Appendix A
Discussion

Discussed below are some related topics/issues this paper has not addressed fully.

A.1 Adaptation to Different Car-Types

Due to the harsh climate of the region we are residing in, special car-types, such as electric vehicles (EVs), hybrid EVs (HEVs), or plug-in HEVs (PHEVs), are less common and, therefore, DAPL's evaluation on them is difficult. Nevertheless, we discuss some adjustments need to be made on DAPL for different car types. For a gasoline-engine vehicle, the major magnetic field sources are alternators, batteries, relay switches, engines, tires (while spinning), etc [40]. EVs/HEVs/PHEVs introduce another major magnetic field source: batteries [40], [52]. The distribution of magnetic field thus depends highly on the location of their batteries. These components can emit both stable magnetic field in basic operations [41] and transient magnetic field variation (MFV) when certain controls take place. For example, when the car is accelerating/braking, the current drawn from batteries changes, and hence causes the magnetic field to change [53].

DAPL can already handle transient MFV or BT RSSI fluctuation by utilizing Trend Extractor as shown in Fig. 8c. To deal with the static magnetic field due to basic operations, we give an example of adapting the movement feature table to an HEV with batteries located under the right rear seat [54]. In this case, the strongest magnetic field exists in the right rear passenger seat while the driver seat has the weakest magnetic field [41]. In such a case, we can reverse the value assignment of ($\nearrow$) and ($\searrow$) in the magnetic field column of Table 2 to apply DAPL in HEVs/PHEVs/EVs with a similar structure. To adapt itself to different car makes/models, DAPL can obtain the corresponding movement feature table by looking up the model information embedded in BT beacons.

While the current version of DAPL is designed for common four-seat vehicles (*i.e.*, sedans and SUVs), applying DAPL to other vehicle types is also part of the future work. Here we discuss some adjustments need to be made if an developer wants to apply DAPL to different car types. Suppose we now have a 2×3 (row$\times$column) seat vehicle. If the two rightmost passenger seats exhibit similar magnetic field measurements, the developer can utilize DAPL's original 4-zone design as shown in Fig. 19a and update each entry in the feature table accordingly. Otherwise, each seat should be treated as an individual zone (Fig. 19b) and the feature table should be expanded to cover all the possible seat-level movements. The developer can also follow this principle to apply DAPL to other vehicle types (*e.g.*, a 3×2 seat vehicle).

A.2 Deployment of DAPL

DAPL is mainly designed to help those people who are aware of the danger of phone-distracted driving but sometimes forget to manually activate the driving mode or for those people who do not have enough incentives/interest to activate it manually. Note that distracted driving is illegal in most states in the US, but there are still distracted drivers [35]. Another potential user group/target of DAPL is teenage drivers (*i.e.*, the drivers who have tendency of texting while

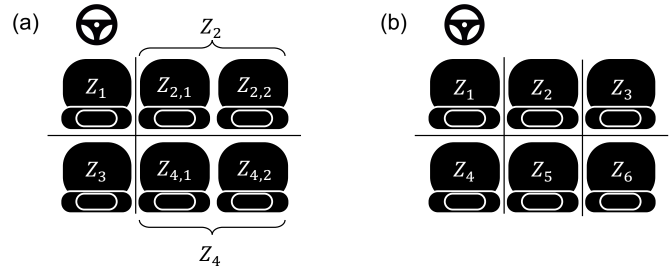

Fig. 19. This figure shows the potential zone partition scenarios.

driving [4]). Parents will have incentives to buy phones with DAPL built-in, or install parental control apps[5],[6] with DAPL functionality on their teenagers' phones for their safety.

There are three deployment options for DAPL. It can be implemented as a built-in OS function (by the phone manufacturer), as an API/library, or as a stand-alone app. As a built-in OS function, DAPL could be the future default driving mode that is embedded in phone OSes and cannot be deactivated by the driver, *i.e.*, built-in prevention of distracted driving. As an API/library, DAPL may provide other apps the ability to determine whether the phone is in the driver seat or not, to support their customized functions for the driver or the passenger. As a stand-alone app, DAPL will be a convenient and safer "upgrade" of the existing driving mode that helps the drivers automatically activate the driving mode to reduce the "unintended" distracted driving (*e.g.*, the distraction caused by notifications).

For insurance companies, they want to prevent car accidents to boost their profit. To make their customers drive more safely, the insurance companies will be willing to provide their customers premium discounts if their customers choose to use devices that have functions for prevention of distracted driving (*i.e.*, DAPL). Thus, users will have incentives to buy and use phones with DAPL. Consequently, phone manufacturers will also have incentives to produce phones with DAPL. Since carmakers just need to enable beacon broadcasting of built-in Bluetooth transceiver to install DAPL, they won't have any difficulty in deploying DAPL. Furthermore, their cars will have fewer accidents thanks to DAPL which can increase their sales. Last but not the least, the most obvious incentive for users to choose the phones with DAPL is to make them safer. The users who cannot resist the temptation of web browsing/texting while driving and/or forget or don't care to manually turn on driving mode, will be incentivized to use DAPL thanks to its automatic detection and the premium discounts provided by the insurance companies.

Specifically, the survey of EverQuote[7] indicates that approximately 80% of EverDrive[8] users with iPhones use the driving mode function (*i.e.*, "Do Not Disturb" of iOS) and 32%

5. How to Use the Parental Controls on a Smartphone - Consumer Reports. https://www.consumerreports.org/smartphones/how-to-use-parental-controls-on-a-smartphone/

6. Teen Driving: Apps to Keep Your New Driver Safe. https://www.parentmap.com/article/teen-driving-apps-to-keep-your-new-driver-safe

7. https://www.everquote.com/blog/car-insurance/do-not-disturb-phone-feature/

8. An app for monitoring driving behavior. https://www.everquote.com/everdrive/

of EverDrive users indicate that they will download apps with the driving mode function if their phones do not have such a function, indicating people's willingness to install apps that can mitigate distracted driving (*e.g.*, DAPL) . The report of Insurance Institute for Highway Safety (IIHS)[9] also states that 50% of iPhone users still activate the driving mode manually. The report also shows that 40% of the manual users "wouldn't be frustrated at all if they receive a reminder prompt" to activate the driving mode and 27% of manual users would be very likely to use the driving mode if they receive a reminder.

Appendix B
Supplementary Materials on System Design

B.1 Location/Trajectory Estimation Error Bound

Even though the initial estimation of the phone orientation from OS API may be affected by the vehicle's acceleration, its effect on orientation estimation will not be significant if the vehicle does not undergo any drastic maneuver change (*e.g.*, flooring the gas or brake pedal). Fig. 20 shows the (theoretical) error bounds of orientation estimation for different vehicle accelerations, and Fig. 21 further shows the maximum location deviation/error caused by the maximum orientation estimation error for different car accelerations. The statistics of car acceleration extracted from 110 traces in Safety Pilot open dataset [44] show that for 92.67% of the time, the car acceleration will be less than or equal to 1 m/s^2 (Fig. 22). These statistics indicate that for most of the time, the location error caused by the inaccuracy of initial phone orientation estimation will be bounded by 0.0508m, 0.1016m, and 0.2033m when the phone experiences within-seat (d=0.5), adjacent-seat (d=1), and large/diagonal inter-seat (d=2) movements, respectively.

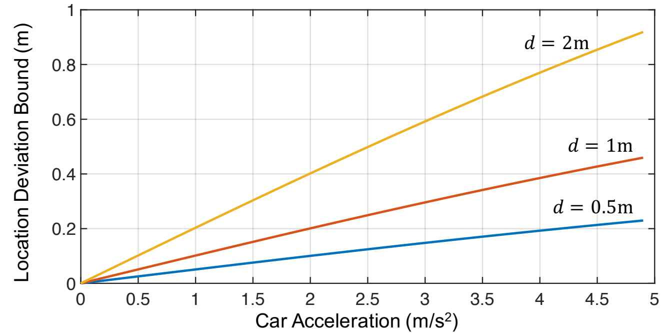

Fig. 21. Location deviation bound caused by vehicle acceleration under different phone displacement (d).

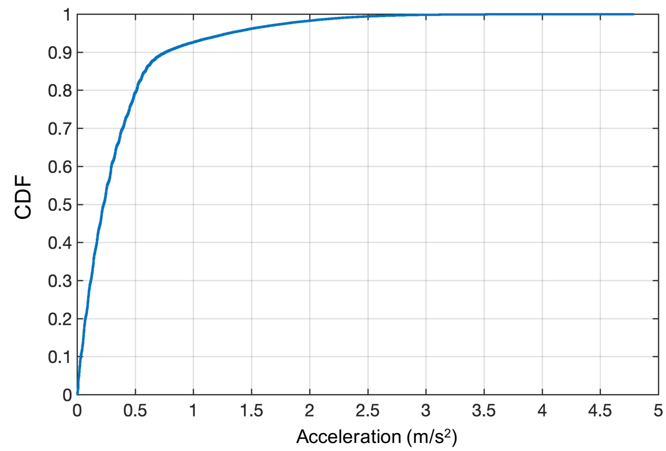

Fig. 22. Statistics of car acceleration extracted from 110 traces in Safety Pilot open dataset.

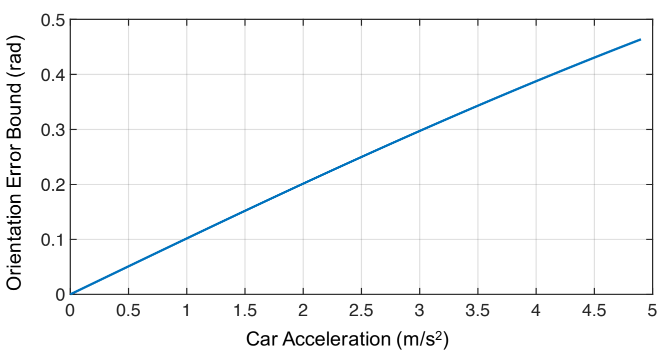

Fig. 20. Orientation estimation error bound under different vehicle acceleration.

Appendix C
Supplemental Evaluation Results

C.1 Test Case Information

We would like to stress that DAPL was evaluated under practical conditions, which are, to the best of our knowledge, much harsher/severer than any prior work. For each scenario, most natural phone movements were tested with different combinations of initial and ending orientations. As mentioned in Section 4, we tested cases in which the phones can be rotated along with multiple axes or even flipped (*i.e.*, 360° rotations) during the movement and can be moved with different initial phone orientations (*i.e.*, how the phone is placed). Also, the traveling distance and bearing change of the car during a phone movement can be up to 94.9m and 174° (*i.e.*, a "U" turn), respectively. The time duration of a phone movement can be from <1s to 10s.

While Fig. 10 shows the statistics/CDFs of the phone orientation change after a movement and the overall phone rotation in the test cases, Fig. 23 shows an example of the test case where the phone is originally placed vertically (with its screen facing towards the right side of the car) and, after the phone movement, it is held by the user with its screen tilted 45° toward the user. The orientation/rotation during the movement can also be observed by the acceleration readings captured by the phone (Fig. 24) in which the gravitational acceleration shifted from Y-axis to both Z- and Y-axes.

Furthermore, we did not deliberately maintain a constant vehicle speed, bearing or traveling elevation. Instead, all the experiments were conducted during busy daytime hours requiring frequent accelerations and decelerations. Also, the vehicles experienced turns or even elevation changes during our evaluation. See Figs. 25–27 for example traces of vehicle speed, bearing and elevation during DAPL's evaluation. Fig. 28 further shows the CDFs of vehicle speed and bearing change during the phone movements. Specifically, the maximum bearing change during DAPL's evaluation is

9. https://www.iihs.org/api/datastoredocument/status-report/pdf/54/1

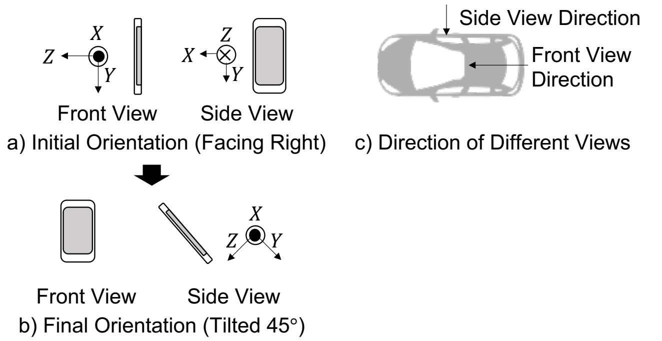

Fig. 23. This figure shows a test case example, where the front view and the side view indicate the conditions in which a person is observing the phone orientation when facing towards the head of the car and facing towards the left side of the car, respectively.

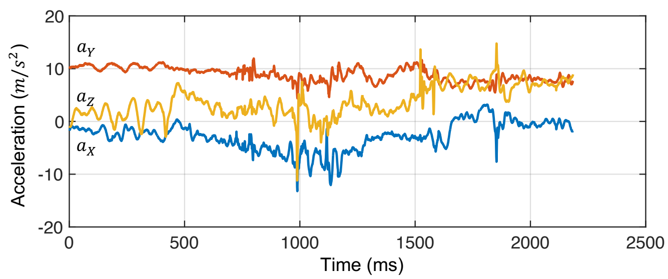

Fig. 24. This figure shows the acceleration readings of the example in Figure 23.

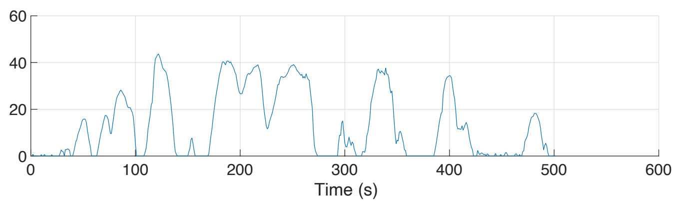

Fig. 25. This figure shows an example of vehicle speed trace (km/h) during `DAPL`'s evaluation.

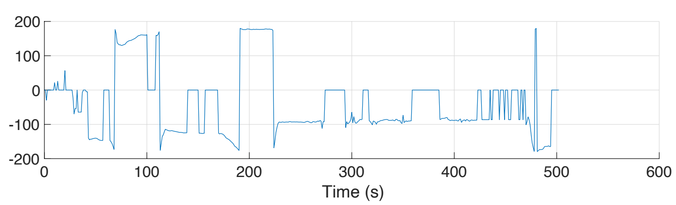

Fig. 26. This figure shows an example of vehicle bearing trace (degree) during `DAPL`'s evaluation.

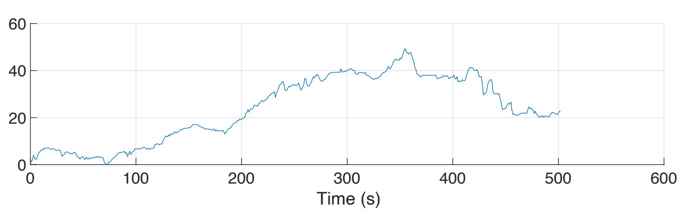

Fig. 27. This figure shows an example of vehicle elevation trace (in meters) during `DAPL`'s evaluation.

174° (*i.e.*, a "U" turn) and more than 60% of the experiments are performed under the conditions where there are vehicle bearing and/or speed changes (*i.e.*, $> 1°$ and > 0.5 km/h, respectively).

See Figs. 29, 30, and 31 for examples of vehicle bearing, vehicle speed and relative elevation during the experiments of phone movements in driver's clothing, respectively.

C.2 Reducing Sampling Rate for Energy Saving

Another way to reduce the energy consumption overhead further is reducing the sampling rate of the sensors. We use the same set of traces used in Section 4 and downsampling them for accuracy evaluation. The tested sampling periods are 5 (default), 10, and 20ms. We can observe that the localization accuracy drops to 86.17% (86.25%) when the sampling period increases to 20ms (10ms). Since Android API does not provide functions to directly control the sampling period of a sensor, the sampling period that we can set in *registerListener*[10] is just a hint/suggestion to the operating system. During our evaluation, we did not observe any difference when the sampling period is set to 5–20ms. Therefore, we do not provide the energy overhead measurements while varying the sampling period. Based on this observation, we suggest the sampling rate set to the highest rate to ensure the best detection accuracy while adjusting R_{act} is a better way to achieve the desired setting.

10. https://developer.android.com/reference/android/hardware/SensorManager.html

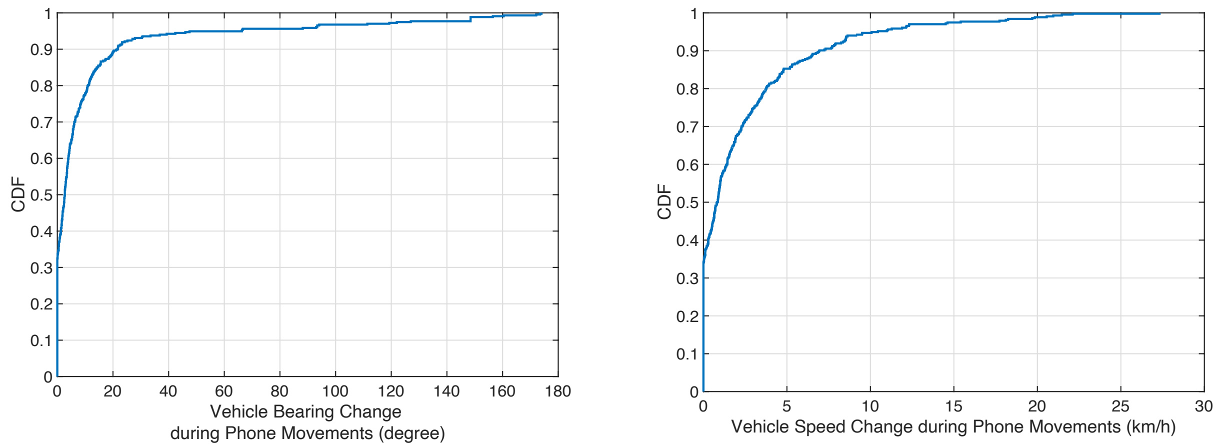

Fig. 28. This figure shows the CDFs of vehicle speed and bearing change during the phone movements in `DAPL`'s evaluation.

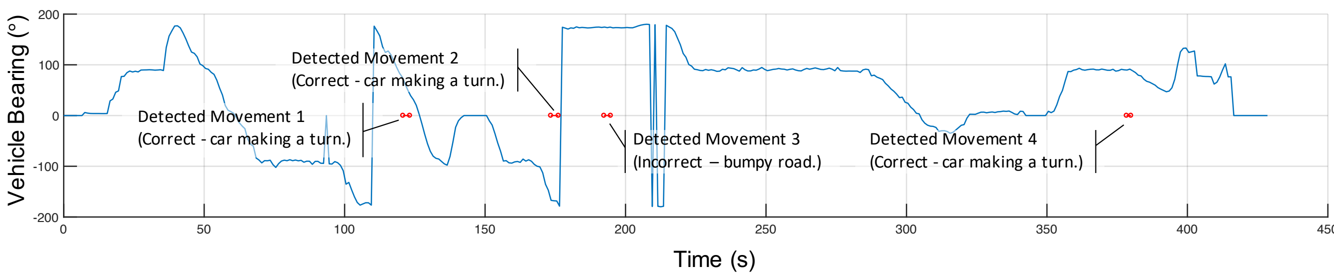

Fig. 29. This example shows the vehicle bearing during the experiment where the phone is kept in the right pocket of driver's pants.

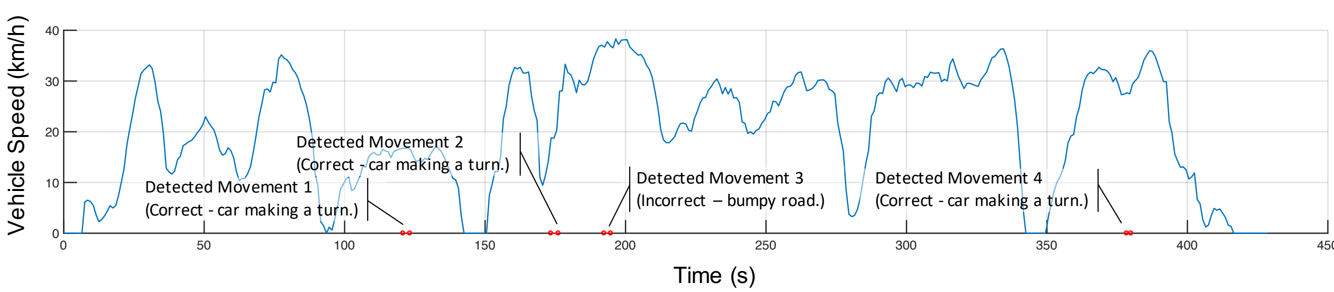

Fig. 30. This example shows the vehicle speed during the experiment where the phone is kept in the right pocket of driver's pants.

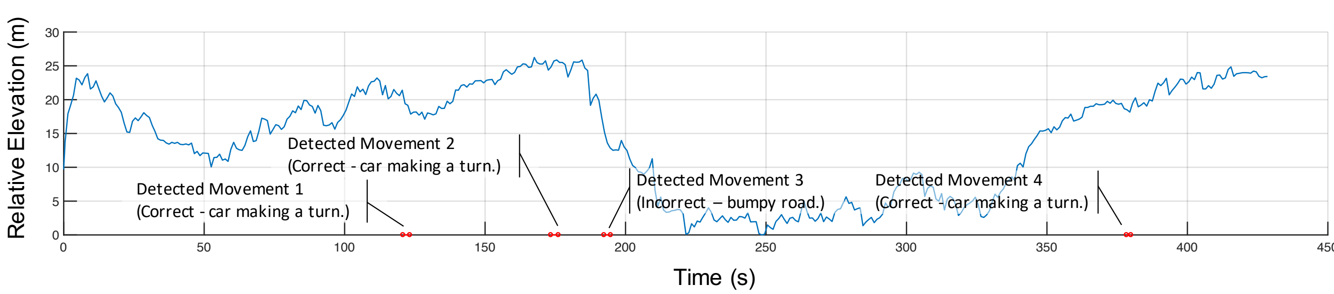

Fig. 31. This example shows the relative road elevation during the experiment where the phone is kept in the right pocket of driver's pants.