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Unsafe Driving Detection System using Smartphone as Sensor Platform

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Abstract: Unsafe driving mainly includes driving either rashly or driving under the Influence (DUI) of alcohol, is a major cause of traffic accidents throughout the world. In this paper, we suggest a highly efficient system which helps at early detection and alert of dangerous vehicle maneuvers typically related to rash driving. The entire system requires only a mobile phone which will be placed in vehicle and with its inbuilt accelerometer and orientation sensor. After installing a program on the mobile phone, it will compute accelerations based on sensor readings and compares them with typical unsafe driving patterns extracted from real driving tests.

Keywords: Unsafe Driving Detection, Mobile phone, Accelerometer, Orientation sensor.

I. INTRODUCTION

A. Motivation

Number of accidents caused by impairment of alertness in vehicle drivers pose a serious danger to people, not only the drivers who are driving their vehicle but also to the general public pose a serious threat due to unsafe driving [1]. According to the report of U.S. National Highway Traffic Safety Administration(NHTSA), more than a million people have died in traffic crashes in the United States since 1966. During these tragedies, drunk driving is one of the main causes. These tragedies become a major concern about health care sector. According to the Central of Disease control, the annual cost of alcohol related fatalities are more than $51 billion [3]. In a 2009 study by the American Automobile Association(AAA) Foundation for Traffic Safety, "As many as 56% of deadly crashes between 2003 and 2007 involve one or more unsafe driving behaviors typically associated with aggressive driving" [4]. These actions include excessive speeding, improper following, erratic lane changing and making improper turns. Currently many companies, including the Department of Motor Vehicles (DMV), utilize call service systems with "How am I driving?" bumper stickers on their vehicle fleets to monitor driver safety. These systems claim that drivers who know they are being monitored are less likely to engage in distracted or unsafe driving, however, today these systems are ineffective due to the fact that many states prohibit use of cell phones while driving. In order to report an erratic driver, one would need to remember both the number to call and the vehicle ID, or have a passenger.

B. Our Contributions

In this paper, we propose utilizing mobile phones as the platform for drunk driving detection system development, as they naturally combine the detection and communication functions. As a self-contained device, mobile phone presents a mature hardware and software environment for the development of active drunk driving monitoring system. The system based on mobile phone can function effectively on its own because mobile phones are highly portable, all necessary components are already integrated therein, and their communication services have vast coverage. The minimum requirement for such mobile phone platform is the presence of simple sensors, e.g. accelerometer and orientation sensor. Currently, many phones, especially smartphones, meet this requirement. They contain multiple types of sensors, including accelerometer and orientation sensors. And their communication module and speakers are naturally good enough for alerting. Such phones are very popular and widely accepted in our society. We summarize this paper as follows:

- We propose utilizing mobile phones as the platform for unsafe driving detection. To the best of our knowledge, we are the first to introduce mobile phones in the area of drunk driving detection.

- We design the algorithm for detecting drunk driving in real time using mobile phones. We analyze the Unsafe driving related behaviors and extract its fundamental cues based on lateral and longitudinal accelerations of vehicle, which are determined by accelerometer and orientation sensor readings in mobile phones.

- We design and implement the unsafe driving detection system on mobile phones. The system is reliable, non-intrusive,lightweight and power-efficient.

Paper Organization The rest of the paper is organized as follows. Section II presents related work. We extract the cues of unsafe driving in Section III. We present the system description in Section IV. In Section V, we present system Implementation. In Section VI and VII we evaluate our solution and conclude the paper.

II. RELATED WORK

Existing Systems:

There are some existing research on the development and validation of technological tools for driving monitoring. Some of them are known under the name of driver vigilance monitoring, and they focus on monitoring and preventing driver fatigue. In detail,following are the existing systems:-

A. Camera-aided driver fatigue detection system:

In this system Visual observation is used to detect driver fatigue. Zhu et al. have used two cameras on dashboard to capture the visual cues of drivers, such as eyelid movement, gaze movement, head movement and facial expression, in order to predict fatigue with a probabilistic model.

Drawbacks:

- **Camera Performance:**
  - Here performance of camera decreases at night as light inside the car cabin is too low. For that special night vision camera has to be used for night driving, but in terms of cost it will become expensive.
- **Camera Position:**
  - Here camera position should not get disturbed for proper working of the system.

B. Breath-analyzing ignition system (AlcoKey):

The automobile manufacturer Saab has proposed an experimental product AlcoKey which collects a breath sample of drivers before they start the vehicle. Then the AlcoKey's radio transmitter sends a signal to the vehicle's electronic control unit to allow it to be started or not based on the alcohol level in the breath sample. These researches use the interactions between human and vehicle to indicate drunk driving.

Drawbacks:

- Every time breath sample has to be provided for starting the car, which is inconvenient and time consuming.
- The system is hard to implement on current fleet of cars on the road.
- The system is expensive as both ECU and ignition of the car has to be modified.

C. MIROID (A Mobile-Sensor-Platform for Intelligent Recognition of Aggressive)

In the MIROAD system, it used a sensor fusion based on rear-facing camera, accelerometer, gyroscope and GPS, the system was implemented on a smartphone.
The MIROAD system had to be mounted in the center of a vehicle windshield with the rear-camera facing forward, the device flush with the dashboard, and a car adapter attached for power. It used the data set from the sensors to detect driving events and behavior.

Drawbacks:

- The system had to be mounted on fixed place over the windscreen of the car.
- MIROID used multiple sensors such as gyroscope, GPS, camera etc. for detection which is not available on most of the middle range smartphones in the market.
- Due to use of multiple sensors the energy efficiency of the system is quite which is not practical for daily usage of the system.

III. ACCELERATION BASED RASH DRIVING CUES

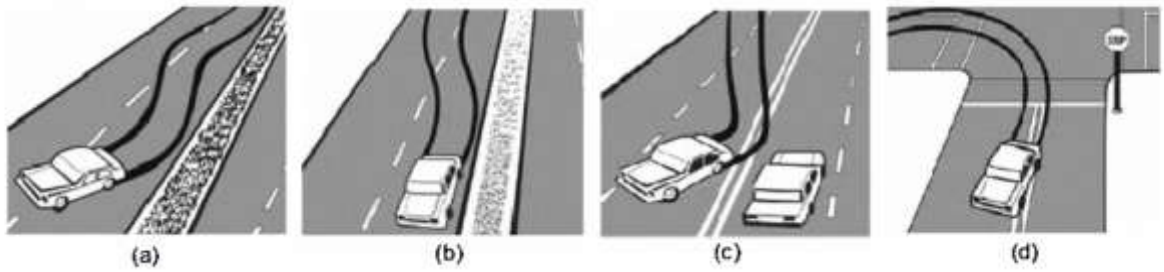

Fig. 1. Problems in maintaining the lane position : (a) weaving, (b) drifting, (c) swerving, (d) turning with a wide radius [5].

In this section, we analyze the Rash driving related behaviors and extract fundamental cues for Unsafe driving detection. Our analysis is based on the accelerations of vehicles. In the U.S. NHTSA's study on drunk driving, the researchers have identified cues of typical driving behavior for unsafe drivers. Based on their work, we summarize these unsafe driving related behaviors into three categories. The first and second category focus on driving behaviors related to vehicle movement itself, such as the movement trace or the movement trend; the third category is about the driving behaviors related to subjective judgment and vigilance of the driver. We present these three categories of behaviors as follows.

- Cues related to lane position maintenance problems: such as weaving, drifting, swerving, and turning abruptly, illegally or with a wide radius.

- Cues related to speed control problems: such as accelerating or decelerating suddenly, braking erratically and stopping inappropriately (e.g. too jerky).

- Cues related to judgment and vigilance problems: such as driving with tires on center or lane marker, driving on the other side of the road, following to closely, driving without headlights at night, and slow response to traffic signals. These are also cues which indicate rash driving.

For the purpose of developing actively detecting system for Unsafe driving, we focus on the cues of problems of lane position maintenance and speed control. We map these cues into lateral acceleration and longitudinal acceleration of vehicles.

A. Lateral Acceleration and Lane Position Maintenance

In general, the lane position maintenance problems result in abnormal curvilinear movements, including weaving, drifting, swerving and turning with a wide radius. They all cause a remarkable change on lateral acceleration. U.S. NHTSA's report gives out the clear illustrations of these situations, as shown in Fig. 1.
As illustrated in Fig. 1 (a), weaving means the vehicle alternately moves toward one side of the lane and then toward the other. Apparently, the lateral movement is caused by a steering wheel rotation toward one direction and a following steering correction toward the other direction. Similarly, the drifting, swerving and turning with a wide radius have the abnormal lateral movements, as shown in Fig. 1 (b)(c)(d).

B. Longitudinal Acceleration and Speed Control in Driving

A rash driver often experiences difficulty in keeping an appropriate speed. Abrupt acceleration or deceleration, erratic braking and jerky stop are strong cues to show that the driver is having unsafe driving behavior. They will all be reflected in the changes of longitudinal acceleration. We assume that the longitudinal acceleration is positive toward the head of the vehicle. The abrupt acceleration of vehicle will lead to a great increase of longitudinal acceleration (positive values). On the contrary, the abrupt deceleration, erratic braking or jerky stop will cause a great decrease of longitudinal acceleration (negative values).

In summary, the patterns of lateral acceleration and longitudinal acceleration of a vehicle may indicate abnormal lateral movements and abrupt speed variations, which reveal the driver's problems in maintaining lane position and controlling speed. These problems are two main categories of unsafe driving related behaviors, and are the strongest cues for detecting unsafe driving. Therefore, the acceleration (either lateral or longitudinal) pattern provides fundamental cues for unsafe driving detection.

IV. SYSTEM DESCRIPTION

A. System Overview

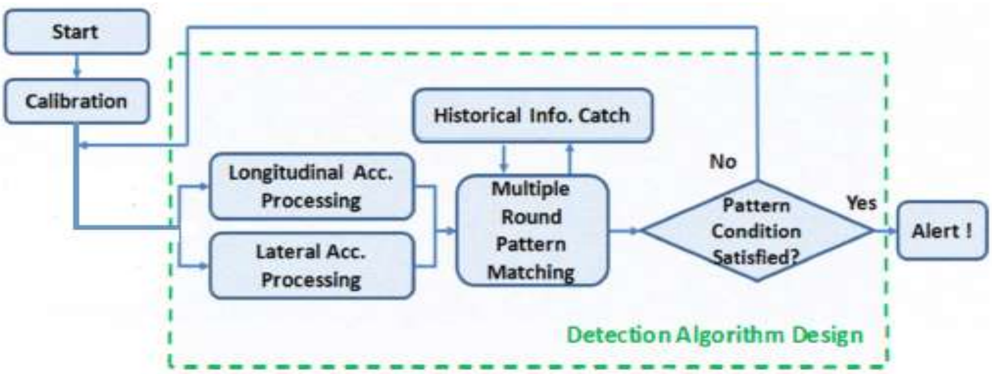

Fig 2. Working Procedure of Unsafe driving detection system

The drunk driving detection system is made up of four components, as presented in Fig. 2. They are (1) monitoring module, (2) calibration module, (3) data processing and pattern matching module and (4) alert module. The third module implements the detection algorithm, as marked by a dashed box. Our design is general, not constrained to any particular brand or type of mobile phone. And our design is also power-aware, as hardware such as the screen is only activated when necessary. The work flow of our drunk driving detection system is also illustrated in Fig. 2. After the system starts manually, a calibration procedure is conducted when the system detects that the phone is located in a moving vehicle. Then the main program launches, working as a background daemon. The daemon monitors the driving behaviors in real time and collects acceleration information. The collected information includes lateral and longitudinal acceleration. They are processed separately, and used as inputs to the multiple round pattern matching process.

B. Design of Algorithm

We design the detection algorithm based on accelerations, and apply it to the mobile phones equipped with 3-Axis accelerometer and orientation sensor. The acceleration readings are usually provided by accelerometers in directions of x-, y-, and z-axis, correspondingly represented by Ax) Ay and Az. For generality, we assume that the directions of X-axis, y-axis, and z-axis are decided by the orientation of the phone. As illustrated in Fig. 3, the x-axis has positive direction toward the right side of the device, the y-axis has positive direction toward the top of the device and the z-axis has positive direction toward the front of the device. A mobile phone's orientation can be determined by orientation angles, i.e. yaw, pitch, roll values that are denoted as B_x, B_y and B_z, respectively. The yaw means rotation around the z-axis, while pitch and roll represent the rotation around x-axis and y-axis. They are also shown in Fig. 3. The values of them can be obtained via the orientation sensor.

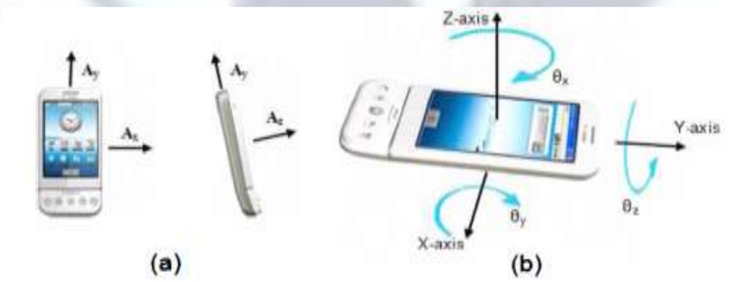

Fig. 3. (a) Acceleration readings in direction of x-, y-, and z-axis with regard to the body of the mobile phone. (b) The posture of mobile phone is decided by yaw (θ_x), pitch (θ_y) and roll (θ_z).

1). Calibration

In real detection process, both the lateral acceleration and the longitudinal acceleration should be based on the vehicle movement direction.The acceleration information of the mobile phone, A_x, A_y should be transformed into the accelerations of the vehicle. In real situations the mobile phone may be laid in the vehicle arbitrarily, neither flat nor heading toward the head of the vehicle. Therefore, we set a calibration procedure to help the system determine what direction is longitudinal. We first obtain the horizontal components of A_x and A_y, which are denoted as A_{xh}, A_{yh}, by Eq. 1.

$$\begin{cases} \mathbf{A}_{xh} = \mathbf{A}_x \cos\theta_z \\ \mathbf{A}_{yh} = \mathbf{A}_y \cos\theta_y \end{cases} \quad (1)$$

The calibration procedure begins to work when the system detects the vehicle starts to move. Its starting movement gives the mobile phone a continuously initial longitudinal acceleration, either forward (to get off directly) or backward (to back off the vehicle first). We denote this acceleration as vector A_I. It is much different from that in human movement. Our experiments show that the acceleration keeps above 2.65 m/s^2 for several seconds (at least 3 seconds) during the vehicle's starting movement. During the human movements even in the running, the average acceleration in a time window of 3 seconds is no more than 2 m/s^2. Actually, the most of accelerations in human movements keep below 1 m/s^2. So it is easy for system to detect when the vehicle starts. A_I's amplitude can be obtained by Eq. 2; while its direction is determined by the direction of A_{xh} and A_{yh}.

$$|\mathbf{A}_I| = \sqrt{|\mathbf{A}_{xh}|^2 + |\mathbf{A}_{yh}|^2} \quad (2)$$

Next, we denote the angle between vector Axh and AI as α, the angle between vector A_{Yh} and A_I as β. These two angles can be calculated by Eq. 3.

$$\begin{cases} \alpha = \arccos(\mathbf{A}_{xh}/|\mathbf{A}_I|) \\ \beta = \arccos(\mathbf{A}_{yh}/|\mathbf{A}_I|) \end{cases} \quad (3)$$

Then, the lateral acceleration vector A_{lat} and longitudinal acceleration vector A_{lan} of the vehicle can be inferred by Eq. 4.

$$\begin{cases} \mathbf{A}_{lat} = \mathbf{A}_{xh}\sin\alpha + \mathbf{A}_{yh}\sin\beta \\ \mathbf{A}_{lon} = \mathbf{A}_{xh}\cos\alpha + \mathbf{A}_{yh}\cos\beta \end{cases} \quad (4)$$

The last step of calibration is to determine the correct direction of two vectors A_{lat} and A_{lan}.

2). Pattern Matching

The system collects the motion data from the accelerometer and orientation sensor continuously at a rate of 25Hz in order to detect specific maneuvers. The Lane maintenance and speed control problem is of interest here. In order to detect when events began, we used a simple moving average (SMA) of the lateral acceleration and longitudinal acceleration.
The DTW algorithm was originally designed as a speech recognition technique by Sakoe and Chiba. Here we extend it to driving event recognition. The algorithm is summarized below.

Consider two vectors: $X = \{x_1, x_2, x_3, \ldots, x_m\}$ and $Y = \{y_1, y_2, y_3 \ldots, y_n\}$ on the left and bottom sides of an m x n grid respectively. Each cell in the grid represents the euclidean distance between each point in the signal:

$$D(i,j) = ||x_i - y_j||$$

The DTW algorithm is designed to find an optimal alignment of two signal vectors. In our case, we aligned the currently detected event signal with the pre-recorded template signals. For each alignment there exists an optimal warping path p, consisting of the minimum distances between points using a distance function D(i; j). The sum of these distances along the warping path p describes the total cost Cp of the alignment path:

$$c_p(X,Y) := \sum_{k=1}^{K} c(x_{mk}, y_{nk})$$

The template with the lowest warping path cost is the closest match.

We have recorded templates of various rash driving behaviors and also of normal driving, the system matches the incoming signals of A_{lat} and A_{lon} with pre-recorded templates to detect unsafe driving.

3). Alert Module

The system after detection of unsafe driving provides a voice alert to the driver so that the driver improves his driving behavior. A SMS alert is also generated with current GPS co-ordinates and vehicle details such as registration number, make, model etc. and sent to the phone number specified by the user during registration on the system.

V. IMPLEMENTATION

We develop the prototype of the Unsafe driving detection system on Android HTC one phone. The phone provides an accelerometer sensor and an orientation sensor. In the following part, we describe the implementation details of the prototype.
We implement the prototype in Java, with Eclipse and Android 4.4.2 SDK. It consists of 11 class files. They can be divided into five major components: user interface, system configuration, data processing and alert notification.

After the system is started, it finishes the configuration automatically. The system keeps running in background as a Service in Android, collecting and recording the readings of sensors. These readings are processed and used to detect unsafe driving. When unsafe driving is detected, the alert notification component works to alarm and remind the driver of dangerous driving and sends a message alert to predefined number. We compile and build the system project, create and sign the .apk file and install it onto HTC one phone by ADB tool. The size of the .apk application file is about 619 KB.

VI. CONCLUSION

In this paper, we present a highly efficient mobile phone based unsafe driving detection system. The mobile phone, which is placed in the vehicle, collects and analyzes the data from its accelerometer and orientation sensor to detect any abnormal or dangerous driving maneuvers typically related to unsafe driving.

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