

Automatic Driving Maneuver Recognition and Analysis using Cost Effective Portable Devices

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ABSTRACT

The use of portable devices for in-vehicle environments has become a major cause for driver distraction which can be a contributing factor in crashes of varying intensity. Despite this fact, the number of drivers choosing to use using these devices while driving is increasing rapidly. On the positive side, smart portable devices are equipped with a variety of useful sensors such as cameras, microphones, accelerometer, gyroscope, etc. which could be leveraged to help reduce driver distraction. Careful utilization and delivery of information extracted from these sensors could potentially prove more useful to drivers rather than distracting them. As a proof of concept, using the sensor information available from an off-the-shelf smart portable device, an automatic system is proposed here for driving maneuver recognition and analysis. Driving maneuvers form the basic building blocks of the driver's intent in completing a route. Being able to automatically identify these and understand how they are performed can help assess the current situation of the driver and evaluate variations in driving patterns. An accuracy of over 90% is achieved in identifying driving maneuvers solely based on portable device sensor information, which is an absolute increase of 15% compared to using CAN-Bus signals. After identifying maneuvers, further analysis is performed to assess deviations from normal driving patterns. In addition to analyzing the entire maneuver, we also examine maneuvers in shorter segments (1 second) to obtain a finer insight into where and how often the deviations occur. Such an analysis provides valuable information on changes in driving habits, and hence can help build and adapt a more comprehensive driving history record.

CITATION: Sathyanarayana, A., Sadjadi, S. and Hansen, J., "Automatic Driving Maneuver Recognition and Analysis using Cost Effective Portable Devices," *SAE Int. J. Passeng. Cars – Electron. Electr. Syst.* 6(2):2013, doi:10.4271/2013-01-0983.

INTRODUCTION

Today, individuals spend more time in their cars than ever before (on average between 10,000-14,000 miles or 300 hours each year). With more time spent in vehicles and a corresponding increase in the number of cars on the roads, safety and infotainment of the commuters have become the two most crucial aspects for auto manufacturers. Although driving might appear an obvious (second to habit) task, it is highly attention seeking, requiring the driver to stay focused on the road as well as controlling the vehicle. Even the slightest lapse in attention is sufficient to cause an accident. The 100-car Naturalistic Study reported that over 75% of crashes and 65% of near crashes were caused due to driver inattention [1]. Hence, care has to be taken such that there are no new features introduced in vehicular environment which require drivers to compromise their attention from the primary driving task in performing other secondary tasks.

The proliferation of smart portable devices has made an impact even in the automotive industry. Given the constant increase in demand for infotainment systems in the vehicular

environment, these devices provide users with the ability to: listen to music, speak over the phone, send/receive emails and messages, browse the web, access navigation and weather assistance systems, search for nearby destinations - to mention a few. Nevertheless, operating portable devices with such features is distracting for the drivers requiring their physical, visual, and cognitive attention. This severely affects drivers' attention towards the road which can in turn compromise their ability to safely control the vehicle. National Highway Transport Safety Administration (NHTSA) has identified the use of portable electronic devices (which includes portable tablets and smart mobile phones) within the vehicular environment as one of the major causes for driver distraction [2].

Considering the infotainment demand from the drivers, many auto manufacturers are cautiously introducing new features into their latest models where the driver has instant access to emails and messages, online and cloud services such as Pandora and Facebook. These services are all available through driver's controls and visible on the dash

board. The influx of infotainment systems into the new generation of vehicles prompted NHTSA to release new guidelines for auto manufacturers to increase occupant safety [3].

In recent decades, the automotive industry has made tremendous advancements in increasing vehicle safety for their occupants. From seat belts and air bags to anti-lock braking systems (ABS), Embedded Stability Program (ESP), Forward Collision warning (FCW), and Collision Mitigation by Braking (CMBB), there are advanced safety features in present cars which constantly monitor the vehicle and its surroundings to ensure occupant safety. This has been made largely possible by a variety of sensors and actuators, and a robust network which connects them through the embedded controllers. This network is called Controller Area Network (CAN) [4] which carries all signals and information within the vehicle including driver controlled signals such as vehicle speed, steering wheel angle, and gas/brake pedal pressure. Since CAN-Bus carries all the vital information on the current state of the vehicle, auto manufacturers ensure the security of the data stream so as to make it difficult for any unintended manipulation of data from unknown sources. Some part of the CAN-Bus information is made available to the outside world through an On-Board Diagnostic (OBD) port. This mainly helps in troubleshooting the vehicle as well as obtaining emission and diagnostics information. Many fleet management systems and also insurance companies such as Progressive [5] use this information to find some basic information on the driver/driving condition. However, the remainder of the CAN-Bus data is restricted from direct access. It is of great challenge to access, decrypt, and sometimes approximate the signals from this restricted area. It should also be noted that the decryption procedure is not necessarily the same for all cars, as manufacturers employ different ways to embed the data. This makes it difficult to develop, test, and deploy advanced safety features in vehicles without the help and support of car manufacturers.

In order for active safety systems to provide proper assistance to drivers, they need to learn information about the driver's intentions while driving. In the changing environment, road and traffic conditions, it is a complex decision making process which helps the driver to control and navigate the vehicle by performing maneuvers [6]. Some of these maneuvers are directed by changing road conditions, while some other are due to changing traffic conditions. There are also evasive maneuvers which the driver performs during critical scenarios. Hence, understanding how these maneuvers are performed becomes essential in driver assistance and safety systems. Research in maneuver recognition is not new [6, 7, 8, 9, 10]; several studies have employed CAN-Bus signals [8, 9] and obtained over 90% accuracy in maneuver identification task. However, since CAN-Bus information is not easily accessible, the use of inertial measurement units (IMU) has been shown to be promising for this task with accuracies as high as 95% [6]. Also, using portable systems in applications such as detecting

driving style and drunk driving [11, 12, 13], suggests that the sensors available in smart portable devices can have a high potential in assisting drivers. Sensors such as accelerometer, gyroscope, magnetometer, and GPS receivers are available in most portable devices, and being used in developing novel applications to help drivers. Special *car mode* features ensue that the driver is least distracted while operating the portable device and driving.

The need for independence from car manufacturers for developing and testing new advanced in-vehicle safety features, and the potential of portable devices to be utilized in driver assistance systems, are the primary motivations in this study. To benchmark the utility of cost effective smart portable devices against the expensive instrumented vehicle, the fundamental task of driving maneuver recognition is performed using available sensor information from CAN-Bus and an off-the-shelf portable device (Samsung Galaxy Tab 10.1"). In [12], the recognized maneuvers were compared with fixed templates to detect any deviations from normal driving patterns. However, since each driver has a preferred driving pattern, in this study a driver specific and adaptive system using the Mahalanobis distance is evaluated on features obtained from portable devices. Results are only dependent on the individual driver's performance, and are independent of the specific vehicle being driven.

SETUP AND DATA DESCRIPTION

There are a variety of factors influencing driving performance, which make it important to understand how individual driving behaviors and vehicle performance as well as surrounding environmental conditions impact every action of the driver. In order to develop safety systems it is imperative to analyze how the three major aspects (i.e., vehicle, driver, and environment) interact. Multimodal data acquisition platforms play a critical role in synchronously acquiring and recording sensor information from all modalities. Researchers in the automotive field have been instrumenting their test vehicles with various sensors and recording platforms to capture and analyze all variable parameters from different modalities. Generally termed as "Instrumented Vehicle", these vehicles can be very expensive depending on the variety of sensors added. However, they provide the most reliable synchronized information possible for the researchers to analyze test data and develop new algorithms and systems for a safe and comfortable drive. Hardwiring these sensors with required additional power supplies generally makes such instrumentation not easily portable and hard to generalize research results across different cars, makes, and models. Additionally, instrumenting more than one vehicle or even maintaining these research vehicles turns out to be very expensive. One such instrumented vehicle is from the UTDive project [14].

UTDrive Instrumented Vehicle

The UTDive project was part of an international collaboration for collecting large-scale vehicle corpora and conducting research on driver behavior modeling and analysis [14]. A 2006 Toyota RAV4 was instrumented (see figure 1) with various sensors carrying information related to the driver and driving characteristics. The following is a list of sensors the Toyota RAV4 was instrumented with:

- Two cameras, one facing the driver and one facing the road, are mounted to capture driving patterns, driving environment, road and traffic conditions. Data from the cameras can also be used as a baseline for ground truth generation.
- A microphone array and a close-talk microphone to capture both driver and any other in-vehicular speech activity.
- Gas and brake pedal pressure sensors to capture the actual pressure with which the driver presses the brake and gas pedals. Each driver has a pattern in which they feel comfortable driving.
- A GPS receiver that provides location information.
- A head sensor to measure the distance each driver maintains to the vehicle ahead.



Figure 1. Instrumented UTDive Data collection vehicle along with all the sensors.

CAN-Bus signals are accessed through the OBD port and decoded to obtain driving information such as vehicle speed, steering wheel angle, engine rpm, and gas/brake pedal pressure information. Without the car manufacturer's support, this is the only option extracting these signals from the CAN-Bus for research purposes.

All the above noted signals are acquired and synchronously recorded through a data acquisition system called Dewetron (DA 121). More details on this instrumented vehicle can be found in [14]. Over 100 drivers have driven

the UTDive vehicle on pre-defined routes with real road and traffic conditions (normal driving conditions). Data collected from different modalities and the research through UTDive project have provided a good insight into various driver and driving characteristics [15, 16]. However, as mentioned before, instrumenting and maintaining the vehicle is both expensive and time consuming and also requires technical skills.

UTDrive Portable Device

Portable devices, especially in the form of smart phones and tablets, have revolutionized the infotainment industry, and majority of drivers use them on a regular basis within the vehicular environment. An off-the-shelf portable tablet is equipped with a variety of sensors which help provide a better user experience in handling the device. Some of the commonly available sensors are as follows:

- Cameras (generally front and back)
- Microphones
- GPS receiver
- 3-axis accelerometer
- 3-axis gyroscope
- Digital compass (Magnetometer)
- Ambient light sensor
- Proximity sensor

The 3-axis accelerometer and gyroscope can be utilized to understand vehicle dynamics. Previous efforts in [6, 8, 11, 12] show that IMUs are useful in capturing vehicle movements. With all these sensors in a portable device, instrumenting a vehicle seems to be easily achievable. Current portable devices are also equipped with a very high computation power. Clocking at over 1 GHz, they have single or multi-core processors along with at least 1 GB RAM which is more than sufficient for basic computations.

To validate the utility and measure the effectiveness of the portable device platform, an application (app) was developed on a Samsung Galaxy Tab 10.1" WiFi for capturing all the available sensor information synchronously along with the audio and video. The tablet was mounted in the instrumented UTDive vehicle as shown in figure 2. The developed app has been tested to work on any Android platform (greater than version 2.2) and on both tablets and smart phones. The application developers chose Android platform for its open platform, easily available API, and online help. However, other platforms and devices (as reported in [12]) could be adopted as well.

The app (as seen in figure 3) has the capability to capture video either facing the driver or the road with desired video quality (to save memory). In addition, using OBD-to-Bluetooth converter (e.g., ELM327), the app is also able to

synchronously record the CAN-Bus signals via Bluetooth onto the tablet.

Designed to minimize excessive battery usage, data from all the available sensors including audio and video are captured in fixed time intervals as selected by the user. With 32 GB of internal memory available on the Galaxy Tab, the app can record over 400 miles of driving data. A car mount is used to firmly fix the tablet on the windshield (in landscape orientation), thereby reducing any undesired device vibrations, as well as reducing a visual obstruction for the driver.

With this portable device in the already instrumented UTDrive vehicle, all driver maneuvers and driving situations are captured simultaneously on both platforms (i.e., the CAN-Bus and portable device).



Figure 2. Inside UTDrive data collection vehicle along with the portable device mounted on the windshield.

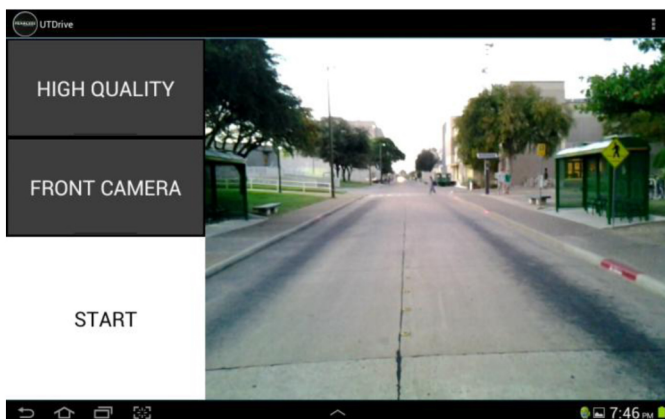


Figure 3. UTDrive portable android application user interface with camera facing the road.

Route and Data Description

As mentioned earlier, driving maneuvers are the basic actions performed by the driver to navigate the vehicle through the surrounding environment. To collect data for the driving maneuver recognition and analysis task, the UTDrive instrumented vehicle with the portable device mounted in it, is driven multiple times by multiple drivers. In this study, for the sake of consistency, two fixed routes (as seen in figure 4) are chosen. The routes pass through a diverse set of road and traffic conditions and also through residential and business/shopping areas as highlighted in figure 4. Each route takes approximately 10 minutes to complete and is driven both in clockwise and counterclockwise directions. The GPS on both devices help in automatically transcribing known maneuver regions such as turns, road curves and stops. Lane change maneuvers are manually transcribed by two independent transcribers using video data to mark lane change boundaries. The maneuvers considered in this study include Right Turn (RTR), Left Turn (LTR), Right Lane Change (RLC), Left Lane Change (LLC), Right Road Curve (RRC), Left Road Curve (LRC), Straight (STR) and Stop (STP).



Figure 4. Two separate routes selected with turns, road curves, stops and straight segments.

Signals from all modalities are recorded synchronously and stored in separate files. However, as this study focuses on maneuver recognition, only relevant signals are used. Since video and GPS co-ordinates are utilized for transcription, they are not exploited for the maneuver recognition task.

Driver dependent CAN-Bus signals such as vehicle speed, steering wheel angle, engine rpm, and gas/brake pedal pressure are used for analysis. These signals have previously been shown to contain reliable information for extracting driving conditions [15].

From the portable device, all the sensors and sensor information are employed which include, 3-axis accelerometer, 3-axis gyroscope, GPS -vehicle bearing and vehicle speed, 3-axis magnetometer, 3-axis gravity, 3-axis linear accelerometer, 3-axis rotation vector, 3-axis