Vulnerable Road User Protection through Intuitive Visual Cue on Smartphones

Practice Paper

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ABSTRACT
As vehicle communication standards mature, protecting vulnerable road users (VRUs) using vehicle communication technology is looming as a promising and useful application. The current vehicle-to-pedestrian (V2P) communication as stipulated by the standard such as SAE J2735 implies that it is mainly the vehicles that take the responsibility for VRU protection. In this VRU protection framework, user devices are essentially beacons that transmit Personal Safety Messages (PSMs). Upon receiving these PSMs, the drivers (or autonomous vehicles) take necessary measures to protect them. We, however, believe that the road users could also use the information about nearby vehicles to avoid dangerous situations. This paper discusses how the most distracted road user type, i.e., smartphone users, can use the Basic Safety Messages (BSMs) from nearby vehicles to notice approaching danger and take appropriate defensive actions. We build a complete prototype based on the IEEE Wireless Access in Vehicular Environment (WAVE) standards, and demonstrate how it can be used by pedestrians to notice imminent danger even while they are gazing at the smartphone screen.

KEYWORDS
VRU, protection, visual cue, WAVE, smartphone

1 INTRODUCTION
As vehicle communication standards mature and are expected to be enforced by law from 2020 [1], protecting vulnerable road users (VRUs) using vehicle communication is receiving attention. In the Wireless Access in Vehicular Environment (WAVE) framework, the IEEE 802.11 [2] and IEEE 1609 protocols [3–5] specify the protocol stack, while the Society of Automotive Engineers (SAE) J2735 specifies the message set dictionary for over-the-air communication. In its latest revision in 2016, the J2735 standard adds a new message called the Personal Safety Message (PSM) [6]. It is essentially a beacon message from a VRU that warns approaching vehicles so that the vehicles may avoid collision with the VRU (Figure 1(above)). According to the standard, there are four types of VRUs: pedestrians, pedal cyclists, public safety workers, and animals. Among these, pedestrians occupy the largest fraction of fatalities and injuries [7]. In fact, a study in Europe recently found that almost one in five pedestrians use their phones while crossing the street, whether making calls, texting or using apps [8]. In this paper, we focus on protecting the most prevalent and most distracted pedestrian type, i.e., those who are gazing at the smartphone screen near the road.

The current vehicle-to-pedestrian (V2P) communication as stipulated by the standards such as SAE J2735 implies that it is mainly the vehicles that take the responsibility for VRU protection [9]. User devices are essentially beacons that transmit PSMs, and upon receiving PSMs, the drivers (or autonomous vehicles) take necessary measures to protect them. The message receiving capability in the user device is considered optional. We, however, believe that the road users also could use the information about nearby vehicles to protect themselves from dangerous situations (Figure 1(below)).

Figure 1: Communication allowed between vehicles and people in WAVE: person to vehicle (above); vehicle to person (below)

Some might criticise that protecting pedestrians distracted by the smartphone in any other way than discouraging the use itself is practically encouraging bad behavior and worsening the problem. But we believe it is more practical to concede that people are not going to stop looking at their phones anyway, and devise schemes to protect them, whether they behave or not. In fact, some Dutch
cities have installed light bars in the pavement so that the pedestrians with their heads buried in their phones can see the light in their peripheral vision and notice the signal at pedestrian crossings (Augsburg in Germany and Chongqing in China have also made similar allowances for smartphone-obessed pedestrians) [10]. This approach, however, would incur enormous cost in large cities. Moreover, dangers to pedestrians are not limited to crossings. Thus, in this paper, we aim to propose a VRU protection approach for smartphone users that are absorbed in looking at the smartphone screen instead of the vehicle movements unfolding on the street that might threaten their safety. Our scheme offers a cheap and intelligent way to tackle the VRU protection problem and to reduce the risk of accidents. We implement a working prototype, and it has the following desirable properties:

- We built the prototype based on the WAVE standard framework, so that it can interact with commercial WAVE on-board units (OBU) that transmit BSMs.
- Our scheme presents the exact movements of the nearby vehicles on the edges of the smartphone screen based on their BSMs, so that the information does not interfere excessively with ongoing applications.

Being fully conforming to the WAVE standard, our smartphone-based implementation can reap much more benefit than just VRU protection. In particular, when carried in a vehicle, it can work as a WAVE OBU. Moreover, the higher layer WAVE protocols (Logical Link Control (LLC) and WAVE Short Message Protocol (WSMP)) and the application are all implemented on the Android platform, so it has high flexibility to harness WAVE to create other interesting applications in future. The second property is also important. By using only the edges of the smartphone screen, our VRU protection application does not block the screen and interfere with the ongoing application. This less intrusive approach than previous work [11–13] allows the pedestrian to use her discretion as in the case of the light bar crossings above. We believe it is necessary because today’s smartphones cannot yet provide enough intelligence for its softwares to assess the safety features of the given road position. For example, in a busy city, curbs or guardrails can safely divide the pedestrian walkway and the street. In this case, simply judging the danger by the speed and direction of the approaching vehicle can issue unbearably high number of alarms to the VRU protection software user. Worse yet, if everytime the alarm blocks a large area of the screen and displays a warning message, the user will very soon decide that it is hardly useful and only annoying. It will most likely spoil the user experience (UX) and cause the user to turn off the software. Without caution and sophistication, the false alarm problem could beat the whole purpose of any VRU protection software.

2 RELATED WORK

There are prior works for VRU protection using other technologies than the standard Dedicated Short Range Communication (DSRC). For instance, one work uses Wi-Fi or Wi-Fi Direct as replacements of DSRC [14]. This work ingeniously replaces Wi-Fi SSID field with movement information, which is exchanged between vehicles or between vehicles and pedestrians carrying smartphones. However, the non-standard approach has serious issues for safety-critical message exchanges, such as security [3] and congestion control [15]. Without them, anyone could forge false movement messages to cause dangerous consequences, or the wireless channel will be too congested to accommodate more critical messages if there are hundreds of vehicles and thousands of pedestrians near the road. Moreover, the SSID field is too short to contain all necessary information for precise vehicle movement description [6]. Meanwhile, the DSRC technology is mature enough so that a major chip vendor has already integrated DSRC in their platforms (e.g. [16]). Also, an automaker did test VRU protection using DSRC technology [17], with no technical detail released to the research community. Moreover, the U.S. Government is ready to enforce the mandatory deployment in new cars in as early as 2020 [1]. So, the time is ripe for the research community to answer with standard-based and practical proposals to help VRUs to have a means to assess risks and take appropriate actions.

As we discussed in the previous section, an important issue with existing VRU protection proposals [11–14] is that they run the risk of getting fraught with false alarms, which lowers the utility of the whole idea. With the limited situation awareness capability of today’s smartphones, no smartphone-based collision prediction model is immune to the problem, especially in urban environments. False alarms will not only spoil the user experience of the WAVE technology, but could even threaten the safety of both the vehicles and the pedestrians by unnecessarily frightening them. At the least, it may discourage the use of the technology. So our approach instead provides intuitive visual cues to the smartphone user looking at the screen, so that they can use their discretion to determine the level of danger for themselves.

3 PLATFORMS

In this work, we propose a visual cue-based VRU protection method, particularly targeting the road users whose head is buried in a smartphone. Moreover, we implement a prototype system. It is composed of a working DSRC module that can be connected to a smartphone (Fig. 2) and the software module including Wireless Access in Vehicular Environments (WAVE) and SAE J2735 protocols that enable the smartphone to communicate with WAVE-enabled vehicles. Below is the description of the hardware and the software platforms of the prototype.

3.1 Hardware

We developed a plug-in module for Android smartphones, which operates in the DSRC band. This DSRC module implements the IEEE 1609.4 and IEEE 802.11 MAC in outside the context of a BSS (OCB) activated mode. It not only transmits PSMs, but receives nearby vehicle’s Basic Safety Messages (BSMs) using IEEE 802.11p/1609.4 protocols through a DSRC channel. In this paper, however, we focus on the VRU side application that utilizes the BSMs heard from ambient vehicles, we do not discuss PSMs further. (As the PSMs are likely to be used on another service channel than the safety channel that BSMs use, the WAVE devices will have to have dual radio for PSM use.)

Note that the hardware module does not implement the higher-layer stack (e.g. IEEE 1609.3) nor applications. They are implemented in software on the smartphone, which allows us to minimize...
the hardware module complexity and to maximize the flexibility of software development. Our hardware module could be made small enough to be packaged as a smartphone case.

We connect the smartphone and the DSRC module through USB, and upload firmware using the application on the smartphone. Although not used by our prototype, other means of communication such as Bluetooth could be employed for the connection to the smartphone. After selecting the channel to receive the BSM (e.g. Public Safety Channel = 172), the software on the smartphone configures the corresponding transmission frequency and the bandwidth (10 MHz) at the DSRC module. Upon receiving the BSMs, the module forwards the messages in the form of the IEEE 802.11 MAC frame to the smartphone via the USB port. The WAVE protocol stack on the smartphone decodes and parses the BSM received by the DSRC module.

Figure 2: Our DSRC prototype module attached to an Android smartphone via USB port

3.2 Software

The software on the smartphone (Fig. 3(right)) handles the IEEE 802.11p MAC frames from the DSRC module by performing the following operations.

1. Fetches a frame using Android USB Host APIs from the connected DSRC module in the USB Host Mode.
2. Checks the MAC frame for the WSMP payload and extracts the WSMP packet.
3. Demultiplexes the WSMP header, and obtains the BSM from the frame.
4. Extracts the information of the vehicle that transmitted the BSM by performing ASN.1 decoding [6].

As we do not implement any other application than the VRU protection, we decided to put the WAVE stack and the VRU application together as a single application. Splitting them for more general architecture will be done in our future work. The VRU protection logic receives the BSM from the 1609.3 stack. It also uses the smartphone’s GPS to determine the current time, latitude, longitude, direction of travel, and moving speed of the phone. Finally, it uses the accelerometer and the magnetometer sensors to determine the direction and the attitude of the smartphone.

In our experiments for VRU protection application, we use a commercial WAVE OBU (Fig. 3(left)) as a counterpart. It has a full WAVE stack on the device, but lacks the BSM transmitting application, so we program it. On our smartphone system (Fig. 3(right)), on the other hand, we need to implement the LLC and the WSMP layers in the application.

4 VISUAL CUE-BASED VRU PROTECTION

Our VRU protection application informs the smartphone user of potential collision risks by using visual cues on the edges of the smartphone. It highlights the screen edge on the incoming vehicle side, and the highlighted ‘blob’ moves along the edge and changes color and intensity according to the relative speed and location of the passing vehicle (see Fig. 6). Plotting a visible blob for each vehicle uses the information in the BSM from the vehicle and the GPS coordinate, heading and speed information of the smartphone, along with the attitude of the phone that is measured by its motion sensors. We determine the position of the highlighted blob on the screen edge so that the smartphone user can intuitively infer the location of the approaching vehicle. Specifically, the blob is put at the intersection between the screen edge and the projection of the line segment between the screen center and the blob towards the vehicle. Finally, the application runs in the background, so that the smartphone user is not excessively interfered while using other applications.

To obtain the position coordinate of the smartphone, our application consults the smartphone GPS at 1 Hz. For attitude estimation, we obtain the yaw (θ), pitch (ϕ), and roll (ψ) of the phone by using the SensorManager class of the android.hardware API. Combining these and the GPS coordinate of the BSM sending vehicle, we compute where to present the visual cue for each approaching vehicle on the smartphone screen. First, let the plane that is parallel to the road surface on which the vehicle moves and intersects with the center point C of the smartphone be α. Based on the coordinates of the vehicle (say k) and of the smartphone, we compute the angle $\theta_{C,k}^{(\alpha)}$ and the distance $d_{C,k}^{(\alpha)}$ from C to the vehicle at the coordinate $(x_k, y_k)$ on plane α. Fig. 4 depicts this step. For convenience, we will consider the roll later, and assume $\psi = 0$ for the moment. In order to compute $\theta_{C,k}^{(\alpha)}$, we use the vehicle coordinate to compute
the angle $\theta_k$ between the East and the line segment $\overline{Ck}$ between $C$ and the vehicle $k$. Then $\phi_{C,k}^{(z)} = (\theta_k + \phi) \mod 2\pi$, where $\mod$ is the modulo operation.

![Figure 4: Determining the coordinate of the vehicle representation on the smartphone edge](image)

Now that we accounted for the yaws of the phone and of the vehicle, we deal with the pitch. Given the pitch of the smartphone $\phi$, we get from Fig. 4,

$$
x_k^{(\beta)} = d_{C,k} \cos \theta_{C,k}^{(z)} \tag{1}
$$

$$
y_k^{(\beta)} = d_{C,k} \sin \theta_{C,k}^{(z)} \cos \phi \tag{2}
$$

where $(x_k, y_k)^{(\beta)} = (x_k^{(\beta)}, y_k^{(\beta)})$ is the coordinate of the vehicle projected to plane $\beta$ that contains the phone’s plane $P$.

Next, we consider the roll. Suppose the phone rolls on to plane $\gamma$ and the roll is $\psi$. Then from Fig. 5 we get

$$
x_k^{(\gamma)} = x_k^{(\beta)} \cos \psi \tag{3}
$$

$$
y_k^{(\gamma)} = y_k^{(\beta)} \tag{4}
$$

where $(x_k, y_k)^{(\gamma)} = (x_k^{(\gamma)}, y_k^{(\gamma)})$ is the projection of the vehicle’s coordinate to plane $\gamma$. Now, the angle $\theta_{C,k}$ is given as

$$
\theta_{C,k} = \cos^{-1}\left(\frac{x_k^{(\gamma)}}{\sqrt{(x_k^{(\gamma)})^2 + (y_k^{(\gamma)})^2}}\right) \tag{5}
$$

Finally, we put a blob at the intersection $(x_k, y_k)$ of a smartphone edge and the line segment between $C$ and $(x_k^{(\gamma)}, y_k^{(\gamma)})$ on plane $\gamma$.

Each time the smartphone receive a BSM from vehicle $k$, we compute $(x_k, y_k)$ for it and add it to the list $L$ of vehicles to present on the screen edges. In each period of presentation, we draw the entirety of $L$. When we present the vehicles on the screen edges, we let them appear on top of any other application that currently runs on the screen. But the blobs only use the minimal areas near the edges, they do not overly occlude the main app that currently runs on the screen. Also, whenever the smartphone attitude changes, we reflect the change to $L$ so that the vehicles always appear on the projected direction from the screen center $C$ to the vehicles no matter how the phone attitude changes.

We also color-code the visual cue based on the distances to the vehicles. This is to provide the user with additional visual information for risk assessment. It is also necessary for the user to distinguish the most dangerous vehicles when multiple vehicles are presented on the screen edges. Obviously, the visual cue should take account of the distance to the vehicle and the vehicle speed. Broen et al. [18] shows the braking response times of drivers is 1.27 seconds at the minimum and could exceed 2 seconds. We add 1 second to the worst case as a safety buffer, so warn the user with the highest level alarm when the vehicle can reach the user in 3 seconds. Between 3 and 6 seconds, we use yellow. For others, we use green. The last case includes the vehicles moving away from the VRU, no matter how close they are.

### 5 PROTOTYPE

We test our prototype on the road. We equip a vehicle with the commercial OBU that uses two 4.5 dBi antennas for DSRC communication and a u-blox GPS antenna. On the smartphone side, we have a WAVE module (Fig. 2) that has two 4.5 dBi antennas, which is connected to the smartphone through USB. We use SONY XPERIA D6653 smartphone with Android 6.0.1 OS that runs our application that processes BSMs and visually displays the blobs for the vehicles that sent the BSMs on the edges of the smartphone screen. Fig. 6 shows the operation of our prototype as the test vehicle passes the smartphone that runs our system.

We observe in our preliminary tests that the vehicle-indicating blob tracks the vehicle and intuitively indicate its location relatively well. But we also observe that the blob shakes rather visibly. This phenomenon is partly due to the GPS inaccuracy, but turns out to be more contributed to by the smartphone attitude sensing. The former will improve because GPS is being upgraded so that much higher precision may be achieved by civilian devices in future [19]. For the latter, we will employ an appropriate filter to provide more smooth user experience in our future work.

As we briefly mentioned above, our DSRC module and the smartphone-based WAVE stack and application software can be easily leveraged...
to create interesting and useful WAVE applications. One could carry the system on vehicles to use it as a WAVE OBU, or create applications more geared towards smartphone users. For example, Fig. 7 shows an application in which we can see the locations of the vehicles in the vicinity to know the traffic situation. Finally, when the DSRC-integrated Wi-Fi chipsets [16] are used by smartphones, the VRU protection functionalities proposed in this paper will be more easily implemented.

6 CONCLUSION

This paper demonstrates that WAVE technology can be harnessed by smartphones to help vulnerable road users (VRUs) to notice the dangers from incoming vehicle traffic even while they use smartphone applications. We implement a prototype that includes a small form-factor DSRC communication module and the software that processes the WAVE stack and the VRU protection application. By using only the edges of the screen, we can avoid ruining the user experience and undesirable ramifications from false alarms when providing the visual cues for the incoming traffic. Finally, with its WAVE application software implemented on the smartphone side, our prototype can be easily leveraged to create other interesting WAVE applications as well.

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