# Detecting Aggressive Driving Behavior with Participatory Sensing

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**Abstract.** Aggressive driving increases the risk of accidents, and it is normally a consequence of the impatience, frustration, or anger of drivers. In this paper, we present a case study showing the feasibility of using participatory sensing to enable drivers to report and gain awareness on aggressive driving behavior. We describe the design and development of the Driving Habits System prototype, a mobile application that enables drivers deploying sensing campaigns to collect data about their driving habits. We also discuss the results from a 5-weeks deployment study, where 23 drivers used the system in their everyday lives in the city of Ensenada, Mexico. Our results indicate that our prototype was useful and easy to learn. Its design allows drivers to raise awareness on their driving behaviors and motivates them to engage on a participatory sensing campaign to identify issues on the factors that affect driving. We close discussing design issues for ubiquitous applications to be used while driving and the potential impact of such tools in promoting self-reflection and behavior change.

## 1 Introduction

Aggressive driving increases the risk of collisions, and is common on drivers, motivated by impatience, annoyance or hostility. According to [12], aggressive driving can be recognized by: running red lights, traffic weaving, tailgating and forced merging. Some research projects have proposed using smartphones for identifying different maneuvers that relate with aggressive driving [5]. In this work we propose making drivers to reflect into their own data as they are driving, allowing to raise awareness on aggressive driving behaviors, and promoting safer driving styles.

Although, works like MIROAD [2,5] show that the use of sensors in smartphones, combined with classifiers, are appropriate to infer driving behaviors, little has been said about how this data could be used to provide drivers with awareness of their driving behaviors and eventually promote positive behavior change. Nowadays, apps like Automatic (automatic.com), Zubie (zubie.co), Dash & Drive Smart (dash.by) and TalkyCar (http://goo.gl/LvQtw7) use a smartphone and OBD-II interface devices to assessing the quality of driving in


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terms of the number of aggressive behaviors a driver may exhibit like braking, accelerating, and speeding.

However, some of these apps are only available for the market in USA; and when they are used in developing countries with challenging road conditions, the issues that affect road quality can provide a biased evaluation of the aggressive driving behaviors, producing drivers' frustration and discouraging their usage and jeopardizing adoption. Also, there is limited evidence of how these commercial applications could be used to deploy participatory sensing campaigns for gathering collective knowledge. These related efforts open new research questions around the design of mobile technologies making use of specialized sensors and taking advantage of the notions of participatory sensing that are appropriate and easy to use while driving.

In this work, we describe the design of the Driving Habits System prototype for conducting participatory sensing campaigns on aggressive driving behaviors and present a case study in the concrete scenario of the city of Ensenada, Mexico. We finish this work with some design issues for ubiquitous applications intended to be used while driving and its potential impact in promoting self-reflection and behavior change.

## 2 The Driving Habits System

The Driving Habits System is a mobile application designed to enable drivers deploy participatory sensing campaigns and gather data about aggressive driving behaviors and the quality of roads. We followed a user centered design methodology to iteratively design our prototype. First, we conducted 11 interviews with pedestrians (n=4), drivers (n=6) and transit officers (n=1), and 10 hours of non-participatory observation. Then, we conducted three participatory design sessions (one hour long in average) with a multidisciplinary team with expertise interaction design (n=1), and in human computer interaction and ubiquitous computing (n=3). We evaluated the design of our prototype during a focus group with drivers with at least one-year experience (n=5) and experts in human computer interaction (n=1). In what follows, we describe the resulting prototype.

The main component of the Driving Habits System is a mobile sensing application running in Android devices (Fig. 1) for monitoring aggressive driving behaviors. We define an aggressive behavior as any of the four aggressive maneuvers that the Driving Habits System is capable of recognizing: swerving, braking, accelerating and speeding. The Driving Habits System automatically registers an aggressive behavior event when it recognizes and geo-localizes one single maneuver that exceeds a normal driving threshold.

The application's interface is similar to a traditional GPS navigation system, as this interface is familiar to drivers and we wanted to reduce the cognitive effort associated with the use and interpretation of the information being displayed.

There are two visualizations notifying drivers when incurring in aggressive driving behaviors. First, the driver's trajectory is drawn in colors depending on the vehicle's speed on top of a traditional navigation map (Table 2). Second, next


**Fig. 1.** The driving habits system. Upper left, the application main screen, Bottom left, the ELM327 device plugged into the vehicle OBD-II port, center, the android device running the application mounted over the dashboard, Upper right, the emotion status survey, Bottom right, the aggressive behavior event survey.

to the map, the user can review a tile with four icons indicating how aggressive the driver is related to each one of the aggressive behaviors. Both the color of the icons and user trajectory changes in response to the driver's performance, from green to yellow and red, based on the aggressiveness level of their driving: green, less aggressive; yellow, somewhat aggressive; and red very aggressive (Table 3).

The Driving Habits System also provides audio feedback when detecting an aggressive behavior event by reproducing a short beep and a verbal prompt using the Android voice synthesizer. Following a conversational interaction model, the system asks the driver to fill an icon-based survey to specify the reason of incurring in an aggressive behavior event (*e.g.*, "Carlos, why did you swerve?").

Drivers use the survey interface for detailing the contextual reasons that might be the cause of that specific aggressive behavior event (*e.g.*, "I swerved to avoid a street bump", Fig. 1, bottom right), or to discard the event automatically detected by the system. This way the survey enables drivers to report a pothole, a street bump, an obstacle, a traffic jam, or even the aggressive behavior of another driver. If the driver is unable or chooses not to answer the survey, it will be dismissed automatically after 15 seconds of waiting for a response.The same notification and survey mechanism is used for requesting drivers to report their current emotional state when beginning a trip (Fig. 1, upper right). This survey presents positive and negative emotions, like, being angry, sad, or happy, defined by the circumflex emotion model [9].

### 2.1 Using the System

To show how the Driving Habits System could be used in practice, here we present an example scenario of use:

*As Carlos begins driving, he touches the play button, indicating he is willing to share his driving data. The voice assistant component uses the Android voice*

**Table 1.** Aggressive driving behavior representation and its thresholds.

| **Behavior** | **Icon** | **Event threshold** |
|---|---|---|
| Swerving |  | The accelerometer senses a lateral acceleration change of ±4 m/s$^2$ [2]. |
| Braking |  | The accelerometer and the ELM327 device infer a longitudinal deceleration of 2.4 m/s$^2$ [2]. |
| Accelerating |  | The accelerometer and the ELM327 device senses a longitudinal acceleration of 2.8 m/s$^2$ [2]. |
| Speeding |  | The ELM327 device senses speeds over 80 km/h. The trajectory color on map follows the next rules: Blue<=0, green 0<speed<=35, yellow 35<speed<=60, orange 60<speed<=80, red 80<speed [4]. |

*synthesizer loudly to say: "The services are active". At this moment the Driving Habits System begins to record data. The system asks, loudly, "Hi Carlos, how do you feel today?", and presents the icon-based emotion self-report survey with eight icons showing emoticons related with the emotional status (Figure 1, upper right). As this time Carlos is happy, he chooses a yellow icon representing a happy face. At this moment, the four icons representing his aggressive behaviors are green. When Carlos begins to drive, his trajectory is depicted over the map, in green colors because he is driving below 35 km/h. In a moment of distraction, he did not react with enough time to brake softly, because the next intersection traffic light is about to change to red. When braking suddenly, the system reproduces a beep, and says: "Carlos, you made a sudden brake, why is that?", and presents an icon-based aggressive event survey (Figure 1, bottom right). The color of the braking icon changes from green to yellow indicating to Carlos, his behavior is somewhat aggressive. Carlos touches the screen and waits to be able to continue driving. When arriving to his destination, Carlos touches the pause button and the Driving Habits System says loud "The services are paused", indicating that he finished collecting the data.*

### 2.2 Architecture

To provide the above mentioned functionality the system uses an Android device running the Driving Habits System Application (i.e. a tablet with 7 in. size display and at least 4 GB of free internal memory) (Fig. 1, bottom left) connected via Bluetooth to an ELM327 interface device plugged into the OBD-II vehicle's port available on all vehicles since 1996. The Android device keeps the collected data in a local repository, and when Wi-Fi access point is available, usually when the device's battery is being charged, sends the data to an application server that stores a representation of the driver's data.

*Inferring aggressive driving events.* As the works reported in the literature [2,5], the algorithms based in accelerometer data require calibration for recognizing the orientation of the device related to the vehicle's moving direction in order to identify properly when the vehicle is going forward or backwards; in other words, braking or accelerating. The normal operation of the vehicle produces vibration, affecting the accelerometer readings. Also falling into a pothole or slamming a door can be easily confused with braking or swerving. One alternative is trusting exclusively in the engine operation data collected from the OBD-II port, insensible to the quality of the road, but this would not provide information about the lateral vehicle's movement, essential for recognizing the swerving maneuvers, nor the perceived sensation of movement. For addressing this issue, as in [5] we use both data sources (Table 1), and in this work we propose human intervention for event recognition using participatory sensing to identify the events related with the quality of the road.

The Driving Habits System extracts and processes raw data from the Android device's accelerometer, following the schema proposed in [2] for detecting erratic driving behaviors. Following their method, the Driving Habits System application recognizes the vehicle's direction during the initial movement and later computes two acceleration vectors: longitudinal and lateral, quantifying the forces that affect the vehicle's movement. Then analyzes these vectors in three seconds long overlapping windows, using the thresholds in (Table 1) (Fig. 2).

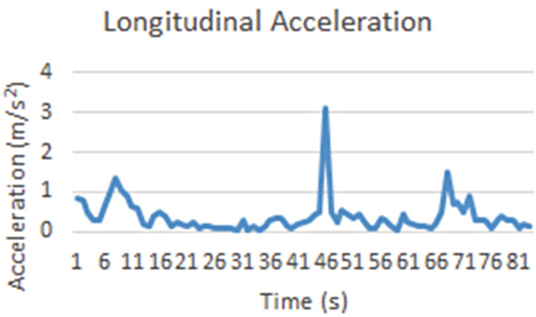


**Fig. 2.** Aggressive braking event example. In the time 46 s, a change of -3 $m/s^2$ happens.

The use of the ELM327 interface device in the vehicle's OBD-II port allows us to gather additional operation data (*i.e.* vehicle starting, the engine revolutions per minute, and the odometer reported speed). The Driving Habits System analyzes a three-element tuple {speed, revolutions per minute, timestamp} using three seconds overlapping windows. This information is used for drawing the trace with the vehicle's speed over the map, using the colors according to Table 2. The threshold for aggressive speeding is based in [4]. Also, for minimizing the noise effect from the accelerometer, this information is processed for detecting the braking and accelerating aggressive behavior events using the same thresholds for the accelerometer (Table 1).

*Geo-referencing the vehicles position and the aggressive driving events.* The Driving Habits System application samples the Android device's GPS sensor data at a rate of one time per second. This allows estimating the current vehicle location, represented by a four-element tuple {longitude, latitude, GPS speed, timestamp}. This information is used to form a trip descriptor, composed by a set of location tuples that describe the traveled trajectory and the set of aggressive driving events detected when using the Driving Habits System application.

*Promoting user participation.* Participatory sensing campaigns cause user burden, as the participant incurs in energy and monetary expenses, due to the effort required for sensing, processing, and communicating data [3]. We based our incentive model in system utility [10], providing feedback related with the aggressive driving events. This information promotes both awareness and self-reflection about the driving behavior.

*Sharing the gathered data.* As a permanent data connection demands additional expenses from the user [3], and this data connection is not available when the vehicle is located in zones without mobile network coverage, we chose to store the gathered data in the Android device. There is a Wi-Fi listening service in the application, and when it detects one convenient connection, it synchronizes the information to our application server without explicit user intervention.

*Providing privacy control.* Participatory sensing allows individuals to decide what data to share, and how to extend mechanisms to protect their privacy [11]. Despite this affecting the quantity of collected data, we chose to let the drivers decide when using the Driving Habits System. We use a play-pause button and an audible notification "The services are active" for notifying when the Driving Habits System is collecting data.

## 3 System Evaluation

We evaluated the system for 5-weeks in the city of Ensenada Mexico to understand the potential adoption, and perceived utility of the Driving Habits System in real-life situations.

### 3.1 Methods

23 participants were recruited, all graduate students, 10 are female, 7 of the participants are in the 18–25 age range, and 16 into the 26–36 years old. We used the Spanish-version of the Driving Habits Questionnaire for screening purposes on their driving [7]. None of them identifies themselves as an aggressive driver.

We used the Car Technology Acceptance Model (CTAM) survey [8] for assessing the Driving Habits System acceptance. The CTAM survey comprises 9 categories provided as a five level Likert scale questionnaire [6]. We calculated the mean, standard deviation and Cronbach's alpha [1] for each category. The Cronbach's alpha ($0 \leq \alpha \leq 1$) shows the degree of internal consistency between the questions in the category, where the closer values to 1 implies a stronger relationship between questions.

Finally, participants filled a survey with a set of five questions extracted from the Spanish-version of the Driving Habits Questionnaire. We performed a t-Student test for comparing their driving behavior awareness before and after participating in the study. We supplemented these surveys along with a semi-structured interview where we asked questions on technology adoption, self-awareness and potential behavior-change on driving habits. Interviews lasted 25 min on average (sd 8:43 min), for a total of 10 hours of recording.

### 3.2 Results

**Use and Adoption.** We collected 508 valid trips, equivalent to 2,751.49 km of mobility traces (with an average trip distance of 6.43 km, sd 5.41 km). This data represents 101.61 hours of total use of the Driving Habits System, (average trip duration 12 min and sd 9.10 min). 85.04 % of those trips where correlated with an initial emotional state manually reported by drivers when starting a trip (Table 2). From this data 68.69 % were positive emotions.

When driving, the participants performed some aggressive driving behaviors events. The Driving Habits System gathered 3,970 events (Table 3). After the Driving Habits System presented the aggressive behavior survey, the participants explained 1,739 events, providing further contextual information.

**System Acceptance.** According to the CTAM questionnaire results (Table 4), the most remarkable aspects of our design correspond with the effort expectancy

**Table 2.** Participants answers to the "How do you feel today?" question

| | | Answers | |
|---|---|---|---|
| Category responses | Response | Quantity | Percentage |
| No answer | Dismissed | 76 | 14.96 % |
| Negative emotion | Stressed | 15 | 2.95 % |
| | Irritated | 8 | 1.57 % |
| | Tired | 19 | 3.74 % |
| | Sad | 41 | 8.07 % |
| Positive emotion | Energetic | 43 | 8.46 % |
| | Relaxed | 116 | 22.83 % |
| | Happy/Quiet | 190 | 37.40 % |

**Table 3.** Aggressive driving behaviors events detected by the system

| Behavior | Collected events | Events by participant | | | | Events survey answered | |
|---|---|---|---|---|---|---|---|
| | | Mean | SD | Min | Max | Quantity | Percentage |
| Speeding | 506 | 22 | 22.92 | 0 | 74 | 287 | 56.71 % |
| Swerving | 1128 | 49 | 82.20 | 0 | 395 | 349 | 30.93 % |
| Braking | 1963 | 85 | 90.46 | 0 | 322 | 935 | 47.63 % |
| Accelerating | 373 | 16 | 18.04 | 0 | 71 | 168 | 45.04 % |

and self-efficacy. However, these categories obtained some of the lowest Cronbach's $\alpha$ values in the questionnaire, along with the facilitating conditions. This could be consequence of the existence of a trade-off between the goals that integrate these questionnaire categories. In general, all the categories have mean values pointing to a positive acceptance of the Driving Habits System, being the perceived safety the lower score, indicating that drivers have some concerns pointing to the demanded attention when answering the aggressive events surveys and the distraction potential as we explain further.

**Table 4.** Statistics of the car technology acceptance model questionnaire

| Survey outcomes | Mean | SD | Cronbach's $\alpha$ |
|---|---|---|---|
| Performance expectancy | 3.25 | 1.04 | 0.6887 |
| Effort expectancy | 4.66 | 0.65 | 0.3133 |
| Attitude towards using technology | 3.72 | 0.91 | 0.7502 |
| Social influence | 3.65 | 1.04 | 0.8290 |
| Facilitating conditions | 3.47 | 1.43 | 0.4641 |
| Self-efficacy | 4.26 | 1.10 | 0.5915 |
| Anxiety | 3.72 | 0.92 | 0.7410 |
| Behavioral intention to use the system | 3.67 | 0.87 | 0.7526 |
| Perceived safety | 2.98 | 1.17 | 0.7242 |

In what follows, we relate the CTAM questionnaire results and show the interpretation from the qualitative analysis of the interviews performed at the withdrawal stage of the study.

*Performance expectancy.* 13 of the 23 participants indicated that the Driving Habits System helped them to improve their performance as drivers and provided awareness on their own driving habits. "I am more aware of over speeding events. The car inertia [when going down hill] heavily increases speed and I wasn't aware of [how fast the car is when going downhill]." [Participant 22] Also, 8 of the 23 participants emphasized installation with the system is somewhat problematic, as it requires too much of their attention that sometimes users are not in a position to give away. “My concern was to install and turn on [the system], it wasn’t automatic, if I’m going late, and [the system] is asking me “How do you feel today?” [Participant 13]

*Effort expectancy.* All the 23 participants indicated that learning how to use the Driving Habits System was easy, and 20 of them highlighted the system is easy to use. “The way to indicate when an incident happen was easy, it shows you the options, it was intuitive [to use] the icons” [Participant 22]

*Attitude towards using technology.* 14 all the participants indicated that using the Driving Habits System makes more interesting and fun to drive: “It was fun to put the tablet over the car dashboard, I found the buttons accessible” [Participant 21]

*Social influence.* 18 of the 23 participants indicated their desire to show the Driving Habits System to their family and friends. In other hand, only 9 of the 23 participants indicated that their passengers were worried about the use of the Driving Habits System, because it could be associated to driving risks related with distractions. “When driving with a passenger, he demanded me to put attention in driving instead of attending the system, sometimes he felt that I’m being more focused in the system” [Participant 1]

*Facilitating conditions.* As 19 of the 23 participants owns an Android compatible device, and all 23 participant’s vehicles are provided with an OBD-II interface, they didn’t find any technical issue regarding the use of the Driving Habits System. As participants in the study we also provide them with the Android tablet.

*Self-efficacy.* 21 of the 23 participants answered that the Driving Habits System allows them to realize their usual activities and solving its problems without needing any help. They declared that even in some cases, passengers without any previous instruction got proficient operating the system, and taking the responsibility of answering the context surveys on some detected events: “[I didn’t label some events], because [the passengers] heard the voice and they already knew that I’d braked or accelerated, and they provided an answer, the system doesn’t interrupt us, they really liked” [Participant 23]

*Anxiety.* Only 9 out of the 23 participants responded having a concern about using the system, and 14 of them indicated being concern about having an accident. “I have three concerns: one: distraction, two: causing an accident, three: getting a ticket because I’m driving distracted” [Participant 6]. Despite those feelings, only 2 participants indicated being uncomfortable about using the Driving Habits System.

*Behavioral intention to use the system.* 16 of the 23 participants said that if they have access to the Driving Habits System, they would use it, and 13 of the 23 participants indicated that if the Driving Habits System were public available, they would use it because their characteristics. "I would use it when driving alone, because you don't feel so lonely, [the Driving Habits System] it becomes your companion" [Participant 20]. The intention of use would be influenced also by the possible positive contribution to their community and the society well-being product of using the Driving Habits System.

*Perceived safety.* 9 of the 23 participants expressed that the Driving Habits System could be insecure. They explained that the system demands for attention in case of committing many driving events. That's why some drivers opted for not labeling more events. "The times when I provided feedback was when someone was with me [a passenger], then it could be better to use voice commands" [Participant 7]

## Driving Behavior Awareness

*Individual driving behavior awareness.* Table 5 details the five questions from the Spanish-adaptation of the Driving Behavior Questionnaire and the quantitative results of this survey. As mentioned in the study design section, participants identified themselves as good and safe drivers, and this perception had not significant changed after the study intervention. When using a t-Student test, we did not find a significant difference in this set of questions, but this is reasonable due to the short period of time that the participants used the system. Despite this, some participants expressed the system did increase their awareness about their own driving profile and how their emotions could impact their driving in specific situations. "You answer that you're happy, and then, you start to drive, and it notifies you about several events, it makes me think that my emotional status in fact affects my driving, sometimes when I'm in a hurry, it's better to breathe and relax and avoid committing an imprudence for being rushed" [Participant 13]

**Table 5.** Change of perception

| Question | Pre-intervention | | Post-intervention | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| Im a good driver | 4.174 | 1.072 | 4.091 | 0.868 |
| Im safe as a driver | 4.087 | 1.276 | 4.455 | 0.8 |
| I commit mistakes as a driver | 2.957 | 1.397 | 3.227 | 1.307 |
| I avoid to break the law as a driver | 4.087 | 1.125 | 4.045 | 1.133 |
| My emotions affect my driving | 3 | 1.128 | 3.227 | 1.066 |

## 4 Conclusions and Future Work

Our results indicate that the Driving Habits System was useful, and easy to use and learn. Drivers explained the reason of 42 % of the aggressive behavior events, and 34 % of them were related to external factors, showing how the problems on the urban infrastructure could induce a bias in the aggressive driving assessment when used in our cities. Some participants expressed concerns around safety. Participants commented they were slightly distracted by the notifications being displayed by the system, and in numerous occasions they did not answer system's requests, as they preferred to direct their full attention to aspects related to driving instead of focusing on interacting with the system. Nowadays, most vehicles allow to deactivate some input features available in the vehicle's dashboard to avoid traffic accidents; doing the opposite, like in our case, perturbed some participants. This opens up questions around the proposal of appropriate "vehicle micro interactions" to investigate how long a participant is willing to interact with the system while driving, and when and how these micro interactions are safe.

Our results also show that the interaction modality we chose for our prototype was not the best one. Although, participants appreciated the use of a voice synthesizer to gain awareness of their driving behavior, they regretted the absence of a similar input modality. Not having a way to input feedback through voice entry commands also reduced the number of events participants labeled – only 42 % of all the aggressive behavior events were explained. The use of a full and bidirectional voice interface, with anthropomorphic characteristics, that is, to use natural language and speech, will heavily improve and simplify user interaction. Our findings also indicate that passengers played an active role as copilots, and helped drivers by interacting with the Driving Habits System. This shows that systems designed for vehicles use must take into consideration collective experiences. This requires systems to adapt their behavior to avoid interfering in the social experience that may happen when having a group of people in the vehicle, as our design somewhat interrupted conversations. Context detection mechanisms to inform when and how to provide notifications will make a more enjoyable experience for the group of people in the vehicle. Alternatively, passenger-only options could facilitate the capturing of data and user interaction.

Our study is limited by the reduced number of participants, and the limited variation in age and driving profiles of our recruited participants. In consequence, our findings cannot be generalized. However, it is important to note that our aim was to exemplify the potential impact of having such a tool in a specific context – like the city of Ensenada. Also, as our study was short and although we had some insights that participants changed some of their driving habits, we could not answer questions around behavior change and demonstrate how permanent this change could be.

As future work we aim to explore the characteristics of the appropriate in-vehicle micro-interactions for finding the right balance that allows raising continuous awareness on aggressive driving without increasing the risk perception as our current design did. Also, exploring new useful incentives. Incorporating features into our system to allow participants take advantage from the collected data from other drivers on road conditions and other drivers' status. For example, provide contextual hints to support the decision process of drivers by taking into consideration road issues (*e.g.*, "if you continue driving by this street, you'll find potholes"), and getting feedback from transit or government authorities on the infrastructure problems reported for incentivizing the use and engage participants on data capturing. Also, it is necessary to conduct a longer study aiming to measure the potential change of behavior, in order to find if the use of these systems promotes the adoption of better driving practices and its effects on drivers' awareness.

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