DRIVER’S MANEUVERING RECOGNITION AND ASSISTANCE SYSTEM BASED ON PARTICLE FILTER

(PARÇACIK FİLTRESİ TABANLI SÜRÜCÜ MANEVRA ALGILAMA VE UYARI SİSTEMİ)

by

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Thesis

Submitted in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

in

COMPUTER ENGINEERING

in the

GRADUATE SCHOOL OF SCIENCE AND ENGINEERING

of

GALATASARAY UNIVERSITY

January 2016

This is to certify that the thesis entitled

DRIVER'S MANEUVERING RECOGNITION AND ASSISTANCE SYSTEM BASED ON PARTICLE FILTER

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ACKNOWLEDGEMENTS

Firstly, I would like to thank my supervisor Assoc. Prof. Dr. Tankut Acarman for his supervision, support and guidance through out my research. Without his help and contributions, it wouldn't be possible to finish this study.

I must to express my deepest appreciation to all my colleges at Informatics and Information security research Center affiliated with The Scientific and Technological Research Council of TURKEY for their supports.

Finally, but most importantly, I wish to thank my family, especially my husband for his encouragement, patience and endless love.

28.01.2016
Elif Nurdan Pektaş

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LIST OF SYMBOLS

ACC	Active Cruise Control
ADAS	Advanced Driver Assistance System
AS	Active Steering
BA	Brake Assist
CIB	Collision Imminent Braking
DD	Drowsiness Detection
FCA	Forward Collision Alert
FDI	Following Distance Indication
GPS	Global Positioning System
IPA	Intelligent Park Assist
LDW	Lane Detection and Warning
LKA	Lane Keeping Assist
PA	Park Assist
SIR	Sampling Importance Resampling
UDP	User Datagram Protocol
WHO	World Health Organization
2D	2 Directional

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ABSTRACT

Road traffic accidents are a serious socio-economic problem which causes moral and material cost. To reduce traffic incidents researchers introduce Advanced Driver Assistance Systems. Essentially, these systems provide real-time warning, information about the traffic flow and environment during driving to enhance safety.

In this study, we present a driving assistant system capable of generating warning to the driver about the possible emergency situation. The main aim of the proposed vision-based driver assistant system is to accurately trigger timely warnings with respect to the driving scenarios especially possible dangerous situations. Moreover, the proposed system can be further used for evaluating the driver's driving performance.

The proposed visual-based system consists of two modules; a reference driver model and a driver evaluation system. While building the reference driving model, the particle filter is used. Basically, the particle filter probabilistically evaluates the driver by taking into account surrounding traffic environment and the interaction with other vehicles. Following that, by feeding the obtained reference model with the driver's behaviors during driving, the system gives support to the driver to improve his/her maneuvering tasks in both longitudinal and lateral direction.

The presented system compares the driver's driving reaction by means of a finite set of decision and maneuvering task. As a result of comparison, if necessary, the system provides warnings to the driver. In case of emergency situations, according to the given scenario, the the longitudinal and lateral actions are suggested to the driver by the system.

To evaluate the driver's maneuvers while driving, a fairly large set of driving maneuvering tasks are established. This set includes both longitudinal and lateral vehicle control capability such as overtaking, braking, etc.,. While performing these maneuvering tasks, usage of a cell-phone is given as secondary task in order to investigate the effect of this secondary task on the driver's authority.

Experiments are conducted through a vehicle simulator. For evaluating our system, a testing set containing young, middle-aged and old drivers is used. Each drivers' performance and authority is tested with and without using mobile phone while driving. The success of the drivers is measured by comparing their actions with the best optimal following action obtained from the particle filter. In the light of these information, our proposed driver assistant system evaluates the performance of the drivers in both longitudinal and lateral task.

Keywords: Advanced driver assistance system, Driver maneuver's decision, Particle filter application

ÖZET

Trafik kazaları ciddi maddi ve manevi sonuçları olan sosya-ekonomik bir problemdir. Trafik kazalarının önüne geçmek için araştırmacılar tarafından İleri Sürücü Destek Sistemleri önerilmiştir. Bu sistemler temel olarak sürüş güvenliği sağlamak için sürücüye sürüş esnasında trafik akışı ve ortam hakkında gerçek zamanlı yardımcı uyarılar/bilgiler sunmaktadırlar.

Bu çalışmada, sürüş esnasında oluşabilecek olası tehlikeleri algılayarak sürücüyü uyaran bir sistem sunulmaktadır. Görüntü işleme tabanlı olan geliştirilen sistemin temel amacı olası sürüş durumları ve tehlike senaryolarında doğru anda uyarılar üretmektir. Bunun yanı sıra sistem sürücülerin sürüş kabiliyetlerini tespit etmek için de kullanılabilir.

Geliştirilen sistem iki modülden oluşmaktadır; bunlar particle filter ile oluşturulan referans sürüş modeli ve sürücü değerlendirme sistemidir. Referans sürücü modeli oluşturulurken yol durumları ve çevresel bigilerin olasılıksal olarak değerlendirildiği particle filter sistemi kullanılmıştır. Elde edilen model, sürüş esnasındaki verilerle beslenerek boylamsal ve yanal araç kontrolu görevleri manevra kararları hakkında sürücüye uyarılar sunulur.

Önerilen sistem, manevra ve kararlardan oluşan bir sonlu küme aracılığıyla sürücünün tepkilerini karşılaştırır. Karşılaştırma sonucunda, gerekli görülmesi durumunda sürücüye uyarılarda bulunur. Tehlike tespit edilmesi durumunda, yorumlanan senaryoya göre, yanal ve boylamsal aksiyonlar sürücüye sunulur.

Sürüş manevralarının değerlendirilmesi için geniş kapsamlı manevra kümesi oluşturulmuştur. Bu kümede hem doğrulsal hem de yanal eksende araç hakimiyet kabiliyeti, sollama ve fren yapma gerektiren görevler bulunmaktadır. Bu senaryolar esnasında sürücüye cep telefonu kullanmak gibi ikinci bir görev verilmiştir ve bunun sürüş hakimiyetine etkisi incelenmiştir.

Testler bir similasyon ortamında gerçekleştirilmiştir. Deneyler boyunca genç, orta yaşlı ve yaşlı profillerinden oluşan test kümesi kullanılmıştır. Herbir sürücü için testler esnasında bir normal sürüş gerçekleştirirken bir de telefon kullanırkenki sürüş performansı test edilmiştir. Kişilerin başarıları parçacık filtresinden elde edilen en iyi bir sonraki adım baz alınarak elde edilmiştir. Böylece, bu çalışmada sürücülerin doğrusal ve yanal hareketlerdeki yetenekleri değerlendirilmiştir.

Anahtar sözcükler: İleri sürücü destek sistemi, Sürücü manevra algılama, Parçacık filtresi uygulaması

RÉSUMÉ

Les accidents de la circulation constituent un problème socio-économique grave qui cause le coût moral et matériel. Afin de réduire les incidents de circulation chercheurs introduisent les systèmes avancés d'assistance au conducteur. Essentiellement, ces systèmes fournit une alerte en temps réel et des informations sur le flux du trafic et de l'environnement lors de la conduite à la sécurité renforcée.

Dans cette étude, nous présentons un système d'assistant de conduite qui est capable d'avertir le conducteur de la situation d'urgence possible. L'objectif principal du projet de système d'assistant de pilote en fonction de la vision est de déclencher précision avertissements en temps voulu concernant les scénarios de conduite en particulier les situations dangereuses possibles. En outre, le système proposé peut encore être utilisé pour évaluer la performance du pilote de conduite.

Le système visuel à base proposé se compose de deux modules; un modèle de pilote de référence et un système d'évaluation du conducteur. Bien que la construction du modèle de référence d'entraînement, le filtre à particules est utilisée. Fondamentalement, le filtre à particules évalue de manière probabiliste le conducteur en tenant compte de l'environnement qui entoure la circulation et l'interaction avec d'autres véhicules. Par la suite, en alimentant le modèle de référence obtenu avec le comportement du conducteur pendant la conduite, le système support pour donner au conducteur la direction longitudinale et latérale.

Le système présenté compare la réaction de conduite du conducteur au moyen d'ensemble fini de décision et la tâche de manœuvre. En tant que résultat de la comparaison, si nécessaire, le système fournit des avertissements au conducteur. En cas de situations d'urgence, en fonction de la situation donnée, les actions longitudinales et latérales sont proposées au conducteur par le système.

Pour évaluer les manœuvres du conducteur pendant la conduite, un grand ensemble de la conduite des tâches de manoeuvre sont établis. Cet ensemble comprend à la fois la capacité de contrôle du véhicule longitudinale et latérale tel dépassement, freinage, etc. Lors de l'exécution de ces tâches de manœuvre, l'utilisation d'un téléphone portable est donné comme tâche secondaire dans le but d'étudier l'effet de cette tâche secondaire sur l'autorité du pilote.

Les expériences sont effectuées par un simulateur de véhicule. Pour évaluer notre système, un ensemble de tests contenant les jeunes conducteurs, d'âge moyen et vieux est utilisé. La performance et l'autorité de chaque pilote est testé avec et sans l'aide de téléphone mobile pendant la conduite. Le succès des pilotes est mesurée en comparant leurs actions avec la meilleure action de optimale suivant obtenu du filtre à particules. À la lumière de ces informations, notre projet de système d'assistant de pilote évalue la performance des pilotes à la fois la tâche longitudinale et latérale.

Mots clés: Système avancé d'assistance au conducteur, Reconnaissance de manœuvre du pilote, L'application du filtre à particules

1. INTRODUCTION

Since introduction of the automobile, it has been playing an important role for humankind. The automobile provides not only flexible transportation but also economic, social and cultural benefit for human society. Accordingly, it becomes an integral part of our daily life and effects all aspects of humankind. Unfortunately, its advantages can be turned into accidents and loss of lifes due to human errors.

In addition to obvious monetary costs of vehicles, fuel, and the provision and maintenance of automobile infrastructure, mass mobilization entails further economic, ecological, and social costs: resource consumption, noise and exhaust pollution, waste of time because of the traffic jam and harmful or fatal traffic accidents (Verhoef, 1994; Holden, 2012; de Freitas Miranda and da Silva, 2012; Schrank et al., 2012).

The fatal traffic incident is surely much more important than other problems related to the utilization of automobile. Fundamentally, as the number of vehicles on the road increases, the number of fatalities and injuries increases. According to the World Health Organization (WHO), every year approximately 1.2 million people are killed in road accidents and 50 million are seriously injured (WHO, 2015).

As shown in Figure 1.2, in Turkey for instance, the number of people killed in car accidents has dropped by 25% percent in the past few years reported by the Turkish Statistical Institute and Turkish National Police (General Directorate of Public Security, 2013), even though the number of accident has increased within this time interval. However, globally, the traffic accidents are still main cause of death among people, especially young drivers whose ages are between 15 and 29 years (see Figure 1.1).

In order to reduce the number of road incidents, improvements have to be actualized in a variety of fields not only in vehicle technology, but also education, road infrastructure, education as well driver support systems.

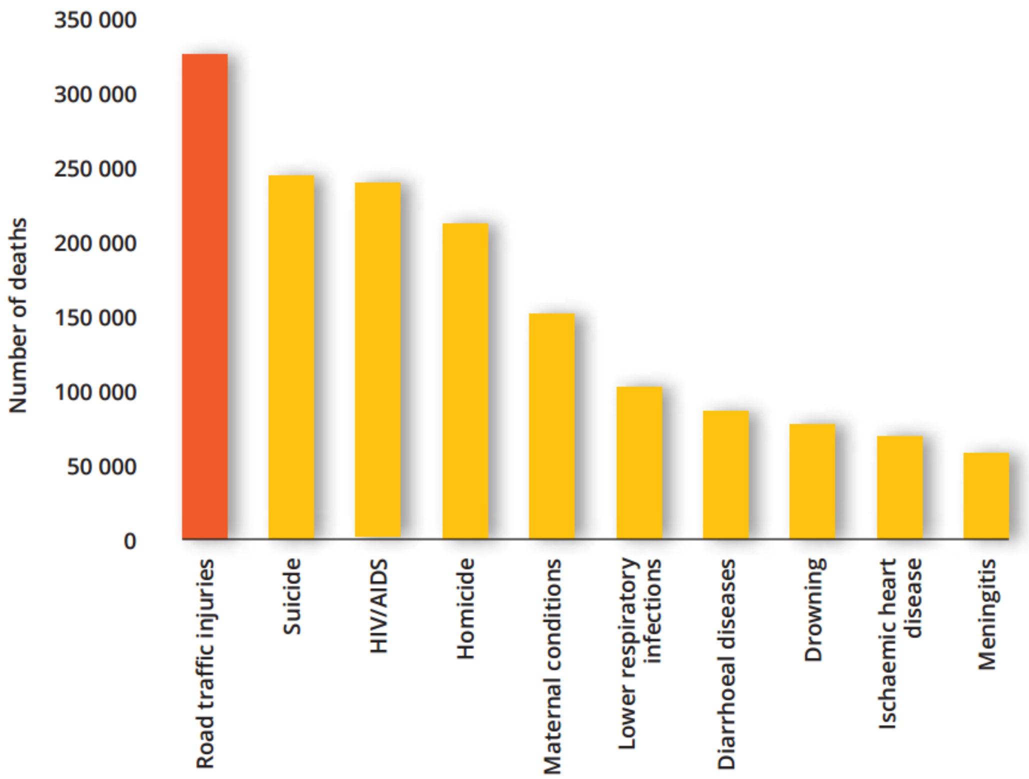
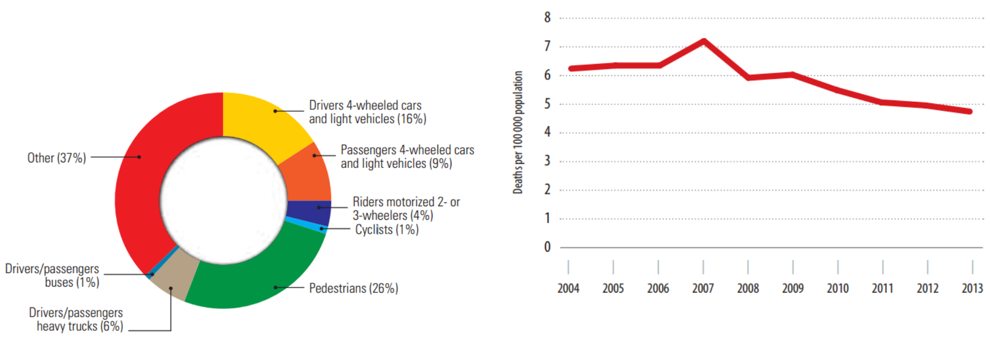


Figure 1.1: Top ten causes of death among people aged 15–29 years, 2012 (WHO, 2015)



(a) Deaths by road user category in 2013

(b) Trends in reported road traffic deaths

Figure 1.2: Traffic accident statistics in Turkey (General Directorate of Public Security, 2013)

To this end, the Swedish Parliament started the "Vision Zero" project on October 1999 to improve road traffic safety (Tingvall and Haworth, 2000). Currently, "Vision Zero" project is adopted by United States, Netherlands, United Kingdom, etc. "Vision Zero" initiative is based on the following principles (Peden et al., 2004)

1. Ethics: Human life and health are a paramount importance in mobility.
2. Responsibility: The providers of the system (regulators) share responsibility with users.
3. Safety philosophy: Road traffic systems should take into account human as beings making errors
4. Driving mechanisms for change: The providers of the system (regulators) are responsible to citizens and must do their utmost to guarantee their safety in the long term.

"Vision Zero" have a great contribution in reducing the number of traffic accidents and injuries. The development and evolution of the in-vehicle technologies, called Advanced Driver Assistance Systems (ADAS), plays a key role in increasing traffic safety. These systems assist and support the driver in different tasks, such as (Geronimo et al., 2010; Brookhuis et al., 2001);

- Adaptive cruise control system
- Collision avoidance (Pre-crash system)
- Lane departure (Lane departure warning system)
- Lane change assistant
- Pedestrian protection system
- Blind spot monitor
- Automatic parking
- Intelligent speed adaptation
- Traffic sign recognition
- Automotive navigation system
- Driver drowsiness detection

1.1. MOTIVATIONS AND OBJECTIVES

It is well-known fact that newly licensed drivers have a higher road accident risk than more experienced drivers. As stated above, it is the young (aged 16 through

25) drivers among all new drivers who have the highest road accident risk (Ferguson et al., 2007; Ouimet et al., 2015; Lambert-Bélanger et al., 2012). A promising way to tackle this problem is to monitor the driver's authority on the vehicle control and provide some useful and vital feedback during his/her driving.

The ultimate aim of our study is to design, develop and evaluate in-vehicle tool that assists the drivers (especially novice) by triggering the necessary warnings to increase safety. The following tasks are achieved in this research:

- Developing and deploying a driving simulator,
- Predicting motion in both longitudinal and lateral direction by using particle filter,
- Providing feedback to drivers for warning purposes.

1.2. THESIS OUTLINE

This document contains 5 chapters which are summarized as follows:

- The chapter 1 introduces the motivation and objectives of the thesis.
- The chapter 2 chapter presents a review of the the technological trends and concepts on driver assistant systems.
- The chapter 3 describes the general architecture of the system and its modules. Firstly, the vehicle simulator used for the evaluation is discussed. Then we present the particle filter employed in finding the best longitudinal and lateral direction during driving.
- The preliminary results of the proposed assistant system for a set of drivers are given and discussed in the chapter 4
- Finally, the chapter 5 provides a summary of the contributions achieved in this study. Furthermore, it presents directions for future work.

2. ADVANCED DRIVER ASSISTANCE SYSTEMS

Advanced Driver Assistance Systems (ADAS) are in-vehicle applications that are designed to help improve drivering safety by performing one or more elements of the driving task, such as parking their vehicle, automatically controlling the speed (i.e. cruise control) or collision mitigation. The Active Cruise Control(ACC) system is the first generation of ADAS introduced into the market by car producers. Then, ACC is extended by integrating speed adaptation and distance-keeping system according to the leading vehicle in the same lane. An evolution of the ADAS is illustrated in Figure 2.1.

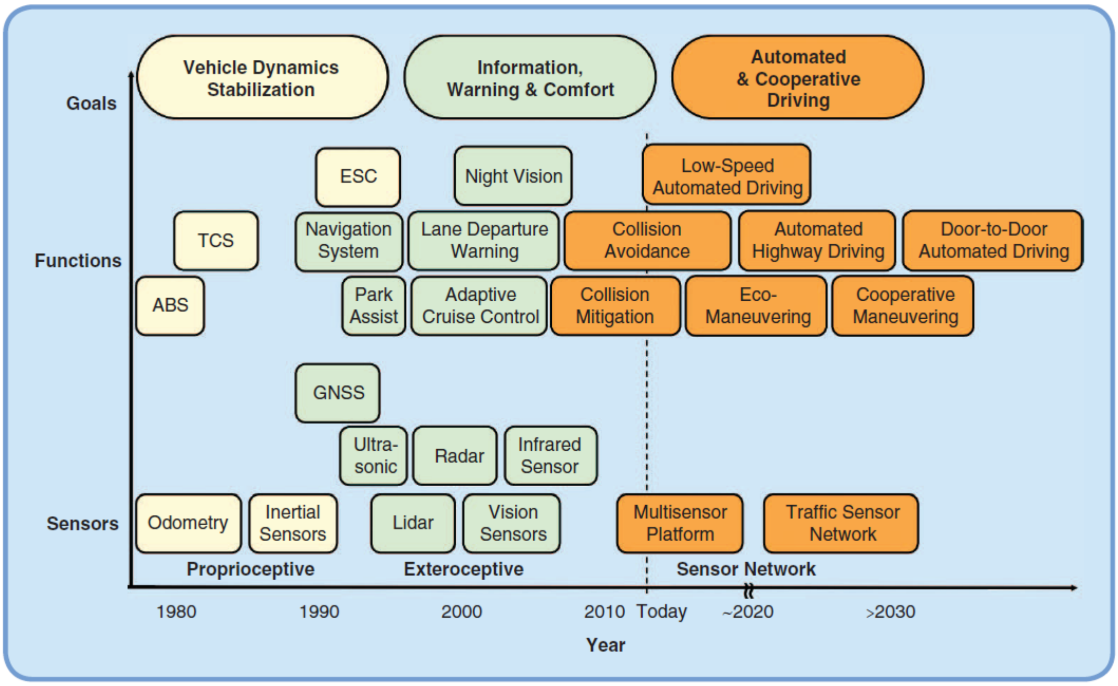


Figure 2.1: Past and potential future evolution of ADAS (Bengler et al., 2014)

ADAS is the keystone of driving safety and driving comfort. Basically, ADAS keeps an eye on the driver behavior and environmental factors during trip. These factors play an important role in determining the functionality of the ADAS. In other words, ADAS depends on understanding both environmental problems in which the driver operates and driver characteristics. These systems make use of the following information from various resources to enhance driving safety;

- The vehicle itself (the vehicle's velocity, steering angle, etc.)
- A navigation system
- GPS based on localization
- Sensors detecting obstacles in the environment, etc.

In general, ADAS can be divided into four groups according to the level of automation (see Figure 2.2). Due to the complexity of driving assistance systems, the boundaries of these groups are not strict. In other words, many of these systems presented aim same tasks.

- Driver information systems
- Comfort systems
- Semi-autonomous systems
- Autonomous systems

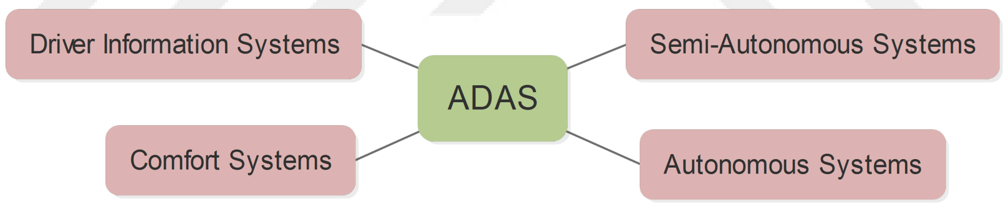


Figure 2.2: ADAS categories based on the level of automation

This classification relies on increasing complexity of ADAS and implications for driving. Driver information systems such as lane departure warning and side warning assistance are already available into market. Comfort systems remain an open area of research. Semi-autonomous systems will integrate comfort system to allow hand-off or foot-off driving experience. Finally, fully autonomous driving is the system that doesn't require any intervention of the driver and controls the car by using environmental sensors and uses decision algorithms according to the current situation.

2.1. DRIVER INFORMATION SYSTEMS

Driver information systems provide information to the driver in the driving task without intervening in vehicle dynamics. Lane departure warning, drowsiness detection and collision warning/avoidance are examples of this systems. Lane detection and tracking systems inform the driver when the vehicle is about to leave its current lane. These systems actively monitor the lanes of the roads by interpreting data from video, laser or other sensor devices placed on the vehicle. Nowadays, many car producers offer such kind of technologies like Lane Keeping Assist (LKA) system.

The goal of collision avoidance; also known as precrash, collision mitigating or forward collision warning, is to inform the driver about imminent collision. In the most cases, once these systems detect imminent collision, they provide a warning to the driver and sometimes take a partial or full actions (e.g. braking or steering) in the case of a failure or inadequate level in intervention from the driver.

An example of collision warning system developed by Mobileye[1] is used in Opel Insignia and Astra as shown in Figure 2.3. This system is mono camera-based system and produces forward-collision warning for impending collision or even for pedestrians(Stein et al., 2014).

Figure 2.3: ADAS categories based on the level of automation[2]

[1] http://www.mobileye.com/

[2] http://www.opel.com/news/index/2015/09/astra-driver-assistance-and-features.html

Another types of driver information system is Drowsiness Detection (DD). The main goal of DD systems is to identify the driver's fatigue level. This system is very helpful when a driver's attentiveness is reduced, especially in long period of driving. Researchers proposed various methods such as image processing, machine learning, neural network, etc. to measure driver's drowsiness (Dinges and Mallis, 1998; Pal et al., 2008; Liu et al., 2010; Lin et al., 2010). Figure 2.4 shows Mercedes's driver drownsiness detection system. As shown in the Figure 2.4, the system employs various sources to detect drowsiness, the key indicator is steering behaviour of the driver.

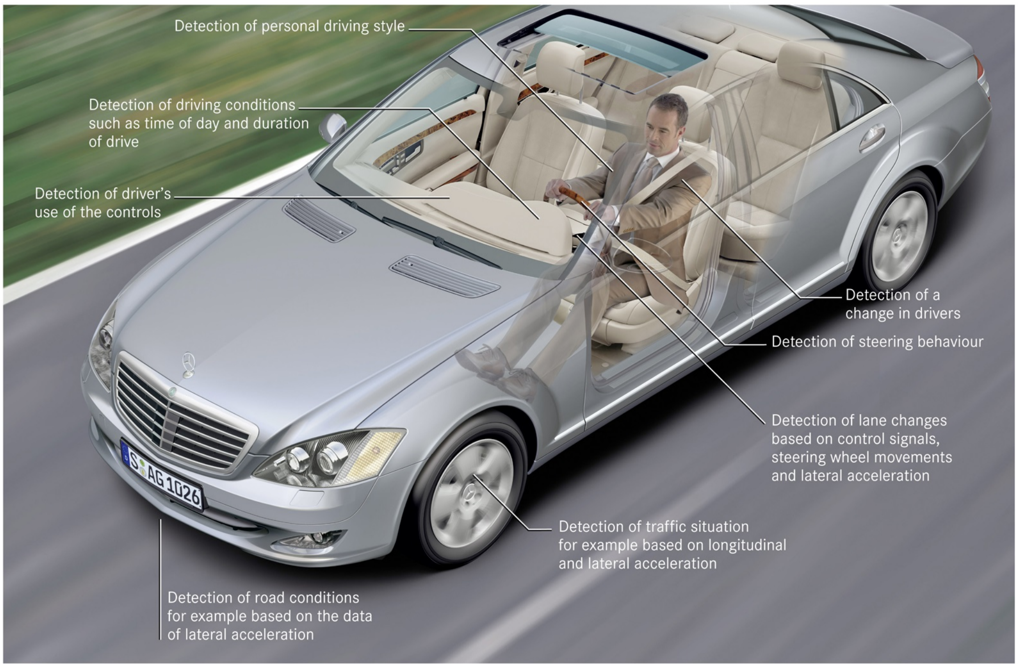


Figure 2.4: Attention Assist: Mercedes' driver assistance system to detect tiredness level [3]

Furthermore, the following driver information systems are available in the market:

- The Following Distance Indication (FDI) informs the driver about the distance to the car.
- The Forward Collision Alert (FCA) provides a auditory and visual warning to the driver about an imminent collision.
- The Collision Imminent Braking (CIB) automatically slows down the vehicle if a possible collision is detected.

[3] http://www.sensormagazin.de/dateien/smonline/redaktion/fachartikel/fachartikel1_sm3_09.pdf

2.2. COMFORT SYSTEMS

Comfort systems are designed to assist the driver in some frequent driving situations by partially taking over vehicle's control. These systems include Adaptive Cruise Control (ACC), Lane Keeping Assist (LKA) or Active Steering (AS), etc.,. The most known example of this category is ACC, which automatically adjusts the speed of the vehicle to maintain a desired distance from vehicles ahead (Rajamani, 2012; Van Arem et al., 2006). Figure 2.5 illustrates the functionality of the ACC:

1. The driver set vechicle cruise control at 70mph.
2. ACC detects a slower vehicle ahead and reduces current speed.
3. ACC adjusts the speed according to the leading vehicle to maintain safe following distance.

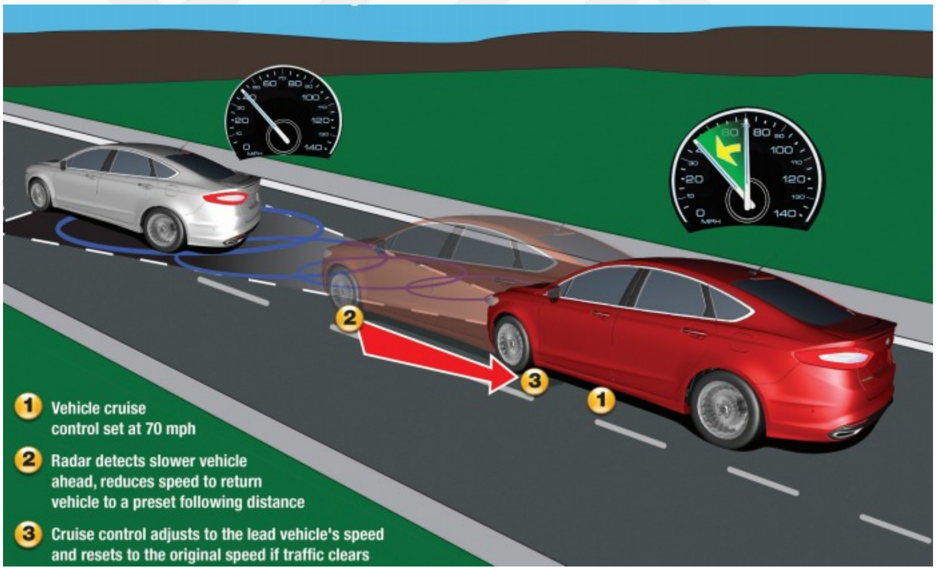


Figure 2.5: Adaptive Cruise Control System [4]

LKA systems are enhanced version of the LDW systems. Instead of solely informing the driver about an imminent lane crossing, LKA systems apply a small countersteering force to aid the driver to stay within lane while attempting to drift out of its lane. Plenty of research and development are being done in this field (interested readers can look at (Mineta et al., 2003; Hwang et al., 2009; Kuehn et al., 2009)). These systems generally use the following sensors:

[4] http://www.holidayfordusa.com/blog/how-to-use-ford-adaptive-cruise-control/

- Video cameras (placed behind the windshield glass)
- Laser sensor (placed on the front of the vehicle)
- Infrared sensors (placed behind windshield glass)

Active Steering is another example of comfort systems. AS is a steering concept that adjusts the steering wheel angle in response to the driver turning the steering wheel at different speeds. This system helps to improve stability at high speed and helps to reduce driver's steering wheel workload at low speed; especially for parking situations and in an urban area traffic maneuvers. Figure 2.6 shows the difference between a car AS on and off.

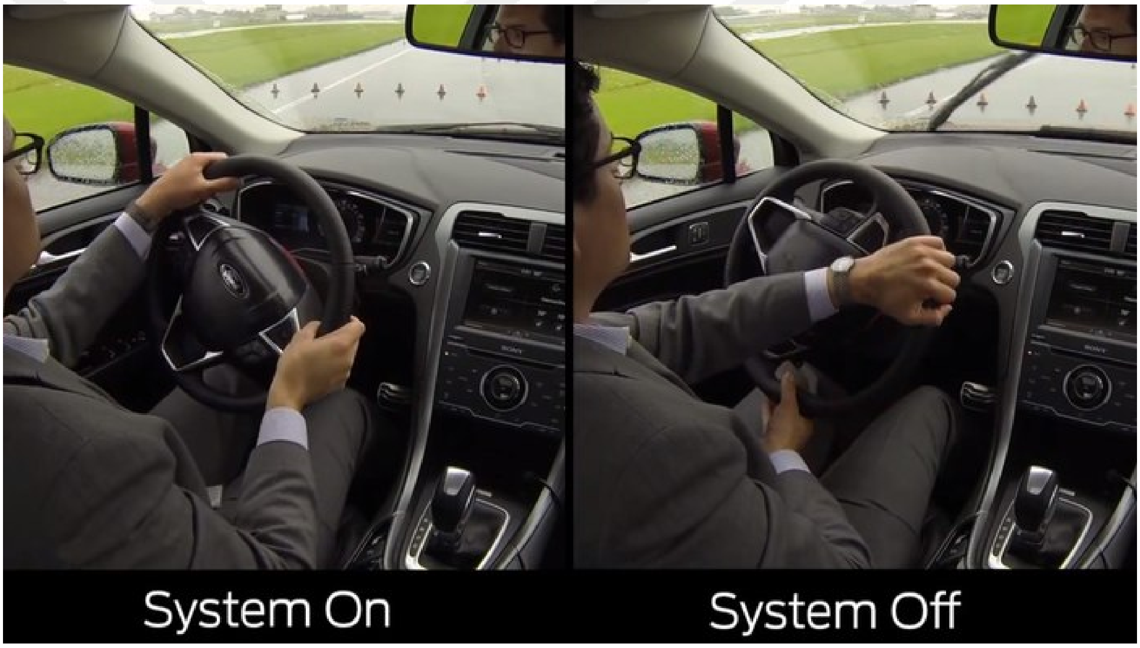


Figure 2.6: Adaptive Steering System [5]

2.3. SEMI-AUTONOMOUS SYSTEMS

Semi-autonomous systems helps the driver while performing complicated maneuvers by taking over the vehicle's control under specific scenarios. The main difference between semi-autonomous and autonomous systems is that semi-autonomous systems require driver involvement, autonomous system controls completely the vehicle.

[5] http://www.gizmag.com/ford-adaptive-steering-system/32413/

Intelligent Park Assist (IPA) systems are one of the famous semi-autonomous systems. Essentially, IPA can steer the vehicle into a parking space by partially taking over the control. Figure 2.7 shows the Ford's active park assists which involves the following steps:

1. Identify a feasible parking space through ultrasonic sensor
2. Prompts the driver to accept PA. Then, PA takes control and steers the car into parking space while the driver operates the gas and brake pedals.
3. PA notifies the drivers about the proximity of the car and objects. However, while PA steering the vehicle, the driver can interrupt the PA by grasping the steering wheel.

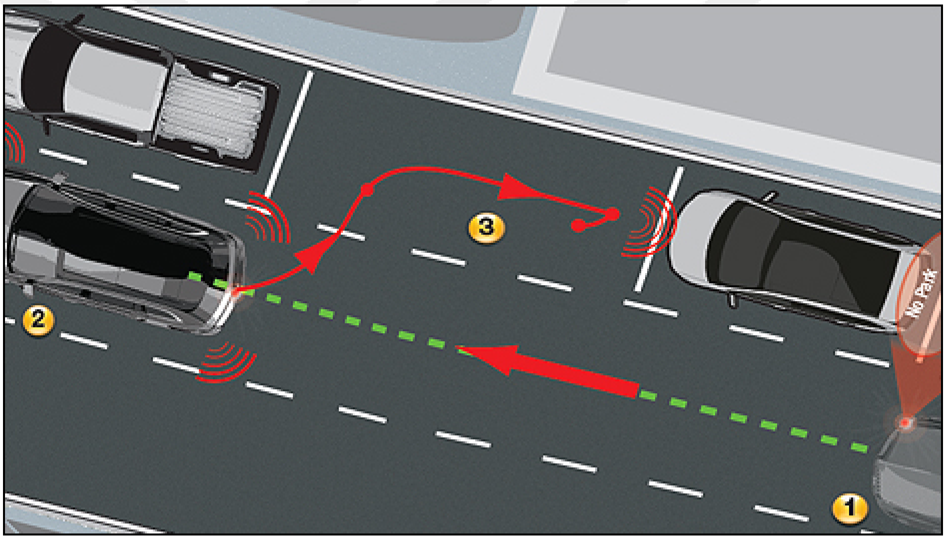


Figure 2.7: Ford's Enhanced Active Park Assist[6]

In order to prevent from collisions or reduce speed in case of collision, researcher introduced Brake Assist (BA) techniques (Page et al., 2005; Breuer et al., 2007; Strohm et al., 2005). Indeed, the primary goal of these systems is to perform an emergency brake once it detects a possible collision. Regardless of the risk level of the situation, however, the driver needs to press on the brake pedal, before the system is activated. Some types of BA performs the emergency brake by taking control of the vehicle. Figure 2.8 shows typical BA system.

[6] http://www.moto123.com/imprimer_article.spy?artid=108365

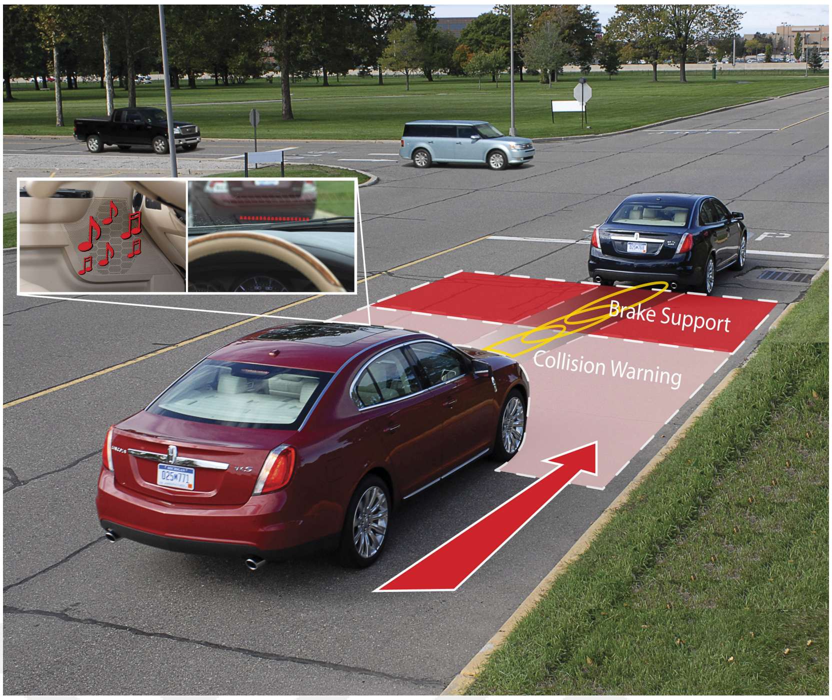


Figure 2.8: An Example of Brake Assist Systems[7]

2.4. AUTONOMOUS SYSTEMS

Autonomous systems, also known as driverless car and self-driving car, control the vehicle without any human intervention. Since they take full driving responsibility, they have to involve the complex environment sensing and situation analysis algorithms. Consequently, developing autonomous car is very challenging and requires appropriate knowledge and skills in various domains. The ultimate goal of autonomous systems, as name suggests, is to produce an autonomous vehicle as shown in Figure 2.9.

Although there are a lot of research efforts in autonomous car (Petrovskaya and Thrun, 2009; Thrun, 2010), only very few will be available in commercial vehicle. This systems must sense the environment with radar, lidar, GPS, odomerty and computer vision techniques.

[7]http://modifiedcarphoto.blogspot.com.tr/2010/09/collision-warning.html

Figure 2.9: Self-Driving Car[8]

[8] `http://www.engadget.com/2012/12/03/volvo-self-driving-cars-2014/`

3. METHODOLOGY

The proposed driver's maneuvering assistance system consists of three major stages. An overview of our system including its main functionalities is presented in Figure 3.1.

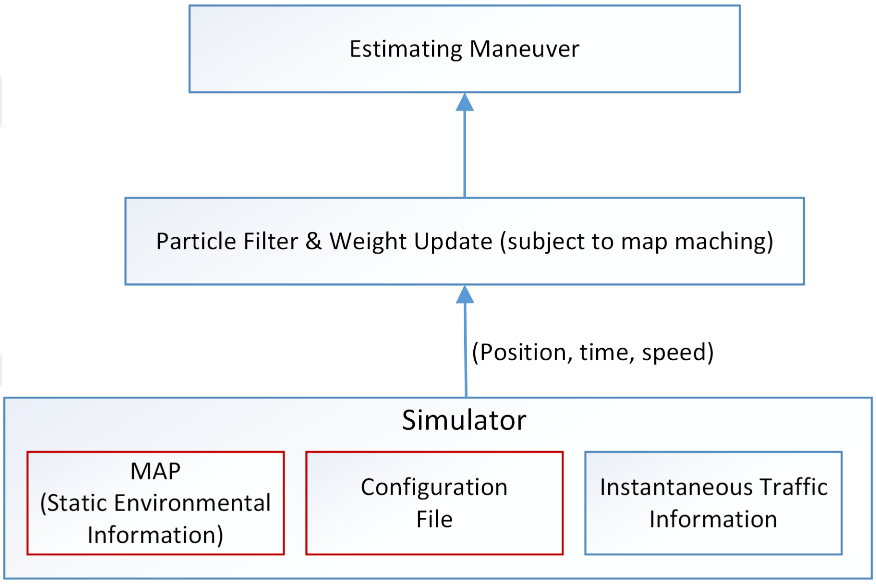


Figure 3.1: Overview of the proposed driver's maneuvering assistance system

The first stage involves collecting data from input and output files of the simulator. The input files include the map and configuration which describes the static environment and information about the others vehicles like the speed, appearance time and direction, respectively. The output file holds instantaneous traffic information like the speed and 2D position of human control car, others car position as well as timestamp. Based on these files, our virtual test environment is built.

At the second step, the particle filter algorithm takes information gathered from previous step as input to decide the following optimal position. Basically, the particle filter probabilistically estimates the position by calculating the distance between particles and environmental obstacles such as buildings, barriers, other moving and parked vehicles.

Finally, after obtaining the following average position of the human controlled car, if necessary, some assistance can be offered to the driver. To determine the action to show to the driver, we used finite state machine. The state of the machine includes longitudinal and lateral actions, e.g. braking, left and right turn, accelerate, etc.

3.1. CAMSIM: VEHICLE SIMULATOR

To perform the driving test, we used the CanSim vehicle simulator created by Can Göçmenoğlu for his graduation project to get the Bachelor of Science degree at Galatasaray University. The reasons for the usage of a vehicle simulator are:

- the possibility to create the same traffic conditions with different test drivers, and the repeatability of the test drives,
- the repeatability of the tests in case of accident, and
- the cost effectiveness.

The CanSim is developed in C programming language by using OpenGL graphics library [1]. It provides an accurate driving experience with the depth in the perception of the graphics and the real-world scenarios.

The map editor of the CanSim simulator allows us creating different maps for different scenarios by using various components of its object library. The library includes the following elements of the traffic and road environment.

- 2-3-4 or 6-lane freeways,
- cross sections,
- road curvatures,
- traveling vehicles,
- speed limitation signs,
- traffic lights with their timings,
- stationary or traveling vehicles with a constant velocity,
- stationary obstacles,
- buildings of various heights

[1] https://www.opengl.org/

- pavement stones.

A screen-shot of the vehicle simulator can be seen in the following chapter in Figure 3.2. Left and right mirrors displaying the oncoming vehicles from the adjacent lanes, and rear mirror displaying the rear traffic is included to create full information about the surrounding traffic to the driver.

Figure 3.2: A Screen-shot from the Can-Sim

The vehicle simulator is also equipped with a driver assistance system which triggers various warnings according to the current traffic situation. The system observes headway distance, lane departure and blind-spots to find out the distance of oncoming vehicles from adjacent lanes.

The simulator triggers audiovisual warnings if the driver ignores keeping a safe headway distance, approaches or crosses the lane boundaries and initiates a lane change maneuver when there are oncoming vehicles on the intended lane. The simulator offers also an overtaking assistant warning the driver when he/she initiates an overtaking maneuver in the case of an oncoming vehicle in a previously specified distance. The overtaking assistant also allows us to determine if the lane is available when the driver turns on the lane change indicator.

3.1.1. DATA COLLECTION

Three different kinds of data are gathered from simulator environment as follows:

1. Map file: It provides information about static global environment such as positions of obstacles, routes and other types of immobile objects and their rotations.
2. Configuration file: It gives information about velocity of each type of cars. Thus, in particle filter, the probability of collision can be calculated.
3. Test drive data: All data concerning the human driver's driving characteristics and surrounding traffic elements are recorded by the vehicle simulator. The data is delivered to MATLAB by an UDP connection with a timestamp. Even the simulator records all events, the information about driver's car's two dimensional position information, its velocity, others cars' position and type is used in our study.

According to the above information we created our matlab simulator to visualize all traffic events.

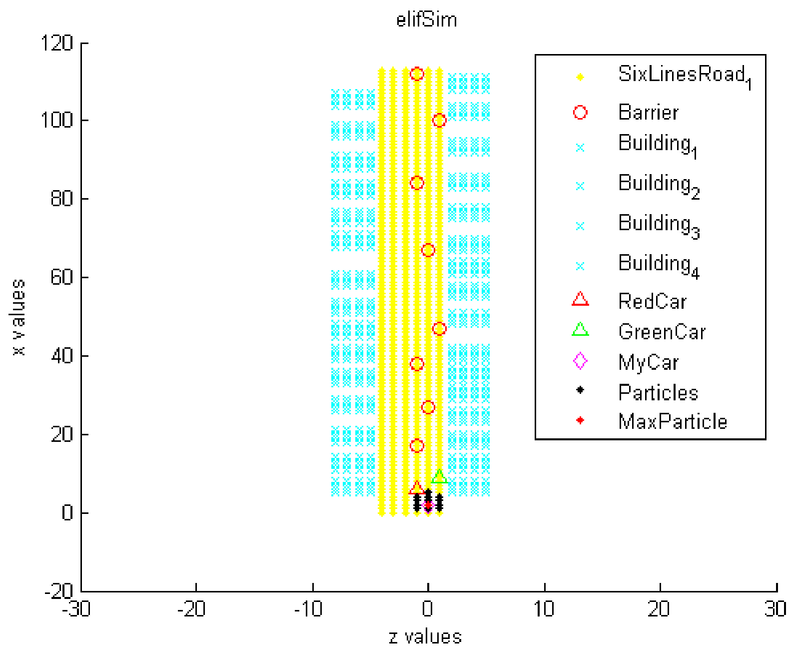


Figure 3.3: Our Matlab Simulator developed for visualization of the driver's maneuvering decisions

3.2. PARTICLE FILTER

Kalman filter (Stauffer and Grimson, 2000; El Najjar and Bonnifait, 2005; Doumiati et al., 2012; Snook et al., 2011) and particle filter (Isard and Blake, 1998; Padole et al., 2010; Peker et al., 2011; Nieto et al., 2012) is the two popular and promising methods in the field of advanced driver assistance system. These methods are widely used in the camera based driver assistance system.

The particle filter is an algorithm to implement a recursive Bayesian filter by Monte Carlo solution. Particle filter is useful than the Kalman filter, especially when the quantity to be estimated has multi-modal distribution.

3.2.1. BAYESIAN FILTER

Consider a system with state x_t at a given time t. Initial system state can be modeled by its probability distribution $p(X_0)$, where X_0 is the state at time $t = 0$. Since the system is a Markov process of first order probability distribution at current time t, depends only on the previous state, which can be denoted by $p(X_t|X_{t-1})$. System can be monitored by sensor measurements z_t, subject to noise. Probability distributions $p(e_{t-1})$, $p(w_{t-1})$ and $p(X_0)$ are assumed to be known but not supposed to be Gaussian (Gustafsson et al., 2002). Probability of receiving measurement z_t given the current state of system is given by $p(Z_t = z_t|X_t)$. Computation of the posterior density $p(x_t|Z_t)$ is memory-less, and complete state history is not needed. Under these assumptions, the posterior density is given as follows:

$$p(x_t|Z_t) = \frac{p(z_t|x_t)p(x_t|Z_{t-1})}{p(z_t|Z_{t-1})} \tag{3.1}$$

$p(x_t)|Z_{t-1}$ is the prediction for the probability of the vehicle's position x_t subject to the history of sensor measurements Z_{t-1}. Prediction is calculated by integrating motion model $p(x_t|x_{t-1})$ over posterior $p(x_{t-1}|Z_{t-1})$,

$$p(X_t|Z_{t-1}) = \int p(x_t|x_{t-1})p(x_{t-1}|Z_{t-1})dx_{t-1} \tag{3.2}$$

$p(z_t|Z_{t-1})$ is a normalizing constant, denoted by k_t. Inserting Equation 3.2 into Equation 3.1, the update statement of the Bayes filter is calculated:

$$p(x_t|Z_{t-1}) = k_t p(z_t|x_t) \int p(x_t|x_{t-1}) p(x_{t-1}|Z_{t-1}) dx_{t-1} \tag{3.3}$$

Posterior probability is calculated from previous position by integrating the motion model and sensor data. Minimum mean square estimate $\widehat{x}_t$ is calculated by use of posterior probability,

$$\widehat{x}_t = \int x_t p(x_t|Zt) dx_t \tag{3.4}$$

3.2.2. PARTICLE FILTER

Particle filter is a numerical approximation to the Bayes Filters. The sampling importance resampling (SIR) algorithm is one of the most widely used sequential Monte Carlo methods, which allow the system state estimation to be computed on-line while the state changes as it is the case for tracking algorithms. A SIR filter usually manages a fixed number of possible system state hypotheses x_t^i, where superscript i denotes the $i-th$ individual particle. These individual particles approximately generate the distribution of the system state, $p(X_t)$. The SIR algorithm is computed at each discrete time step.

Posterior probability $p(x_t|Z_t)$ is approximated by a weighted sample set of particle filters. A basic framework with particle filters for localization problems in different application areas introduced by (Gustafsson et al., 2002). This approach converts computationally expensive integral calculation into the simple summation procedures.

3.2.2.1 Implementation of Particle Filter Algorithm

The stages of the Particle filter implementation can be stated as follows:

- Initialize the individual particles $x_0^i \sim p_{x0}$ for $i = 1, ..., N$
- Measurement update, update particle weights by use of likelihood

$$w_t^i = w_{t_1}^i p(z_t|x_t^i), \quad for \quad i = 1, ..., N \tag{3.5}$$

- Normalize weights such that total of weights is equal to zero, $\widehat{x_t} \approx \sum_{i=1}^{N} w_t^i x_t^i$ is an approximation to Equation 3.4 for calculating current state.
- Resampling: If number of efficient samples is below a certain value, resampling is required. The value for efficient samples, denoted by , is dependent on . If the ESS is smaller than this threshold, only small portion of particles are contributing to the estimation. In this case, particles with small weight are deleted. Weights are normalized at the stage of mean calculation. Figure 3.4 shows an example of the distribution of particles before and after resampling.

$$N_{eff} = \frac{1}{\sum_i (w_t^i)^2} \tag{3.6}$$

- Transition: According to the motion model, particles are updated.

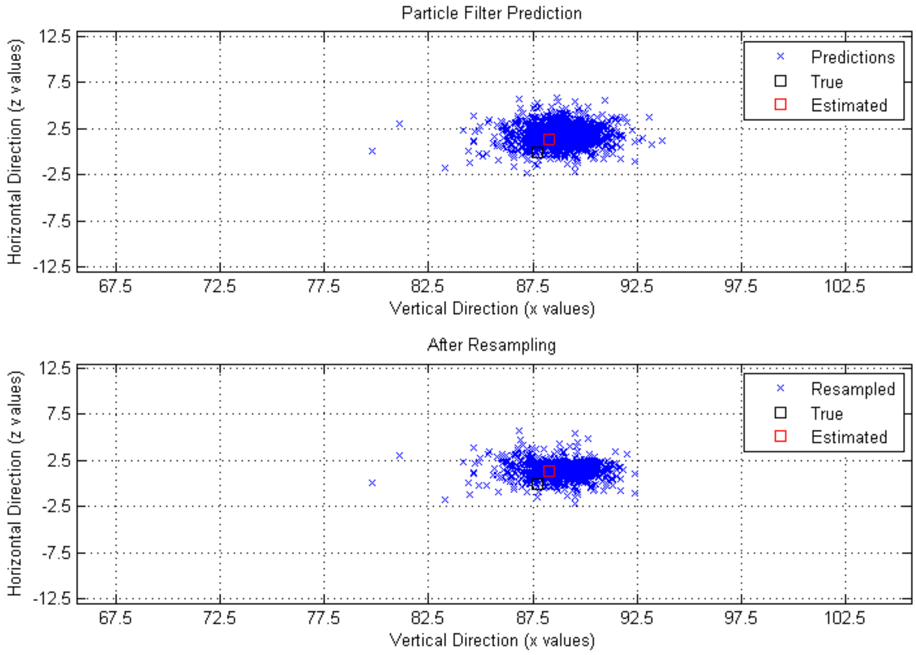


Figure 3.4: Particles Distribution Before and After Resampling

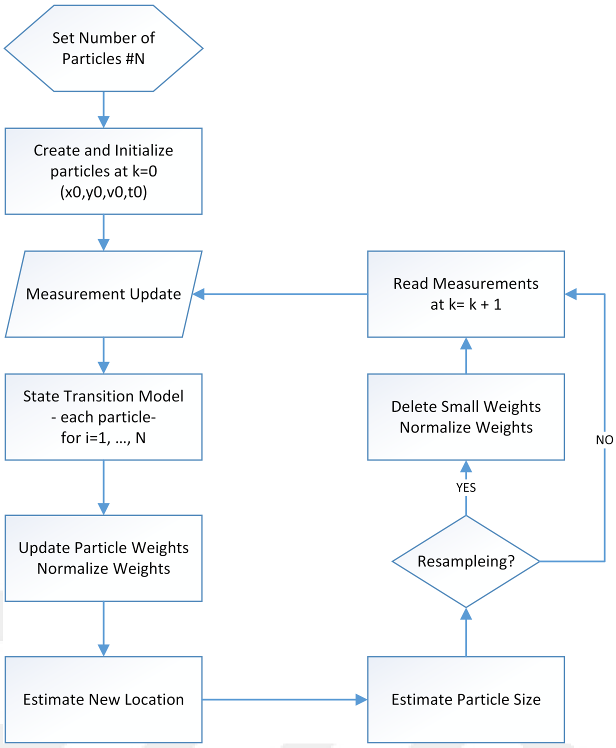


Figure 3.5: Flow Chart of Particle Filter Implementation Algorithm for Maneuvering Estimation

Main stages of the maneuvering estimation procedure by using Particle Filter are illustrated in Figure 3.5. After initialization of particles, the measurement is updated for state transition of the initialized particles. Based on the updated velocity information coming from simulator, denoted by ν_{t-1} at time index $t-1$ in Equation 3.7 and Equation 3.8, a state transition is calculated as arbitrary movement on 2D plane. State transition model is given by:

$$x_t = x_{t-1} + \alpha T_s \nu_{t-1} + w_t \tag{3.7}$$

$$y_t = y_{t-1} + w_t \tag{3.8}$$

where T_s is the sampling interval, α denotes a constant coefficient and w_t denotes uniformly distributed random process noise.

3.2.3. WEIGHT CALCULATION

A different weight is applied to each particle according to the particle location on the map. For each particle, weights are calculated by multiplication of obstacle based probabilistic functions and likelihood function. Detailed explanation of the functions is given as follows:

Reachability search: If the vehicle can reach the particle's pointed position linearly without pass over any obstacles the function returns 1 else 0. Thereby, as our weight calculation is based on multiplication, in case of unreachable target, weight becomes directly 0.

Road probability: This function looks for the location in the map where the particle is assigned. In this case, there are three kinds of possibility;

1. If the particle is on any type of obstacle such as buildings, barriers, parked vehicles or on a wide area then the result is 1.
2. If the location is not on a road but above some kind of non-blocking object, so the point is reachable, however we don't totally trust the layer that's why the result is 0.5.
3. Finally if it's on a road, that's what we search for, the result is 1.

Table 3.1: Location probabilities according to blocking objects

Obstacle Type \ Distance(in meter)	5	10	15	20	25
Approaching Vehicle	10^{-4}	10^{-3}	0.1	0.2	0.3
Not Approaching Vehicle	10^{-4}	10^{-3}	0.2	0.3	0.4
Fixed Obstacles	10^{-4}	2×10^{-2}	0.3	0.4	0.5

The 'forward search' and 'backward search' functions utilize the same logic and the table (shown in Table 3.1) but the opposite direction with each other to find out the function result. The purpose of these functions is searching for the safety of the vertical neighbor areas between 0 – 25 meters distance from particle's location. If they discover any kind of obstacles in vertical range of 25 meters, they use the table to assign the safety probability of the area. In case of, clean search which means the surrounding of the particle is totally accessible without the danger of collision, the functions returns 1 as a result. However, for example, let's assume that the location of our vehicle is (x=20, y=30). Here x is the vertical direction and y is the horizontal direction. Forward search function will search for every 5 units forward and map says that after 15 meters there is a fixed obstacle (barrier) so the function will look at the table cell which consists of (fixed obstacles, 15 meter) and the result will be 0.3. But, if the obstacle is a faster vehicle then ours, then as there might be no possibility for collusion, the function would result 0.2 according to the cell (not approaching vehicle, 15 meter). For right now, even it is impossible to collide with the front vehicle; particle filter takes into account the future events and does not want to be the neighbor of a moving car.

Likelihood function: For each particle, their weight update is calculated based on the possibility derived by the measurements of vehicle position. Probability is calculated under the assumption that the deviations of the vehicle measurements are normally distributed and standard deviation is changed with respect to the confidence values. The weight update of particles based on vehicles' measurements is given in Equation 3.9.

$$\begin{aligned} [w_t^i]_{x_{vehiclePosition}} &= \frac{1}{\sigma_x\sqrt{2\pi}} e^{\frac{-([x_t]_{vehicle} - [x_t^i]_{particle})^2}{2\sigma_x^2}} \\ [w_t^i]_{y_{vehiclePosition}} &= \frac{1}{\sigma_y\sqrt{2\pi}} e^{\frac{-([y_t]_{vehicle} - [y_t^i]_{particle})^2}{2\sigma_y^2}} \end{aligned} \tag{3.9}$$

σ_x^2 and σ_y^2 denotes the variance of the vehicle position measurement error in both of the lateral and horizontal direction, respectively.

Finally, after multiplication of all these functions, particle weight is calculated. However as the sum of the all weights must equal to 1, we normalize importance of each weight by $\frac{[w_t^i]}{\sum w_t}$ formula.

4. EXPERIMENT AND SIMULATION STUDY

4.1. SIMULATION STUDY

For the simulation study, we used 64 bit intel core i7 laptop with 8 GB RAM, MATLAB R2014a and Visual Studio 2012. Visual Studio is used for changing some parts of CanSim simulator to adapt our study. MATLAB helped us to get output data from CanSim and create our visual simulator. All calculations of particle filter are done by MATLAB codes.

The simulation study can be separate to two main parts as follows:

1. CanSim: By CanSim map editor, we created a traffic scenario which consists of two way road with 3 lanes, multiple barriers, buildings, 2 types of non-maneuvering mobile car (fast and slow) and a parked car. Speeds, delays (initial time to appear), intervals (needed time to appear new car) and timeouts (time to disappear of the car) of non-maneuvering cars are set up by configuration file of the simulator. Just one way of the road is utilized and there is not any car which goes to other way. Other way is also prohibited for particles as if it's full of barriers.

   After setting up the road map, a human driver is chosen for driving the vehicle. He/she uses left, right, up (speed up), down (speed down) and space (break) buttons from laptop's keyboard for driving the car.

2. Visual Simulator: As it's mentioned before 3 different types of files (map file, configuration file and output file) are taken into account to re-visualize the CanSim simulator in MATLAB with application of particle filter.

   In our simulator, particle filter helped us to find the average maneuver position for each time interval. For now, the filter works offline because of MATLAB UDP issues. However, if the output data of CanSim can be taken online, there is nothing to prevent our simulator to work online.

   After iterating all of the timelines in the output file by visual simulator, some figures are generated to show differences between particle filter solutions and human driver chooses about maneuvering.

4.2. EXPERIMENTAL RESULTS

In our study, 3 different types of people are chosen to drive the vehicle by using CanSim and 2 different tasks are achieved by each person. People types are as follows:

- Young: 18-25 years old, newly get a driving license, mobile phone addicted
- Middle-aged(adult): 25-40 years old, at least 4 years experienced driver, normal mobile phone user
- Aged: 40-60 years old, experienced driver, not good with mobile phone

The given task types are as follows:

- Attentive drive
- Interrupted drive with a very important text message mission

In the test drives, drivers are warned about that any type of collision is not permitted during the test therefore, if the crash occurs the test is repeated from the beginning. However, speed limits and traffic jams are not important for the test drive so the drivers can focus on to the blocking obstacles and the road. As the young and middle-aged drivers were easily adapted to utilize the simulator thanks to computer games, aged driver was needed to repeat the tasks more than one or twice.

Two types of figure are created by each test drive. The first one (see Figure 4.1a for the young driver in task-1) shows the positions of the human based car and the optimum positions calculated by particle filter in return to drivers' decisions. In the title of the figure there is total error rate which is calculated as in the given formula:

$$(Vertical\ errors + Horizontal\ errors)\ /\ total\ iteration\ number \tag{4.1}$$

Where error means driver and particle filter indicate different positions and the particle believes the accuracy of its decision with at least 90 percent. That means the total weight of the particles that shows that position is at least 0.9 over 1 and total iteration number means the sampling number of the simulation in the output file. Every driver is evaluated according to this error rates.

The second type of figure (see Figure 4.1b for the young driver in task-1) shows the directional differences between the particle filter and the human driver decision. The figure at top of the Figure 4.1b illustrates the horizontal decision differences. In the figure 0 means human and particle filter chose the same lane, positive numbers mean human should pass to lanes that is right-side of the driver (for example 1 means next right lane, 2 means 2 next right lane, etc.) and the negative numbers have also same logic with positive numbers but this time for the left-side. The bottom subfigure at Figure 4.1b explains the vertical decision differences and it has also same logic with the figure at top of the Figure 4.1b , however this time positive means human should accelerate his/her speed and the negative numbers means he/she should decelerate the speed. Both of these subfigures are not directly trust particle filters decisions because of some grid issues, because of that there is a minimum trust percentage of particle filters which is 90. In case of decision variances over 90 percent, we accept that human should follow warnings of the particle filter. Also, in the titles of the each sub figure there is the error rates (vertical and horizontal).

Vertical and horizontal error rates are calculated as follows:

$$xErrorRate \ = \ verticalerrors \ / \ total\ iteration\ number \tag{4.2}$$

$$zErrorRate \ = \ horizontalerrors \ / \ total\ iteration\ number \tag{4.3}$$

As it's mentioned before, there are 2 different tasks for each type of drivers. For the first task we asked our drivers to be very attentive against to other cars, barriers and buildings. They tried to do their best for the test. To evaluate their test drive we chose error rate base scoring and we collected all error rate information to Table 4.1. According to the table, middle-aged and aged drivers did not do any mistake in case of gas and brake but the young driver chose to drive faster than others so he did not use his brake accurately. On the other hand, for the lane changing, young and aged drivers were better than middle-aged driver. Totally, as expected from drivers' real life experiences, the aged driver completed our first task as leader, the middle-aged was the second and the youngest was the worst according to average solutions of our particle filter.

Table 4.1: Error rates of the drivers in Task-1

Errors \ Driver Type	Young	Adult	Old
xErrorRate	0.008	0	0
zErrorRate	0.001	0.003	0.001
totalErrorRate	0.009	0.003	0.001

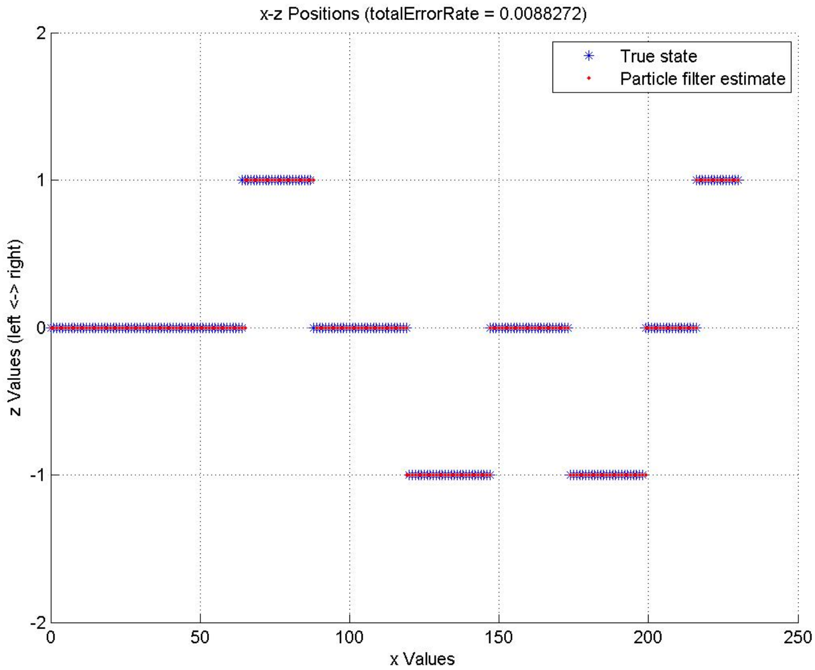
All of the figures of Task-1 that are generated by our simulator for each driver are given in Figure 4.1, Figure 4.2 and Figure 4.3.

The second task was an interrupted drive with an important text message sending mission. Our drivers used the same roads as in the previous task but this time we asked them to write a text message with their mobile phone during the test drive and we evaluated the accuracy of our particle filter. As all the drivers were occupied by text message they could not fully focus on the road. Therefore, the total error rates were higher than the first task as expected. Interrupts generally caused to lately lane changing so the horizontal error rates are augmented (see in Table 4.2). Even the aged driver were very experienced driver, he was not used to send text messages, that's why he finished the second task as the worst driver. Middle-aged driver was the leader and the youngest driver was the second.

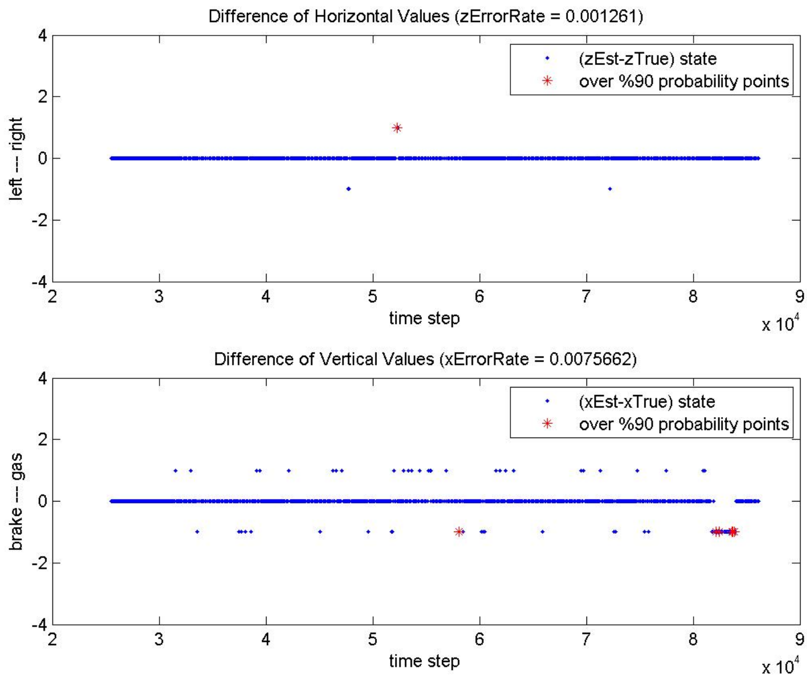
Table 4.2: Error rates of the drivers in Task-2

Errors \ Driver Type	Young	Adult	Old
xErrorRate	0.001	0.001	0
zErrorRate	0.036	0.017	0.092
totalErrorRate	0.037	0.018	0.092

All of the figures of Task-2 that are generated by our simulator for each driver are given in Figure 4.4, Figure 4.5 and Figure 4.6.

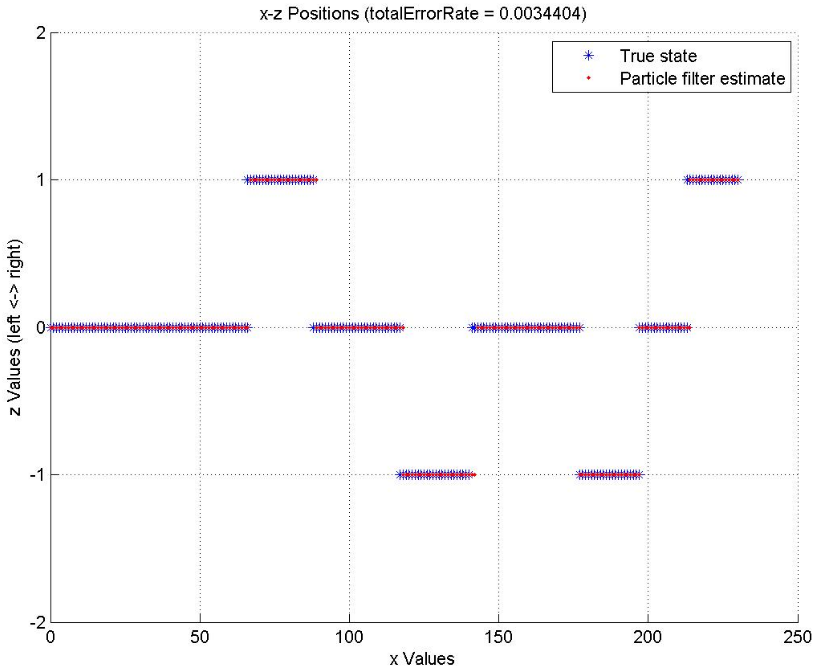


(a) True state and Particle filter estimate positions

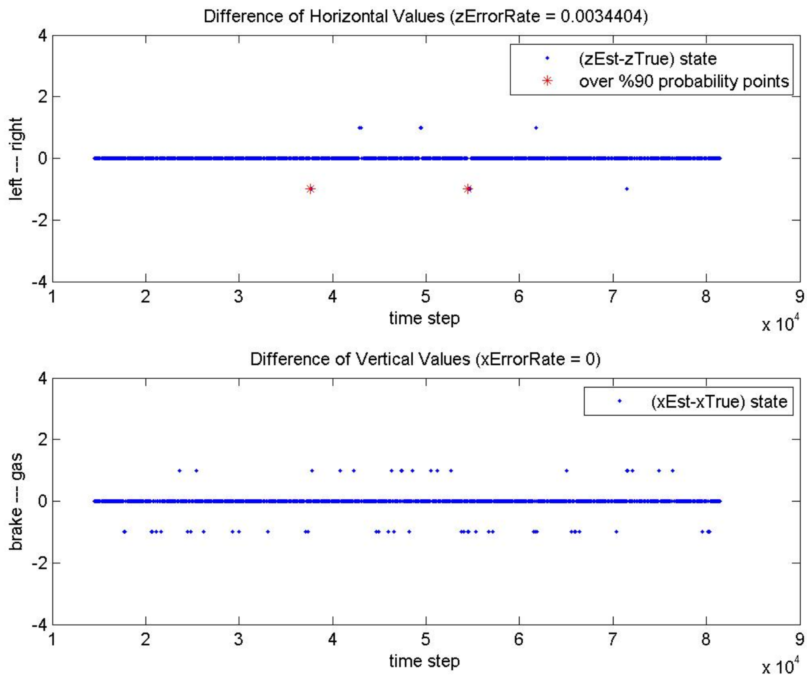


(b) Differences between horizontal and vertical decisions

Figure 4.1: The performance of the young driver for Task-1

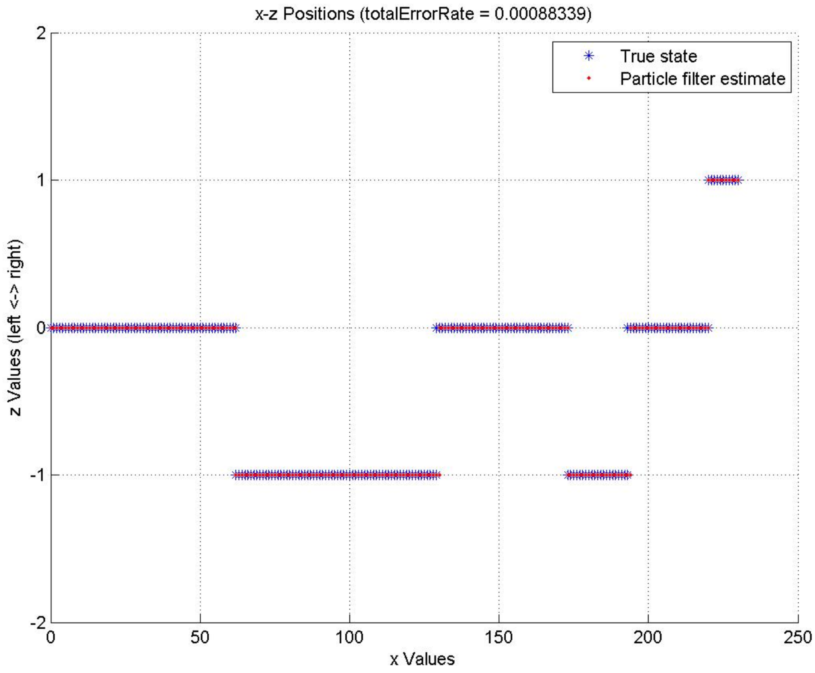


(a) True state and Particle filter estimate positions

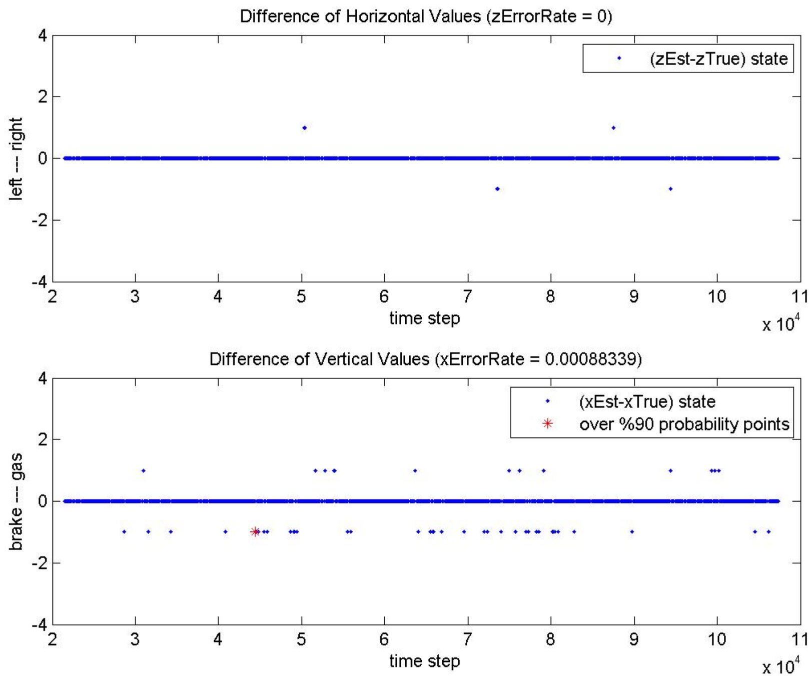


(b) Differences between horizontal and vertical decisions

Figure 4.2: The performance of the adult driver for Task-1

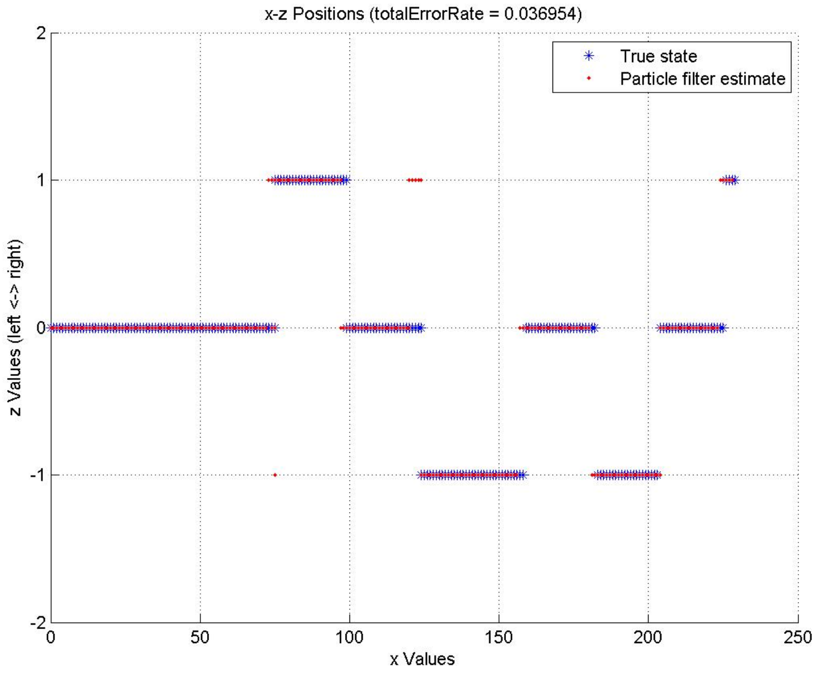


(a) True state and Particle filter estimate positions

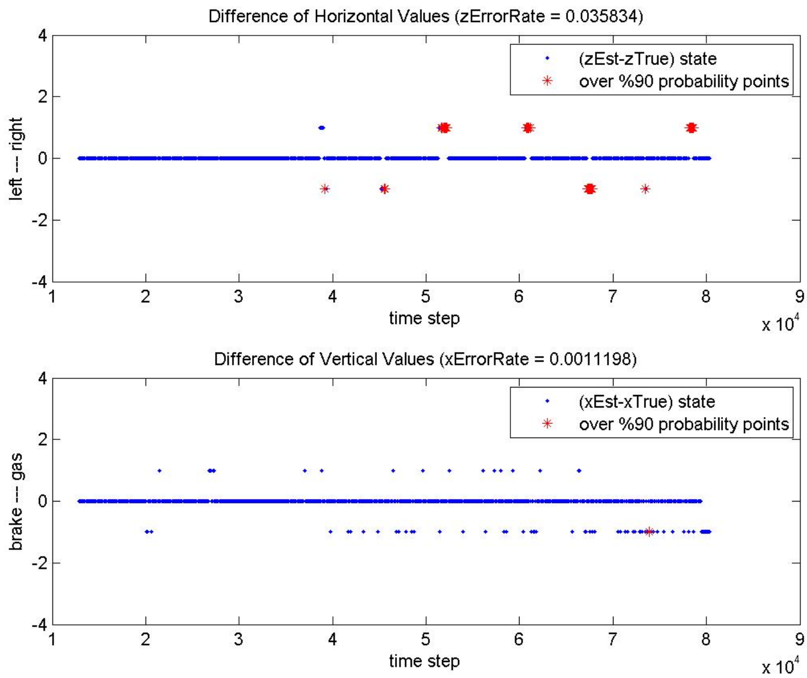


(b) Differences between horizontal and vertical decisions

Figure 4.3: The performance of the old driver for Task-1

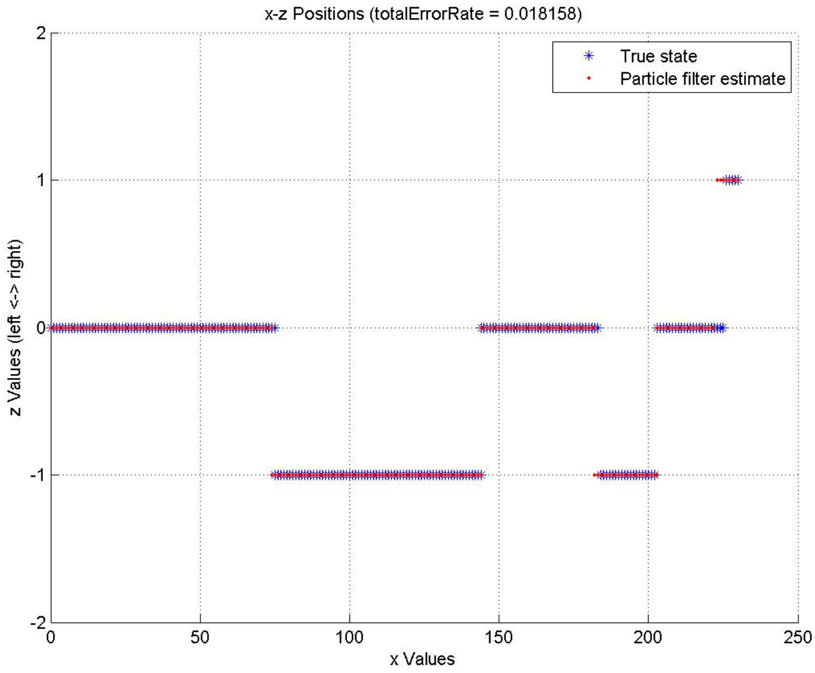


(a) True state and Particle filter estimate positions

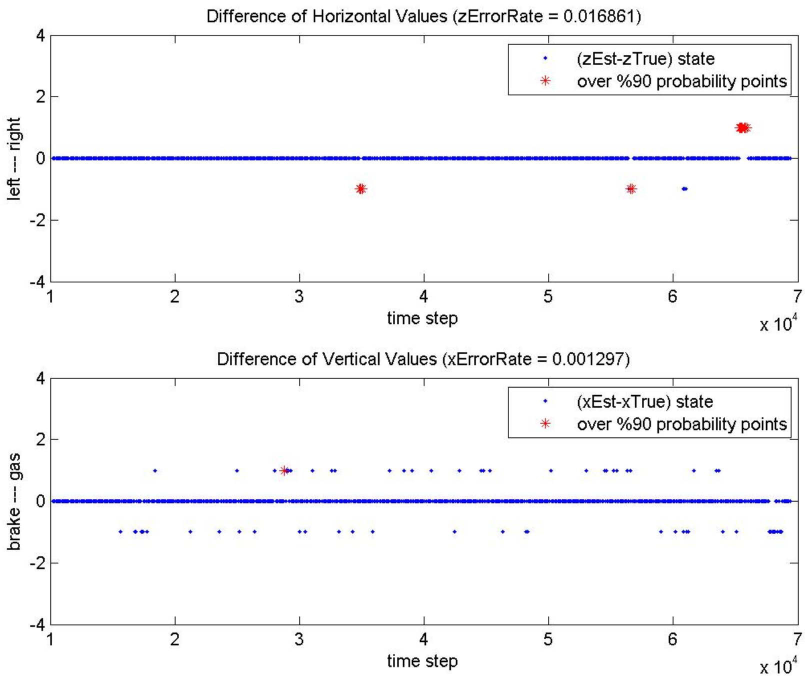


(b) Differences between horizontal and vertical decisions

Figure 4.4: The performance of the young driver for Task-2

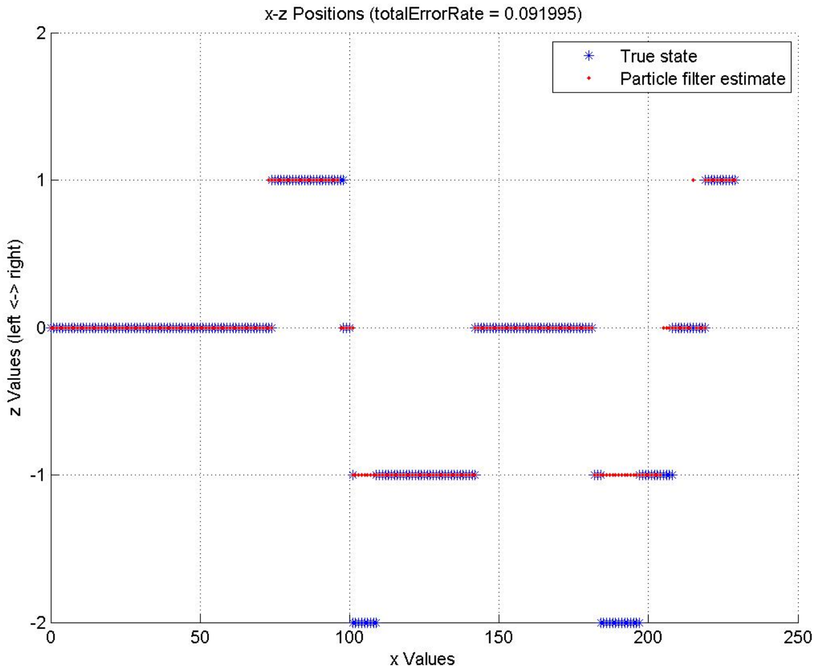


(a) True state and Particle filter estimate positions

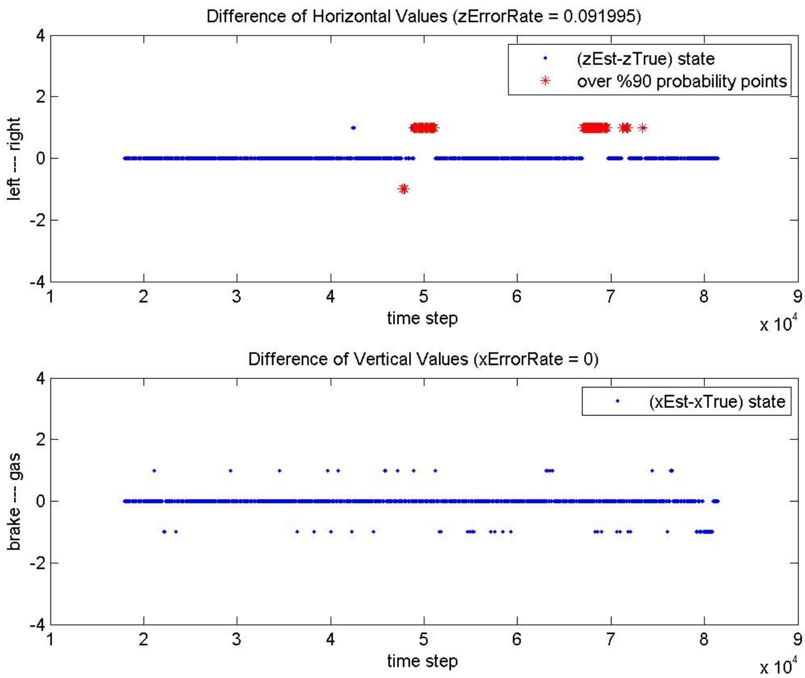


(b) Differences between horizontal and vertical decisions

Figure 4.5: The performance of the adult driver for Task-2



(a) True state and Particle filter estimate positions



(b) Differences between horizontal and vertical decisions

Figure 4.6: The performance of the old driver for Task-2

5. CONCLUSION

Mobility is a key factor in social and economic development. However, it also give rise to vital socio-economic problems, such as accident, pollution and traffic congestion. Researchers have been proposed advance driver assistant systems to solve these problems. In this study, a driver's maneuvering assistance system is presented. A reference driver model is developed using particle filter. The particle filter algorithm takes information from a vehicle simulator used for modeling traffic environment. Basically, the particle filter probabilistically estimates the best position by calculating the distance between particles and environmental obstacles.

Driver's actions taken about the possible maneuvering tasks are compared with the reference model. To demonstrate the feasibility of the presented model, a vehicle simulator is employed. We preferred a simulator because it allows us to repeat the tests scenarios with the same traffic conditions for different drivers.

To evaluate the proposed driver's maneuvering assistance system, a testing set including young, middle-aged and old drivers is used. Each drivers' performance is tested with and without using mobile phone during driving. The success of the drivers is measured by comparing their actions with the best optimal following action obtained from the particle filter. In the light of these information, our proposed driver assistant system evaluates the performance of the drivers in both longitudinal and lateral task and assist the driver.

We are planning to extend the testing set with in terms of the size and diversity of the drivers. Moreover, the proposed particle filter based driver assistance system is considered to test on real-life driving scenarios for future work.

To summarize, our proposed system succeeded in assisting the driver about longitudinal and lateral task. We believe that our proposed system is practical and very useful for drivers.

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