented with low power consumption. Table 2 shows that the power consumption of the sensors used in our system are very low. Additionally, we note that the most significant power consumption of our approach is from data processing using the main processor of the phone. We believe that this power consumption can be largely reduced by leveraging emerging motion processors (e.g., the M7 in phone 5S or the Contextual Computing Processor of Motorola X8 chipset in Moto), which consume much less power than the main processor, and have been widely adopted in many always-on applications (e.g., step counting and activity recognition). In addition, the detection of driver phone use is more likely to be triggered for only few times when the phone is used in a moving vehicle. Therefore, the power consumption of utilizing the accelerometers, gyroscopes, and magnetometers will not be a burden comparing to normal Smartphone usage.

11. CONCLUSION

In this paper we demonstrate a low-infrastructure approach for discriminating between a phone in the driver or passenger position of a moving vehicle by sensing vehicle dynamics. It does not rely on built-in hands free Bluetooth system in the car but only on the phone’s embedded sensors and a simple plug-in reference module for the cigarette lighter or OBD-II port. The insight that the centripetal acceleration varies depending on the position in the car enables us to build a system that exploits the difference of centripetal acceleration at different positions inside the vehicle to determine the driver phone when turning. Our system accomplishes the task by comparing the measured centripetal acceleration at the phone with that from a reference point in the vehicle. Instead of such a reference point, the system could also leverage a second phone in the car to perform detection when available.

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