Universidad del Norte
Department of Electrical and Electronics Engineering

Integrated Vehicular System with Black Box Capability and Intelligent Driving Diagnosis

By

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MASTER THESIS

Advisor
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Barranquilla, Atlántico, Colombia
December 2013

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A dissertation presented to the Universidad del Norte in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE

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ABSTRACT

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Nowadays, one of the most important causes of mortality is traffic accidents. According to the World Health Organization (WHO), traffic accidents claim more than 1.3 million annual victims in the world, including young people and adults, being the ninth cause of death around the world. In Colombia, more than 5000 people are victims of traffic accidents among drivers, co-drivers and pedestrians. Scientific community has taken the initiative to develop vehicular measurement systems, as well as tools that seek to evaluate the performance of the driver, with the aim of establishing: a) the causes that may lead to an accident and b) their own security while driving.

This dissertation presents the development of an Intelligent Driving Diagnosis Agent implemented by a proposed Fuzzy Logic algorithm. The approach of the algorithm includes knowledge about Driving Expert Assessment Criteria (driving rules and secure driving techniques) in order to diagnose drivers behavior finding potential and dangerous driving maneuvers.

Experimental testing to the proposed approach has been performed in real environment. All test drivers perform the proposed test in Barranquilla's streets. It is important to note that all tests are performed safely, so that the driver is always focused on driving safely and responsibly. The testing results show that a driving diagnosis can be achieved through the analysis of telemetry information and the proposed intelligent driving diagnosis agent.

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PART I:

INTRODUCTION AND RELATED WORKS

Chapter 1

Introduction

Chapter 1 provides an introduction related to the presented Thesis work. Particularly, research motivation, the aims pursued and the main contributions are briefly describe. Finally, this chapter concludes presenting an overview of the structure and contents of the dissertation.

1.1 Motivation

Nowadays, one of the greatest causes of mortality is traffic accidents. According to the World Health Organization (WHO), traffic accidents claim more than 1.3 million annual victims in the world, including young people and adults, being the ninth cause of death around the world (Organización Mundial de la Salud (OMS), 2013)(Sminkey, 2013). In Colombia, more than 5000 people are victims of traffic accidents among drivers, co-drivers and pedestrians (Universidad de los Andes - Colombia, 2011).

The main causes involving this kind of accidents are: driving under influence of alcohol or psychoactive substances, lack of driving skills, speeding, reckless driving, among others. With these alarming statistics, is important to propose solutions in order to reduce the high rate of accidents and promote prudent and responsible behavior while driving. Those solutions will certainly lead to a significant decrease in the number of fatalities.

In the present time, the scientific community has taken the initiative to develop vehicular parameters measurement tools, as well as tools that seek to evaluate the performance of the driver, with the aim of establishing the causes that may lead to an accident. Many studies have been made so far to identify these factors. Most of them have come to the following points of convergence: mechanical performance measurement of cars driving, erroneous behavior analysis methods –by audio and video recordings-during a driving tour, mathematical modeling of driver behavior, erroneous driving diagnosis through soft computing, management of mechanical information of vehicle through secure vehicular communication networks, road traffic analysis, etcetera. However, there are no studies that integrate an intelligent driving diagnosis system allowing online monitoring of the vehicle status.

Some of these researches have been focused on the variables that can be taken directly from the vehicle, such as yaw angle rate, pedals movement, speed, acceleration, engine conditions, among others. In many of these cases, the system has black box properties (Cambourakis, Kayafas, Loumos, & Tsatsakis, 1995). There have also been studies in which the approach to study is the basic control of allowed speed limits. Some of the outstanding works (Johari, 2008)(Chet, 2003) have developed systems that inform to the driver when he has exceeded the speed limit, avoiding a large proportion of crash risks.

Implementations with video analysis have been important, and have been successfully implemented (Hickman & Hanowski, 2011). Some studies use video monitoring systems to assess risk behaviors when driving vehicles. Studying video records is possible to observe the behavior and dangerous maneuvers made by drivers. Other studies (C.-C. Lin & Wang, 2010) complement this analysis with real-time transmissions video *in situ* along with vehicle location monitoring by satellite.

Regarding driving diagnoses and driving models, several approaches that utilize multiple mathematical models have been presented (Schwall, Bäker, Gerdes, & Forchert, 2003). These designs were based on the use of a dynamic Bayesian network to determine possible diagnosis failures. They have also been presented works where driver behavior has been studied and modeled (Rakotonirainy & Maire, 2005);(Kumagai, Sakaguchi, Okuwa, & Akamatsu, 2003);(Sathyanarayana, Boyraz, & Hansen, 2008) in order to model driver behavior or erroneous detecting abnormal behaviors.

Nowadays, the significance of the research topic has allowed the availability on the market of devices that do a partial control of the vehicle movement state, its reached position and velocity or acceleration during the journey. These are functional prototypes are named as "black box", and are classified as a partial alternative to solve the problem (KCI Communications, 2013)(Mobileye, 2013).

In this research, these problems are solved by implementing an integration of vehicular signal acquisition tool and "driving diagnostic expert agent". This proposed method evaluates vehicular telemetry signals leading to issue a quantitative judgment of driver performance. Through a diagnostic agent of intelligent fuzzy logic (FIS) approximation. This FIS system has been designed to quantify information being considered subjective in the state of the art, since there is a metric that quantifies a proper driving process. Seeking an abstraction of expert knowledge for driving diagnosis process, a quantification of qualitative process based on logical rules that evaluate the integration of such variables –speed, horizontal acceleration and yaw rate angle- is proposed.

1.2 Objectives

This work focuses on the development of an Intelligent Driving Diagnosis Agent implemented by a proposed Fuzzy Logic algorithm. The approach of the algorithm includes knowledge about Driving Expert Assessment Criteria (driving rules and secure driving techniques) in order to diagnose drivers' behaviors, finding potential and dangerous driving actions.

Problem: The need to address Online Driving Diagnosis based on an Intelligent Agent (implemented soft computing techniques) according to some driving rules and secure driving techniques.

General Objective: To develop an integrated vehicular system that deploys black box functions and intelligent driving diagnosis, allowing registering and data analysis based on the state of motion of the vehicle and the driver's actions.

Goals:

- ✓ Adapting a prototype with "black box" capabilities which records and stores driving parameters (yaw angle rate, position, velocity, acceleration, etc.) of interest.
- ✓ Developing an intelligent driving diagnosis tool that uses recorded data to analyze throughout time the actions (maneuvers) performed by a driver while driving.
- ✓ Testing the functionalities of the integrated system in various scenarios.

1.2.1 Thesis Question

The principal question addressed in this dissertation is:

Could a system that uses computational intelligence perform a driving diagnosis under real conditions based on the driver actions (maneuvers) while he is driving?

1.2.2 Approach

This research proposes the design of an Intelligent Driving Diagnosis System based on the approach of an intelligent agent. The proposal seeks to suggest a general but structured scheme for unattended driving diagnosis, according to International laws, traffic regulations and standardized practices of safety driving. This approach incorporates a driving assessment capable to identify potentially risky maneuvers performed by a driver.

Acquisition of vehicle telemetry data is a preliminary and necessary step before driving analysis. This allows identifying the behavior of each monitored signal and finding the relationship between these signals and the maneuver performed by the driver. In addition, the proposed approach seeks to translate the expert knowledge of traffic laws and safe driving practices so that a diagnosis can be made implementing intelligent computational techniques.

In addition to the acquisition, the "intelligent diagnosis system" includes the analysis of monitored variables. This analysis can be adapted to different test scenarios, so that depending on the type of route (road type, number of vehicles, number of turns, etc.) it can set different criteria for the analysis.

Finally, tests were performed by acquiring real-time signals and performing online analysis, so that while the driver is on board, the diagnostic system is evaluating point to point the performance of the monitored information on the set of all variables. This analysis would be supported by a video record inside the vehicle at the same time that the tests were performed.

1.3 Contributions

This Thesis makes the following contributions on intelligent transportation diagnosis:

- *An intelligent approach of an expert agent implemented by fuzzy logics capable of analyze, using different criteria, information related to driving maneuvers using signals referred to vehicle movement (velocity, horizontal acceleration, yaw angle rate). The expert agent approach design takes into account both Secure Driving Techniques and Driving Rules seeking to diagnosis potentially hazardous maneuvers while driving.*
- *The diagnosis driving process, a computational tool, which integrates online and offline diagnostics adaptable to different kind of scenarios, was developed. In addition, a scheme of integrated vehicular systems with black box capabilities was implemented.*

1.4 Reader's Guide to the Thesis

It is presented a general description of the contents of this Thesis dissertation. This Master Thesis is structured in three main parts distributed by chapters.

Part I: Introduction and Related Works

Chapter 1 provides a motivating introduction based on the main issues, objectives and contributions regarding this Thesis.

Chapter 2 provides a general overview of basic information related transport regulation, vehicle telemetry information, computational intelligent system and intelligent transportation systems necessary for the development of the intelligent diagnosis agent approach described in Chapters 4 and 5.

Chapter 3 provides a general survey of the most relevant works related to the research addressed in this Thesis.

Part II: Proposed Approach

Chapter 4 describes the formal aspects of the energy efficiency management model presented in this Thesis.

Chapter 5 presents the implementation of the approach proposed in chapter 4. This chapter also contributes to complete the description of such proposal.

Part III: Results and Conclusions

Chapter 6 provides experimental results of the implemented approach. Empirical evaluations that evidence the utility, pertinence and feasibility of the overall approach are presented in this chapter.

Chapter 7 discusses and analyzes the results, summarizes the conclusions and contributions of the Thesis and outlines the most promising directions for future work.

Chapter 2

Background Information

This chapter introduces and reviews general concepts of transportation regulations, vehicle telemetry information, Computational Intelligent Systems, Intelligent Transportation Systems mandatory for developing the proposed approach.

2.1 Transportation Regulations

Transportation regulations are important to establish several criteria which contribute to secure driving behaviors basis in order to harmonize in a proper way how harmonize (in an appropriate way) the coexistence of different actors involved in the transport framework.

2.1.1 Definitions

Based on "World Forum for Harmonization of Vehicle Regulations on its 160th session" of 2013 (Economic Commission for Europe Inland Transport Committee, 2013) which studies Conventions on Road Traffic in 1949 (United Nations, 1949) and 1968 (Economic Commission for Europe Inland

Transport Committee, 1968) defined the following terms related to vehicles and persons:

- **Driver:** is defined as a person who drives any kind of vehicle, including cycles, or guides animals on a road.
- **Power driven vehicle:** is any self-propelled road vehicle, except for mopeds and tractors.
- **Motor vehicle:** is any power-driven vehicle normally used for carrying persons, goods or other vehicles on a road.
- **Road:** is the entire surface of any way or street open to public traffic.
- **Carriageway:** is the part of a road normally used by vehicular traffic, and a road has one or more carriageways.
- **Lane:** is a longitudinal strip into which the carriageway is divisible, with or without longitudinal road markings, which is wide enough for one moving line of motor vehicles other than motor cycles.
- **Intersection:** is any level crossroad, junction or fork.
- **Motorway:** is a road especially designed and built for motor traffic, provided with separate carriageways for the two directions of traffic, does not cross at level with any road or path, and is especially signposted as a motorway.

2.1.2 International Driving Regulations

1968 UN Convention (also based in its 160th Session), in its first amendment, also defined other topics about driving. Some of them are listed then:

- **Drivers (art. 8):** every moving vehicle shall have a driver, who shall possess the necessary physical and mental skills, knowledge, ability and condition to drive the vehicle.
- **Position on the carriageway (art. 10):** its direction must be the same on all roads in a territory, and the driver shall maintain the vehicle in

the appropriate lane, without taking the carriageway opposite to the side appropriate to the direction of traffic.

- Drivers shall overtake on the side opposite to that appropriate to the direction of traffic, except if the driver to be overtaken has signaled his intention to turn to another road, to enter a property bordering on the road or to stop on that side, and has moved the vehicle with this intention.
- Drivers shall make sure that:
  - no drivers following him has begun to overtake them or has given a warning of their intention to do it,
  - there is not endangering or interfering with the oncoming traffic on the lane which they will enter for overtaking, and there is a sufficient free distance to do it within a short time,
  - there is a sufficiently wide berth to the road users overtaken,
  - They can come back to its right position after overtaking, especially if the carriageway has at least two lanes reserved for traffic moving.
- It is not allowed to overtake other vehicles when approaching the crest of a hill and if visibility is inadequate, on bends.
- It is forbidden to straddle longitudinal markings on the carriageway.
- A vehicle shall not overtake another vehicle which is approaching a pedestrian crossing signaled at the carriageway.
- If a driver perceives that another driver wishes to overtake him, he shall maintain his way and not accelerate.
- Passing to a faster or slower lane is not considered as a overtaking.

- **Passing of oncoming traffic (art. 12):**
  - A driver shall leave sufficient lateral space and move close to the edge of the carriageway appropriate, if necessary. If there is an obstruction or the presence of other road users, he shall slow

down and stop if necessary, in order to allow the pass other vehicles.

    - If there are two vehicles in opposite directions on a mountain road or similar road, the driver of the vehicle travelling downhill should pull in to the side of the road in order to allow passing the vehicle travelling uphill or, at least, reverse the vehicle until it could be to the side of the road.

- **Speed and distance between vehicles (art. 13):**
    - Legislation shall establish maximum speed limits for all roads, including special categories of vehicles or drivers.
    - Drivers must have the vehicle under control, according to the road and its environment, the condition and load of his vehicle, the weather conditions and the density of traffic, in order to be able to slow or stop his vehicle if conditions are not adequate. In this sense, it is not allowed to drive slowly without proper cause, impeding the normal traffic, and no driver shall brake abruptly.
    - A vehicle moving behind another one shall keep at a sufficient distance from it to avoid collision if the vehicle in front suddenly slows down or stop. It also applies for vehicles over 3 500 kg or 10 m that shall keep a longer distance in order to allow other vehicles could overtake it.
- **Maneuvers (art. 14, 16):** if a driver wish to perform a maneuver (pulling out of or into a line of parked vehicles, moving over another side on the carriageway, turning into another road, making a U-turn, change of direction) shall first make sure that he can do it without endangering or impeding other road users, having regard to their position, direction and speed. In all cases, the driver shall give a clear warning of his intention by means of the direction indicators or his arm, which shall cease as soon as the maneuver is completed.
- **Slowing down (art. 17):** if a driver wishes to slow down to an appreciable extent shall make sure that he can do it without cause

danger or inconvenient to other drivers and shall make an appropriate signal.

- **Intersections and obligation to give way (art. 18):**
    - When a vehicle is approaching to an intersection, its driver shall drive it at such a speed as to be able to stop to allow vehicles having the right to pass.
    - When a vehicle emerges from a path or an earth-track on to a road other than a path or an earth-track, its driver shall give way to vehicles travelling on that road. It applies to vehicles emerging from a bordering road.
    - Even if traffic light signals allow passing, a driver shall not enter an intersection if the density of traffic is such that he will have to stop on the intersection, in order to prevent obstructions of cross traffic.
    - If he has entered in an intersection regulated by traffic light signals, he may clear the intersection without waiting for the way to be opened; always this does not impede the progress of other road users moving in the opened way.

2.1.3 Colombian Driving Regulations

Inspired in the rules given by UN Conventions on Road Traffic, Act 752 2002 (REPUBLICA DE COLOMBIA - GOBIERNO NACIONAL, 2002) adequate those rules to the Colombian environment, establishing a driver, passenger or pedestrian must know and meet standards and traffic signals, obey traffic authorities and not obstruct, endanger or harm other persons (article 55). In this sense, a driver shall:

- Drive in his appropriate lane inside marking lines, except for overtaking, crossing or stopping maneuvers, warning previously about the maneuver and keeping safe conditions for other road users (art. 60 – 65, 67, 68).
- Stop his vehicle when:

  - It comes to an intersection without traffic lights or a round-point (arts. 66, 70),
  - There are two vehicles in opposite directions in a mountain road, and it comes downhill (art. 70),
  - A driver must not stop suddenly without proper cause (art. 66).
- Drive in the proper lane when he wishes to turn left or right (art. 70).
- Warning the proper direction when the vehicle comes from a parked vehicle line (art. 71).
- It is not allowed to overtake other vehicles when approaching the crest of a hill and if visibility is inadequate, on bends, to straddle longitudinal markings on the carriageway (art. 73).
- Slow down to 30 km / h when the vehicle roads in residential areas, scholar zones, under low visibility, near intersections and when traffic signals indicate it (art. 74).

Maximum speed limits are:

- 30 km / h when the vehicle roads in residential areas, scholar zones, under low visibility, near intersections and when traffic signals indicate it (art. 74, 106).
- 60 km / h in other urban places for public transport and scholar vehicles, and 80 km / h for other vehicles (art. 106).
- 80 km / h in national and departmental roads for public transport and scholar vehicles, and 120 km / h for other vehicles (art. 107).

Minimum distances when another vehicle is in front of (art. 108):

- 10 m if speed is 30 km / h or less,
- 20 m if speed is between 30 and 60 km / h,
- 25 m if speed is between 60 and 80 km / h,
- 30 m or more, if speed is higher than 80 km / h.

According to the decree 3245 of 2009 annex one (1) (Ministerio de Transporte - República de Colombia, 2009), a new driver must have practical abilities on the road as coordination acceleration – brake – clutch, gearbox control, acceleration and deceleration, urban departmental and national roads driving, plane and slope driving, overtaking and intersections maneuvers, use of carriageways and lanes, reaction and braking distance, bend driving, parking, speed limits, etc.

2.2 Vehicle Telemetry Information

Telemetry is a set of procedures for measuring, storing and sending data magnitudes from a position distant from the place where they are produced, when there is limited access. This information is commonly transmitted by wireless means (Kapolka, Allard, Beyer, & Schang, 2003).

In the case of motor vehicles, telemetry is applied in two main areas: transport of people and goods, and motor racing competitions. In the first case, it is used to monitor the movement of vehicles comprising a transport fleet. It can also have available other options such as travel time, fuel consumption, among others.

In the case of racing vehicles, it monitors the position of the vehicle, as well as all other parameters that can be obtained as speed, temperature of components, hydraulic pressure, aerodynamic measurements and other parameters that describe the detailed status of the vehicle. In both cases, these data are stored on a computer installed inside the vehicle and sent to a digital standardized communication format.

2.2.1 Global Positioning System (GPS)

A key component is the Global Positioning System (GPS) (Nelson, 1999). This system is serviced by government of the United States of America, and is open to anyone who needed to use. The GPS consists of two parts:

- A set of twenty-four (24) satellites orbiting around the earth. These satellites are located in six orbital planes, each consisting of four (4) satellites. These planes are inclined at 55° from Ecuador, and are spaced at an angle of 60°. These satellites are responsible for providing the position in the system (Fig. 2.2.2-1).

- GPS receivers, which are responsible for calculating the position of the object, according to the information received from three satellites or more. The receiver estimates its position by triangulation, with a difference of a few meters. It is also responsible for storing the position and time data to measure travel time and speed, in case it is required to locate an object in motion.

2.2.2 GPS Receiver Communication – NMEA Standard

The GPS receiver (Fig. 2.2.2-1) itself does not have any capacity to send information by wireless to satellites system. However, the National Marine Electronics Association (NMEA) has developed a set of specific recommendations for electronic equipment used in maritime navigation, including a GPS receiver can send stored data to other devices using a protocol for serial data transmission based on the standard EIA - 422, that can be easily adapted to a computer with few changes (Mehaffey, Yeazel, Penrod, & Deiss, n.d.).

NMEA standard consists of sentences, whose header defines the interpretation of the rest of the sentence. Whatever the device or program that reads the data can watch for the data sentence that it is interested in and ignore other sentences. In the NMEA standard there are no commands to indicate that the GPS should do something different, and there is no way to indicate anything back to the unit as to whether the sentence is being read correctly or to request a re-send of some data it could not get. Instead the receiving unit checks the checksum and ignores the data if the checksum is bad figuring.

Essential data from GPS receiver (position, velocity and time) are sent by NMEA RMC (Recommended Minimum sentence C), which format is shown below:

```
$GPRMC,123519,A,4807.038,N,01131.000,E,022.4,084.4,230394,003.1,W*6A[1]
```

Where:

- GP: Beginning characters from the sentence.
- RMC: Recommended Minimum sentence C
- 123519: Data taken at 12:35:19 UTC
- A: Device Status (A=active or V=Void)
- 4807.038,N: Latitude 48 degrees 07.038' North
- 01131.000,E: Longitude 11 degrees 31.000' East
- 022.4: Speed over the ground in knots
- 084.4: Track angle in degrees True
- 230394: Date - 23rd of March 1994
- 003.1,W: Magnetic Variation
- *6A: The checksum data, always begins with

Data are separated with commas in the sentence. The last version of the NMEA standard was 2.3. It added a mode indicator to several sentences which is used to indicate the kind of fix the receiver currently has. This indication is part of the signal integrity information needed by the FAA, and its values could be A=autonomous, D=differential, E=Estimated, N=not valid, S=Simulator. Sometimes there can be a null value as well, but only the A and D values will correspond to an Active and reliable Sentence.

[1]Example taken from and also available on <http://www.gpsinformation.org/dale/nmea.htm#RMC> Based on (Mehaffey et al., n.d.)

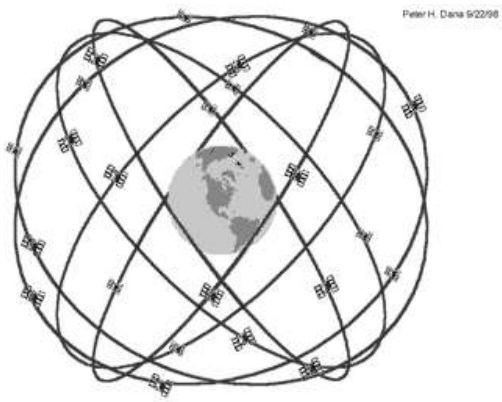

Fig. 2.2.2-1 - Orbits and Satellites Location for Global Positioning System[2]

2.2.3 Video Camera Recording

Most work on road safety operation is based on information obtained through video cameras (Fig. 2.2.3-1). Some of them are used to monitor the driver himself, seeking to determine their level of fatigue, and others are used to monitor the vehicle's environment, the proximity of neighboring objects, such as vehicles and pedestrians, or are in study of the lines of demarcation of the road, in order to detect improper car outlets in his lane. As in any application based on image capture, the results of these developments are subject to the lighting conditions of the target to record (driver's side, driver's head, demarcation of the road, nearby vehicles, pedestrians).

[2]"Satellites – Peter H. Dana" <www.onr.navy.mil>. 2013. 20 June 2013 <http://www.onr.navy.mil/Focus/spacesciences/images/satellites/danagpsorbits.gif>

Fig. 2.2.3-1 - Video Record General Format for Driving Analysis Purpose

2.3 Computational Intelligent System

Newell (Newell, 1994) defines *intelligence* as the degree to which a system approximates a knowledge-level *system*, when an entity rationally brings to bear all its knowledge onto every problem it attempts to solve. It implies the entity has its own goals and objectives for rising. In the other hand, a system is defined as a group of devices or artificial objects or an organization forming a network especially for distributing something or serving a common purpose.

In these senses, a computational intelligent system is one which proposes solutions to complex cases where conventional methods are unable to solve. This type of system combines elements of learning, adaptation, evolution and fuzzy logic to design programs with some level of intelligence. It is based on experience and provides the right decisions despite limitations. Also, an intelligent system must be:

- Able to learn: this implies the system must have a memory for maintaining its learning.
- Autonomous: it must be able to do things by itself or may choose to accept aid, if the system considers it as necessary.
- Able to reason: it must use some form of reasoning, based on known facts and capable of producing insights which later become known facts.
- Able to develop self-awareness: it is related to autonomy, reasoning and learning, but also embodies the need for internal and external senses.

This concept may be subject to ambiguities, and therefore, it is necessary to clarify that a computational intelligence system must meet the mentioned criteria, including treating merely with numerical data and pattern recognition.

Fuzzy logic is a form of multiple-valued logic, which there is more than two logical values (zero or one), and each value has a degree of membership in a fuzzy set, assigned between zero and one. It means that a set of values does not belong entirely to a set but each value could be associated to a set by several compositional rules of inference (CRI). This association, named membership level, is defined by a function that indicates the shape and representation of the fuzzy set. Several membership functions have been developed in order to represent the associate grade with a descriptor, such as: triangular, Gaussian, trapezoidal, sigmoid, among others.

The logic and typical performance of a fuzzy system begins with the way a logic variable is segmented in multiple fuzzy sets, that is named *fuzzifying*. For example, an application in a control system implementing fuzzy logic, an input value is passed through the CRI established for this system. These fuzzy quantities, generated by the CRI, can then be used to determine the corresponding physical actions of controls by a proper interpretation, which is known as *defuzzifyng*.

To implement this approach it is choose a structured inference engine based on fuzzy logic for two main reasons:

- Easy adaptation to different criteria for establishing levels for properly driving behaviors according to Traffic Regulations Laws.
- It allows weighting and integrating the effect of each one variable of the system and determined the influence in the output. Which means that it is possible to quantify a qualitative process both inputs and outputs.

2.4 Intelligent Transportation Systems

According to the Council of the European Union, intelligent transportation system (ITS) is defined as a system in which information and communications technologies are applied in the field of road transport and in and mobility traffic management (European Union, n.d.). It includes infrastructures, vehicles and users, and some capability for interfaces with other modes of transport. An ITS provided by an operational instrument named *ITS application*, through a public or private operator for safety, efficiency, comfort, support transport and travel operations. It could be used by travelers, pedestrians, drivers, road transport infrastructure users and operator, fleet managers and operators of emergency services. In order to specify and deploy an ITS, it shall comply with the following principles:

- Effectiveness, contribution with tangible solutions for solving the key challenges affecting road transportation
- Cost-efficiency between costs and met objectives
- Proportional for different levels of service quality and deployment
- Support continuity of services
- Deliver interoperability: exchanging data and sharing information.
- Support backward compatibility, where the system works with existing systems
- Respect existing infrastructure and network features

- Promotion of equality of access
- Robustness after risk assessment
- Delivering quality of timing and positioning
- Facilities on inter-modality
- Respect of existing rules and standards about ITS

There are four priority areas for de development and standardization of ITS in Europe:

- Optimal use of road, traffic and travel data
- Continuity of traffic and freight management ITS services
- ITS road safety and security applications
- Linking the vehicle with the transport infrastructure

Each area must constitute priority actions as the provision of multimodal and real-time services of travel, traffic security and related information for users.

Others definitions of an ITS as a set of electronics, communications or information processing used to improve the efficiency or safety of a surface transportation system (Federal Highway Administration, 2013). Through the Intelligent Transportation Systems (ITS) Strategic Research Plan, 2010-2014, an ITS must feature a connected transportation environment among vehicles, the infrastructure and passengers' portable devices (Research and Innovative Technology Administration (RITA), 2013), whose benefits are security, risks reduction, real-time information, transportation fleets' management, vehicles connection and automation processes involving motor vehicles.

For European Telecommunications Standards Institute (ETSI), an ITS includes telematics and all types of communications in vehicles, between vehicles, and between vehicles and fixed locations (Fig. 2.4-1) (Research and Innovative Technology Administration (RITA), 2013). ETSI has released some standards respecting ITS on communications and security. The IEEE has an ITS Society, whose interest is in different aspects of electrical and electronics engineering and information technologies applied to ITS, using synergistic technologies and systems engineering concepts to develop and improve ITS (ITSS - IEEE.org, 2013). *Particularly, this Thesis could be appropriate included on the ITS scheme by grouping it on “Satellite Communication” and “Safety Systems” as exposed in Fig. 2.4-1.*

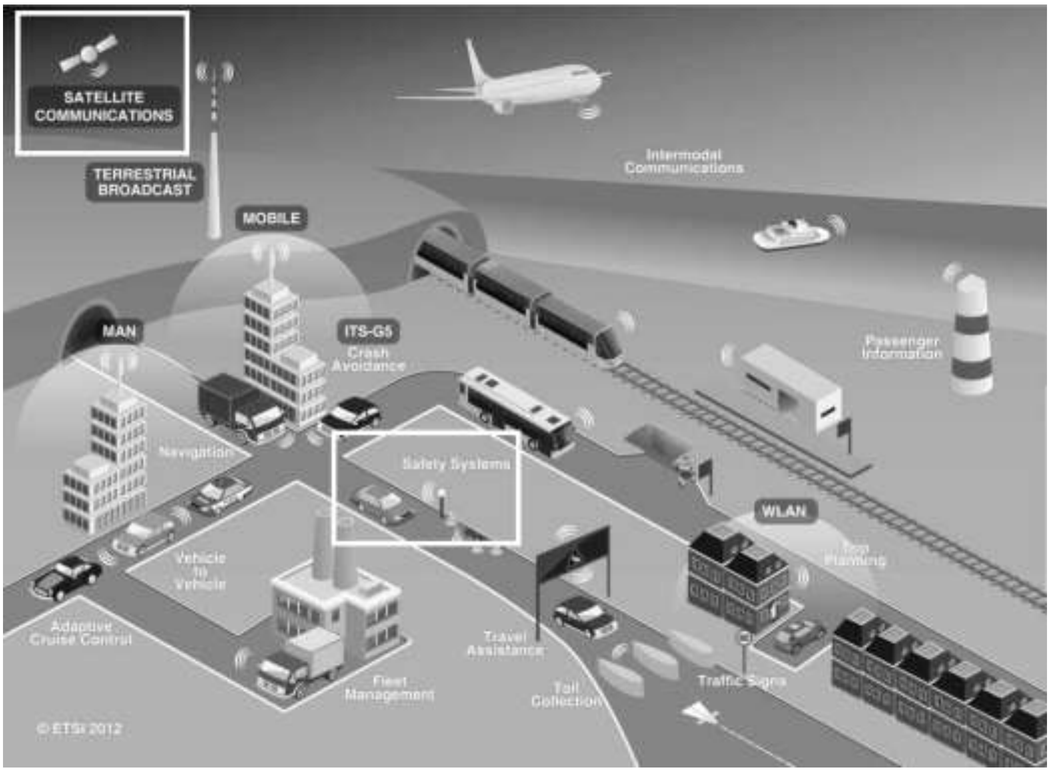

Fig. 2.4-1 - ITS Scheme[3]

In an international level, in the World Forum for Harmonization of Vehicle Regulations, on its 160th session in 2013, different nation representatives agreed in working for the design principles for control systems for Advanced Diver Assistance Systems (ADAS)(Economic Commission for Europe Inland Transport Committee, 2013). These systems use sensors and signal processing to detect and evaluate the vehicle environment. They provide active support for lateral or longitudinal control, information and warnings. These systems are classified into manual, assisted, semi-automated, highly automated and fully automated, and the control principles are divided in the

[3]“ETSI_ITS_09_2012.jpg ”< http://www.etsi.org/ >. 2013. 20 Jun 2013 <http://www.etsi.org/images/files/membership/ETSI_ITS_09_2012.jpg>

following points (ITS - Representatives of Japan and the United Kingdom, 2013):

I. System actions should be easy to override at any time under normal driving situations and when collisions are avoidable.
II. When a collision is determined to be imminent, the system can take actions intended to avoid and/or mitigate the crash severity.
III. For systems that control the vehicle under normal driving situations, the driver should have a means to transition from ON to OFF manually and to keep the system in the OFF state.
IV. For systems that control the vehicle under critical driving situations, the initial set state of the system should be ON.
V. Drivers should be provided with clear feedback informing them when the system is actively controlling the vehicle's speed and/ or path.
VI. Drivers should be informed of the system status when system operation is malfunctioning or when there is a failure.
VII. The driver should be informed when the system detects that conditions are such that normal performance cannot be assured.
VIII. Drivers should be notified of any system-initiated transfer of control between the driver and vehicle.
IX. In cases where systems automatically control the longitudinal and lateral behavior of the vehicle and the driver's task is to monitor system operations, appropriate arrangements should be considered to prompt the driver to maintain their attention to the vehicle, road and traffic situation.
X. Drivers should be notified of the proper use of the system prior to general use.
XI. If symbols are used to notify the driver, a standard symbol should be used if available.
XII. System actions requiring the attention of other road users should be signaled to other road users.

A behavioral model of the ADAS system is shown in Fig. 2.4-2, showing three assistance levels (marked into the black line), all of them depending on three issues relating to the automation of the driving task: Driver mental workload, Trust in automation and Behavioral adaptation.

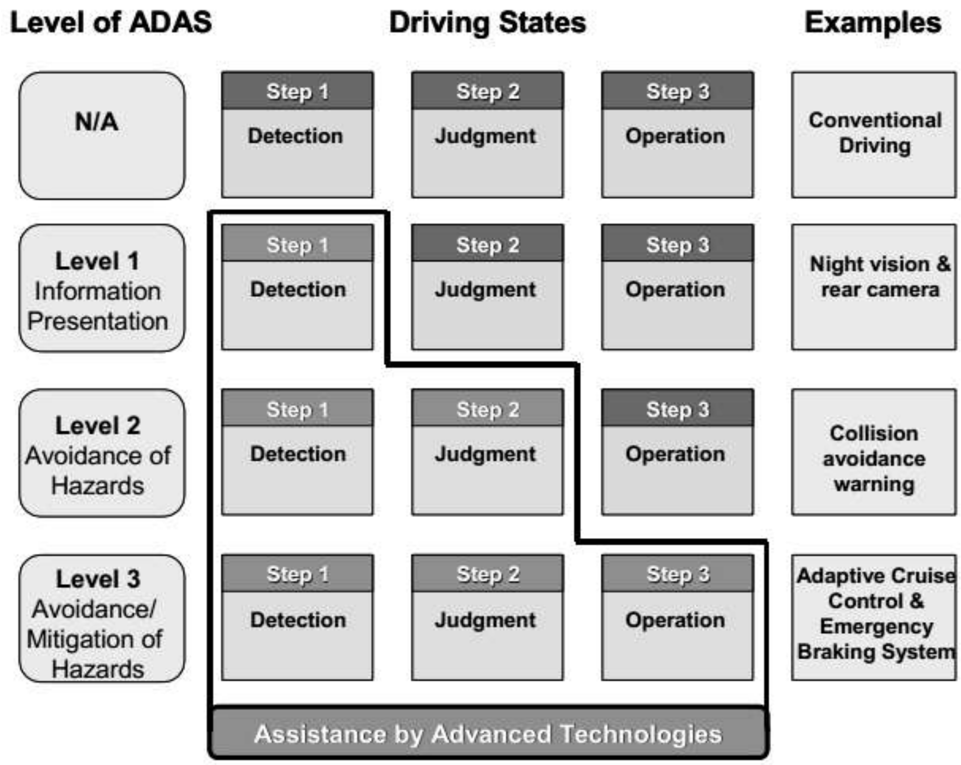

Fig. 2.4-2 - *Behavioral Model of a Driver and Level of Driver Assistance (marked as green)*[4]

[4]"Fig. 2.4-2 - Behavioral Model of a Driver and Level of Driver Assistance" Design Principles for Control Systems of ADAS
<http://www.unece.org/fileadmin/DAM/trans/doc/2013/wp29/WP29-160-15e.pdf>

Chapter 3

Related Works

Chapter 3 presents an overview focusing the main researches works related to the topics addressed in this dissertation.

3.1 Traffic Accidents as a Matter of Study by Research on ITS

Traffic accidents are one of the major mortality causes, according to the World Health Organization (WHO) (Sminkey, 2013). It claims more than 1.3 million annual victims in the world and it is the ninth major cause of death, being youth and adult persons the main victims in this kind of events. Therefore, the "El Decenio de Acción para la Seguridad Vial 2011-2020" worldwide plan was presented, which seeks to dozens of countries undertake, from their governments, to seek new methods in order to save the lives of those who are on road, minimizing the death rate in traffic accidents.

The main causes involving this kind of accidents are health problems, driver's ability as well as awareness and education by people who deliberately driving under influence of psychoactive substances or, more frequently, alcohol.

Nowadays, the scientific community has taken the initiative to develop vehicular measurement tools, as well as tools that seek to evaluate driver's performance aiming to establish the causes that may lead to a traffic accident.

Many studies have been made so far to identify these factors. Mainly, researches have converged into these following topics: Assessment of Mechanical Performance of the Vehicle, Methods for Erroneous driving behaviors, audio and video recording for driving analysis behaviors on route, Mathematical modeling of driver behavior, Erroneous driving Assessment through soft computing, Vehicular Telemetry Systems, traffic congestion analysis, among others. In these cases, no study focuses on integrating those topics as a one single matter.

3.2 Telemetry Data Study and Proposed Analysis Methods

It is mentioned that some of these studies have focused on the measurement of the variables that can be acquired directly from vehicles, such as steering, clutch, speed, acceleration, engine conditions, among others. Cambourakis, G, et al. presented the development of a system with "black box" capabilities that can take vehicle on road registration. This system has four(4) specific features: a) measurement, assistance and representation of the vehicle mechanical parameters, b) vehicle-driver control system that allows simple driving troubleshoot, cooperation with other electronic devices inside the vehicle, c) black box function responsible for taking measurements and checking of vehicle parameters d) travel record data that can be exported or stored in a magnetic media (Cambourakis et al., 1995). Researchers used as a reference the vehicle mechanical performance driving to assess safe driving conditions (through traffic rules established by Regulation Authorities) in order to prevent possible failure of a person while driving. But beyond establishing accurate analysis about the performance of the vehicle, the researchers also took into account possible actions in which drivers could lead into an accident, moreover there are devices designed for enabling controlling speed for report when limits are exceeded (Johari, 2008)(Chet, 2003).

Both Johari et al. and Chet, in separate works, developed systems that inform drivers when they have exceeded the speed limit, avoiding potential accidents; but drivers are not the only ones concerned with it, but also Traffic Regulation Ententes. That is why Johari (Johari, 2008) added the possibility to send data through SMS messages only if the driver exceeded speed limit.

In Colombia, a device named “Testigo Digital Automotor (TDA)” (Sáenz & Unimedios, 2011) was designed, which allows to take a vehicle registration by using solid-state accelerometers capable of acquiring measurements from 5mG to 300 G (unit G-force). This device can store information of the vehicle’s acceleration force once it has been defined. It also allows giving an idea of the types of tracks in which the car was driving: i.e. bridges, slopes and tunnels. Also TAD can register curves, speed reducers, gear declining among others. The use of reports allows large storage capacity due to the type of data obtained, taking up to 10,000 samples per second.

Above, it has been said that the use of devices that send information of the vehicle to control entities, has been studied. Despite this, the development of these technologies goes beyond just transmitting mechanical-vehicle information. Protocols need security during transmission of information from the time of being taken by the "black boxes"[5] to the time it reaches the traffic control authorities, as they will be the ones who can make a judgment about how people drive. This information may not be, under any circumstances, deleted, modified, altered, stolen or publicly accessed.

A research whose main objective was establish secure vehicular communication networks was presented in this research provided secure protocols to these networks in which the information will travel safe, tamper proof as well be only accessed by authorized personnel. For this reason, the

[5]It’s used the term black box to refer to a monitoring device that record several variables in situ so that they can be analyzed later.

study conducted by M. Chammem et al. (Chammem, Hamdi, & Boudriga, 2010), is generalized to real devices as a black box data storage device. However, for this model to be applied to real situation, it is necessary that the information to be oriented to traffic incident monitoring and collisions events, and it's also required that the information fulfill security requirements in which only authorities can have access to it. As well Tehran implemented in the TDA design a robust hardware structure unable to be physically altered and developed software that stores the log information of the vehicle and also has security in their coding for preventing data modification.

3.3 Digital Image Processing Analysis in Driving Environments

There are several devices on the market that have the ability to warn the driver of dangerous behaviors in three specific ways: a) frontal collision, b) off road (either by right or left) and finally c) detection speed, using both visual and audible warnings (KCI Communications, 2013). This system performs the processing of this information by digital image processing taken by a video camera, and using speed sensors that alert the driver if exceed a limit of safe driving. Also, the system is enabled to issue alarms in case the driver is incapable to drive, or if presents any physical condition or is under the influence of alcohol or psychoactive substances (Mobileye, 2013), (Jones, 2012). Neither of these systems provides on-board assistance nor any kind of erroneous driving analysis.

In addition to these reports, it is possible to find studies focused on the design of devices that take a record of all events that occur within the same vehicle and are related particularly to the attitudes that both passengers and driver can take in risky driving situations, providing a visual record of what may happen before and during a car accident. Thus, Hickman S et al. (Hickman & Hanowski, 2011) implemented a video monitoring system to assess risk behaviors when they are driving commercial vehicles. They studied, through a video recording, how to recognize dangerous behaviors and maneuvers performed by drivers who developed deliveries and shipping services tasks, in order to reduce them. These studies showed the implementation of a visual recording low-cost system allowed to highly reducing the probability of a risk event (event per 10,000 miles driven). Not only the use of a video system is enough, researchers were also able to demonstrate that through the intervention of Control entities communicated while drivers are on road, reporting them about inappropriate behaviors while they are driving, which minimizes even more the probability of a risk event for every 10,000 drive completed miles. This suggests that the implementation of systems to identify erroneous driving maneuvers is also important.

Similarly, the audio and video recordings have also been used for registration and control vehicle purposes during a route, allowing sending real-time data or at the end of the tour. In their studies, Chien-Chuan (C.-C. Lin & Wang, 2010) has developed a device that can record tracks in a vehicle, which also performs real-time transmission of the recording video signals. Finally the design presented by Chien-Chuan also allows vehicle satellite location, either in real-time tracking or once the tour is over.

3.4 Driving Modeling and Drivers Behavior Modeling Approach using Telemetry and Bioelectrical Signals Data

In addition to record and register driving vehicle data, there have been many studies that focused on identifying erroneous driving rates closely tied to driving analysis variables. Some of them analyze bioelectrical signals and others implement telemetry data.

By the concept of taking into account bioelectrical information, one of the best works in this area is presented by Bürger M. et al. (Martin, Griesser, Michael, & Waltl, 2008). This research presents an intelligent onboard assistance (consisting of a hardware and software interface analysis) in addition to quantitative analysis of the taken variables from the vehicle, providing a qualitative analysis of how people drive. Similarly, the system uses the measurement of encephalographic signals to make measurements of the physical state of the driver and their reactions and stimuli while driving.

Moreover, Lin et al. (C. Lin, Chen, Wu, Liang, & Huang, 2005) proposed a system which combines a Fuzzy Logic implementation with bioelectrical analysis for assess driver performance. This research assesses driver capabilities through the electroencephalogram signals analysis processed into a Fuzzy Logic approach. Authors declare that their proposed method allows estimating and predicting driving performance by using this particular information. This implementation was developed under laboratory conditions using a 3D simulator.

Furthermore, works that used information taken from a vehicle while driving (in simulation) were conducted by Chen, Liang-Kuang (Chen & Ulsoy, 2001) et al. This research emphasized the modeling of driver is behavior while driving; also they model the uncertainty relate to their behavior. Their studies indicate that once obtained the driver behavior and uncertainty model, the obtained steering behavior varies considerably through the time. This model can be applied to one or more drivers.

Moreover, L. Schwall (Schwall et al., 2003) implemented a vehicular diagnostic low-cost system, by using an application for multiple models for minimized sensors, resulting in a reduction of the cost implementation. This design was based on the use of a dynamic Bayesian network to determine possible failure diagnosis. Studies aimed to predict driver behavior using Bayesian networks was performed by Rakotonirainy A. (Rakotonirainy & Maire, 2005). They concluded in their studies that it is possible, with some probability, to model driver behavior or detect an abnormal behavior and in turn take the information of the vehicle and its environment to assist on-board during the driving process in simulated environments.

Other methods aimed to analyze unusual driving behaviors and driving assistance systems, using hidden Markov models (Kumagai et al., 2003). Studies conducted by Sathyanarayana A, et al. (Sathyanarayana et al., 2008), were focused on maneuvers recognition performed at wheel by analyzing three variables taken from the vehicle, as steering, speed and braking force, in order to process driver behavior signals. The use of hidden Markov models for this kind of applications in which is amide to model driver behavior is very common and requires less computational cost, as found Kumagai T, et al. (Kumagai & Akamatsu, 2004) in their studies, showing that it is much more efficient and easier to implement a system of nonlinear dynamic change, or SLDS.

Researchers have also analyzed the developments in soft computing for intelligent autonomous vehicular traffic. These studies are also focused on performing mathematical modeling of the driver in order to achieve management task, aiming to establish an understanding of the autonomous vehicles techniques that must learn to interact with other vehicles in a specific environment. The computer model presented by Reece D. A. et al., (Reece & Shafer, 1993) uses a simulated environment for describing how to perform management tactics tasks, which in turn incorporates a driving knowledge that describes how other vehicles and other drivers intervene into vehicle decisions. Furthermore, this model has the ability to plot routes through traffic objects (vehicles, signs, etc.) allowing judgments. These studies are promising due to the model was implemented on a robot vehicle that was capable of driving safely avoiding accidents. A similar research also focused the study of smart systems for vehicles in different traffic scenarios using a Bayesian network. This was presented by Forbes J, et al., (Forbes, Huang, Kanazawa, & Russell, 1995). This study seeks to provide a solution to the problem of noise in sensors and possible failures in measurement, as well as enhancing the effect of the uncertainty related to the behavior of other vehicles on the road in which the vehicle have to take intelligent decisions.

This type of research has led to traffic-related applications and intelligent autonomous developments. Thus, Sukthankar R et al. (Sukthankar, Hancock, Pomerleau, & Thorpe, 1996) conducted a tactical driving simulator. This study seeks to drive an intelligent vehicle through traffic simulation environment in situations of high risk driving in high-speed highways. The results showed vehicles were more intelligent on high-speed tracks.

3.5 Black Box and In-Vehicle Data Acquisition Systems

Searching to make the black box systems that have as much information as possible concerning the vehicle, the researchers have been also obtaining records about the location of a vehicle in a specific place. As Chien-Chuan L. (C.-C. Lin & Wang, 2010) in its video recording device, a software application that places via satellite vehicle route was implemented. Other studies –such as those performed by In-ji S.et al., (Sun, Nieto, & Li, 2010);(Sun & Nieto, 2009) present the design and implementation of software that uses GPS devices, Zigbee wireless communication protocol and the use of Google Earth to show the location of trucks and dump trucks used in mining. The obtained results in this work give a satellite reference in the mine vehicles in real time, allowing both heavy equipment operators and operators of trucks, improve visibility problem, providing safer working conditions with low risk of accidents.

An study that links an analysis device with black box properties and a support board to assess driving performance was presented by Angelos A. et al. (Amditis, Pagle, Joshi, & Bekiaris, 2010). This research aimed to maximize efficiency and safety in the driving process, through the measurement of variables –such as steering, speed and acceleration-, the record of road obstacles and vehicle satellite position and the record of the behavior of the driver while driving. Also, Espinosa, F. et al., (Espinosa et al., 2011) implemented a similar system, which seeks to measure the performance of the driver and the vehicle by measuring three important aspects (driver activity, vehicle-mechanical performance, and the characteristics of the route on the road), being presented by a graphical interface. This system can be installed in different vehicles, allowing the analysis of performance of these three parameters in real traffic conditions. This device is also focused on measuring the pollution emitted by vehicles in different traffic situations such as vehicular excess, allowing establishing the cause and effect of excess environmental pollution produced by vehicles.

3.6 Towards an Intelligent Driving Diagnosis

Motivation for Intelligent systems applied in real vehicles has been desirable since the positive results in the simulators. For this reason Michler T. et al., (Michler, Ehlers, & Varchmin, 2000) implemented a diagnostic system in a test vehicle in order to replace human faculties of a driver for an electromechanical system that takes into account all the variables acquired from the vehicle to assess its operation. The results in this system proved to be quite relevant, because the system is easy to install and also adaptable, allowing it to be implemented in different test vehicles.

Other studies use the soft computing to determine variables taken from vehicle –as known driving erroneous rates and vehicle satellite positioning. One of them, conducted by Oñate J. et al. (Quintero, Lopez, & Rua, 2010), implemented artificial neural networks, in order to find wrong driving patterns in a driver when driving in a simulated system. At the same time, the vehicle makes a reference satellite marking pointing places where driving patterns were detected as inappropriate or risky. Finally, it is made a general diagnosis of the route, including driving performance in situations such as: excess speed limit, sudden and rudder movement of pedals, among others.

Similarly, and taking into account telemetry data for an intelligent analysis, A. Aljaafreh et al. (Aljaafreh, Alshabatat, & Najim Al-Din, 2012) presented a Fuzzy Logic inference system which extracts features related to driving styles for driving classification purpose. This proposal is capable to classify the style of drivers just by analyzing two (2) specific signals: velocity and acceleration.

In the same line, an AVG decision making (AVG) was proposed by Y. Liu (Liu, Huang, & Sun, 2012). This vehicle system implements Fuzzy Logic for the quantification of subjective information problem. They conclude their proposal fits suitable for decision making purposes based on a previous AVG system.

Finally, SACA T (Aliane, Fernandez, Bemposta, Mata, & Diez, 2012) and ADES (Kaplan, Kurtul, & Akin, 2012) both implements GPS position systems, OBD analysis for on-board telemetry data and digital image processing for driver assessment. But only ADES implements neural networks for driving signals identification. Both frameworks addressed the problem of developing an automatic tool for signals detection (both images and telemetry data). However, none of these addressed the problem of an Intelligent Diagnosis Agent approach.

3.7 Final Remarks

The problems of assessment and diagnoses have huge importance in the ITS Research Society. Tackling them, it is necessary to establish a Structured Intelligent Diagnosis Agent which combines both, artificial intelligence techniques and expert criteria about driving faculties, rules and safety.

The works presented above use several kind of information related to vehicle physics, due to the fact that telemetry data and bioelectrical signal data are highly correlated to driver capabilities while driving. On the other hand, data analysis focuses on some specifics topics: Autonomous Driving, Driver Behavior Model and On-board Safety. The reviewed models, however, did not have an implementation approaching of expert criteria for Driving Diagnosis Analysis.

Summarizing, it is important to obtain accurate information about people behavior and capabilities while driving. This work presents a proposed Intelligent Driver Diagnosis Agent Approach which evaluates specifics signals in order to assess driver faculties, implementing a soft computing technique for this task. The proposed model incorporates telemetry data analysis, an abstraction of driving rules and driving secure techniques for an Online Intelligent Driving Diagnosis. Also, the selection of analysis parameters will depends on scenarios characteristics, being suitable for many cases of studies.

PART II:
PROPOSED
APPROACH

Chapter 4

Intelligent Driving Diagnosis Agent Approach

This chapter presents the approached intelligent driving diagnosis agent proposed in this dissertation applied to real environment driving scenarios. The main definitions, general considerations and the algorithms for telemetry signals analysis, driving diagnosis and evaluation criteria are introduces in this chapter.

4.1 Problem Statement

Nowadays, the Intelligent Transportation Systems Society (ITSS) focuses all issues related to vehicle safety assistance aiming at specific topics such as: driver safety, driver prediction models and erroneous driving behavior analysis. (Organización Mundial de la Salud (OMS) & Sminkey, 2011). For this reason there are important studies focused on monitoring vehicle signals (Cambourakis et al., 1995);(Johari, 2008);(Chet, 2003);(Sáenz & Unimedios, 2011), mathematical models of driving behavior (Chen & Ulsoy, 2001);(STOLL, 1956) and even onboard assistance systems (Scania AB (publ), 2013);f(Schwall et al., 2003).

Given the current state of knowledge of the problem statement, it is possible notice that many factors that are related to vehicle safety control are being considered. Therefore proposing a solution which integrates vehicular telemetry and diagnostics board assistance online driving allows further study of this issue.

Worldwide, more than one million people are victims of traffic accidents among drivers, co-drivers and pedestrians. Among the most common consequences that motivate this kind of unfortunate events are: driving under influence of alcohol or psychoactive substances, lack of expertise or reckless driving and speeding. Around the world, in an effort to reduce the numbers of accidents in traffic events, the WHO introduced the "Monitoring and Evaluating the Decade of Action for Road Safety" in order to focus efforts on creating a sense of responsibility in people when driving. This seeks to conclusively reduce the high rate of accidents presented in the statistics.

In Intelligent Transportation Systems, the efforts of scientists are focused on trying to design and implement systems for driver assistance or road safety. Also, they have focused on both software and hardware designs that seek to measure variables related to the state of motion of the vehicle in order to quantify the degree of potentially risky maneuvers performed by drivers. However, integrated vehicle systems seeking a rigorous control of the driver's actions while is being performing a driving intelligent diagnosis have not been presented to date.

In this way, the proposed intelligent system will then use vehicle motion information, but is referred directly to the maneuvers that the driver performs during this process characterized by speed, acceleration, yaw angle rate, and satellite position, allowing making a diagnosis to assess potentially erroneous cases while evaluating driver performance along a route. The design and implementation of a computational intelligence system, based on an intelligent agent, dedicated to the task of evaluating the driving process under real conditions is an important tool for generating new research proposals related to this issue. This work could allowing different entities such as transit authorities, insurance companies, car rental houses, transport companies, driving schools, among others, to be aware of how drivers performed the driving task under different contexts and how this may prevent any kind of unwanted event on the tracks, while also providing new research opportunities in the area using this approach.

For this reason the Thesis proposal, regarding an analysis tool intelligent driving diagnosis, has been the basis for carrying out the construction of an integrated driving diagnosis system based on an intelligent agent is presented in this Thesis. Specifically, this dissertation approaches a system that uses computational intelligence to perform a driving diagnosis under real conditions based on the driver actions (maneuvers) while someone is driving in real time and driving conditions.

4.2 Proposed Intelligent Driving Diagnosis Agent

The implementation in a real environment of driving intelligent diagnosis seeks to achieve a drive diagnosis based on a proposed intelligent agent that attempts to approximate the expert knowledge of driving laws and criteria of secure driving techniques (see Sections 2.1.2 and 2.1.3).

To achieve this, it is required to present a structured framework to formalize the proposed approach. Furthermore, it is mandatory to define characteristic properties of the drive diagnosis system[6] based on an intelligent agent. Fig. 4.2-1 shows the formal design of the proposed approach. In this figure it is possible to distinguish the different sections that make up and generally summarize the solution to the problem of study.

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[6]In this case the word *system* is defined as the set of blocks needed to carry out the implementation of the proposal.

Fig. 4.2-1 - Formal Presentation of Intelligent Driving Diagnostic Scheme[7]

Based on Fig. 4.2-1 it is possible to reach a more specific methodology used in this Thesis to solve this problem. Fig. 4.2-2 shows a detailed scheme in terms of implementation achieved. Each of the blocks shown will be explained in detail below.

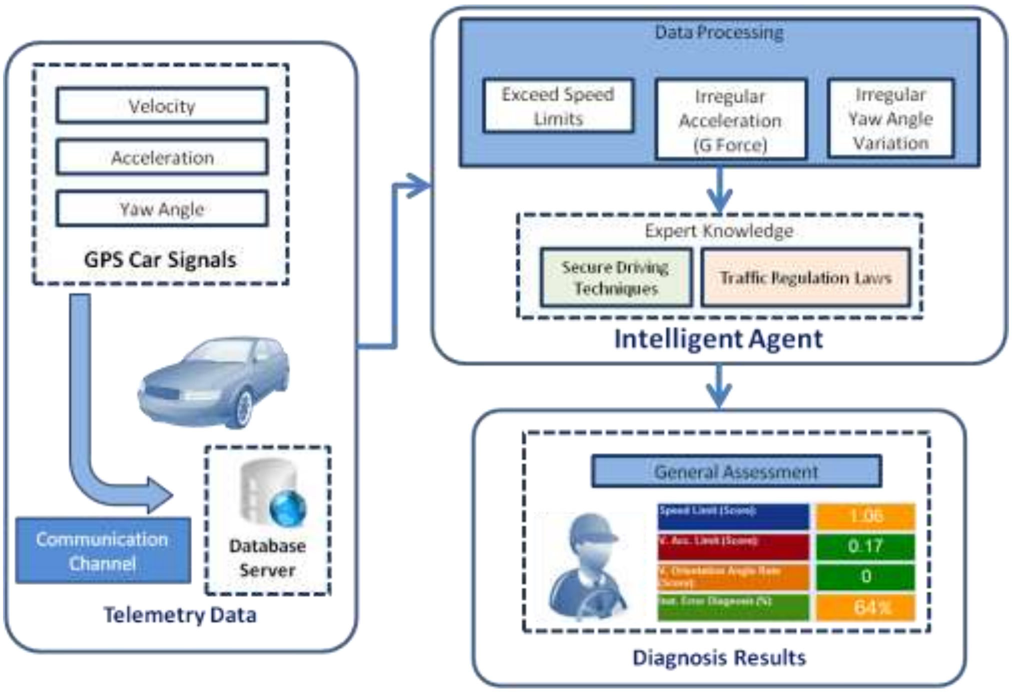


Fig. 4.2-2 - Intelligent Driving Diagnosis System – Block Diagram

[7] Note that certain traffic regulation laws and secure driving techniques were taken into account.

It is possible to note that the approach rigorously conserved the characteristic properties of the system for intelligent driving diagnostic. The three sections that conforms the system are presented: *4.2.1 telemetry vehicle data acquisition, 4.2.2 intelligent diagnostic agent and 4.2.3 driving diagnostic results* (See Sections 2.2 and 2.4).

4.2.1 Data Acquisition by Vehicular Telemetry

Since data are acquired under GPS protocol standards (Mehaffey et al., n.d.), it is important to make an acquisition stage for them to further analysis. Vehicular telemetry information is acquired by the adaptation of a "black box"[8]prototype which monitors variables related to the movement of the vehicle (driver maneuver) as well as a video record which verifies the interior and exterior of the vehicle. When the signals are acquired, the system keeps sending those variables data through Internet so that these can be addressed remotely (See Section 2.2).

The variables selected for analysis are:

1. Speed: Understood by the speed limits that can reach a vehicle on public roads, whether in urban or rural way. Around the world, the speed that a vehicle can reach is a factor of diagnostic performance in terms of safety drivers (Organización Mundial de la Salud (OMS), 2013). For this reason, traffic regulators rely on electronic devices that can determine the speed of vehicles and thus have control over driving practices.

2. Horizontal acceleration: physiological tests allowed establishing the limits of human tolerance to horizontal acceleration. It is known that the human body is capable of being exposed to 2G for at least five (5) seconds before getting physically unconscious. On issues related to driving, the

[8]It’s used the term *black box* to refer to a monitoring device that record several variables *in situ* so that they can be analyzed later.

horizontal acceleration is strongly related to driving behaviors. i.e., best practices to drive establish that the acceleration or deceleration process should be progressive over the time. This represents horizontal acceleration values between 0.1, and 0.23 G, which are considered low. High values of acceleration can be reached in acceleration or deceleration events abrupt, sudden, and irregular and/or hard (e.g. events that go over 20 km/h to 0 km/h in 1 second) represent a strong horizontal deceleration 0,57 G of magnitude, which is a dangerous abnormal conduction process, above by the equation.

$$a = \frac{\Delta v\,(m/s)}{\Delta t(s)}$$

$$G\ Force = \frac{a}{9.8m/s^2}$$

3. Yaw Angle Rate: maneuvers carried out on the wheel are related to the orientation of the vehicle. A low angle yaw rate magnitude represent normal use and not dangerous driving, therefore, one can register a secure driving behavior.

It is mandatory to clarify for all three monitored signals and the proposed approach itself *that although is proposed a driving intelligent diagnosis that takes into account signal monitored with a GPS vehicle,* ***it is necessary to support the diagnosis performed by intelligent agent via video records made with the prototype.*** *With this it is possible to rule out any analysis that might be ambiguous or misunderstood.* All this is necessary because the system is being proposed to be tested in real conditions.

4.2.2 Intelligent Driving Diagnosis Agent[9]

The core of the proposal for an intelligent driving diagnosis approach focuses on the presentation of the characteristic properties of intelligent

[9]In this Thesis the meaning of *agent*, is referred to the set of blocks formed by the process of analysis of vehicle telemetry data and the knowledge base related to secure driving techniques and laws traffic regulations.

agent responsible of the task to evaluate a driver. This driver diagnosis seeks to identify dangerous maneuvers in an instant of time. Thus, it is possible to see that a direct engagement exists between two factors: *the first is given by monitoring physical signs that have a direct correlation with the driver actions executed when driving, and the second is based on how achievable is to apply expert knowledge focused on driving diagnosis in terms of safety or risk behavior that an action can represent* (See Section 2.4).

For this reason, at this stage are two (2) proposed functional blocks necessary for intelligent diagnostic task, these are:

1. Data processing: This block makes acquisition signals processing which comes from the previous step (section 4.2.1). In this stage, required parameters are set for driving diagnosis under the different types of scenario in which the system is running (in section 5.1 will be explained in detail that the scenarios are defined by the type of path where the tests will be executed). The processing of these signals takes into account the evaluation criteria configuration of the three monitored variables, allowing the system to be adapted to different scenarios.

2. Expert knowledge: This block contains an abstraction of the most relevant information in which it is possible to propose an intelligent driving diagnosis (Section 2.1 Transport Regulations). Here a quantitative approach of driving notions, assumptions and subjective definitions are contained, which govern a secure way to carry out the driving process. Thus, this Thesis proposes a *set of rules* based on *subjective evaluation notions* (which are *qualitative*) for the driving diagnostic process.

3. Integration expert knowledge and data processing: The main objective of the Intelligent Agent is to identify possible dangerous events in a given time while someone is driving. For variables analysis, the agent is based on three input signals: speed (V), horizontal acceleration (HA) and yaw angle rate (YAR).

To achieve this, it was implemented a *fuzzy inference engine* containing the *characteristic properties* of an expert person whose diagnoses (based on principles of secure driving) and analyzes the driving process based on the signals listed above.

The postulates proposed in this Thesis for the diagnostic task implemented in the *fuzzy inference engine* are:

- An evaluation of driver performance by analyzing speed magnitude (V), taking into account the speed limits allowed by the Traffic Authorities. This value must not exceed the limit velocity allowed.
- An evaluation of driver performance by analyzing horizontal acceleration magnitude (HA) as an index of performance for braking and acceleration processes performed by the driver.
- An evaluation of driver performance by analyzing yaw angle rate (YAR) as an index of how it is taking the curves, junctions, lane changes and overtaking.
- Evaluating the interaction of the variables monitored to identify both a secure and a risky driving.

Assuming that driver performance is described as a function Φ which depends on three variables that change over time, it is possible to propose the next equation:

$$\Phi(\mathrm{V}, \mathrm{HA}, \mathrm{YAR})$$

Where V, HA and YAR are time-varying as follow:

$$V = v(t)$$

$$HA = a(t)$$

$$YAR = \frac{\Delta\theta(t)}{\Delta t}$$

Is necessary to establish parameters under which the variables will be processed by the intelligent agent. Each reflects maximum allowable limits for each of the variables (V, HA YAR). The normalization proposed in this Thesis for each variable is:

$$V_{Norm} = \frac{v(t)}{V_{limit}}$$

$$HA_{Norm} = \frac{a(t)}{HA_{Limit}}$$

$$YAR_{Norm} = \frac{\Delta\theta(t)/_{\Delta t}}{YAR_{limit}}$$

Where V_{limit}, YAR_{limit}, HA_{Limit}, are constant values and each of them can be adapted according to the testing stage and are based on traffic regulation.

4.2.3 Driving Diagnostic Results

Analysis of driver diagnosis results provides the opportunity to perform the examination of driver's driving awareness given by the intelligent agent. The diagnosis result at first instance will be matter of study through results itself and video recording supports. It would allow identifying whether an erroneous behavior had occurred and whether was well diagnoses or not.

Finally, some routes will be performed in order to analyze intelligent agent performance in various scenarios. Also, *Online* and *Offline* diagnosis will be quite important for establishing possible data misunderstanding while someone drives and is being evaluated.

4.3 Final Remarks

To approach the problem of assessing and diagnosing driver it is required to establish a structured way to present a conceptual framework in which it is possible to establish the characteristic properties of a system for this task. The above is based on laws and principles accepted in a framework subject, according to international regulations of traffic. Thus, the proposed approach at its first stage, seeks to approximate human expert criteria on Driving Assessment Process by an Intelligent Driving Diagnoses System, based on an

Intelligent Agent developed as a fuzzy logic engine capable of quantifying whether the driving process is secure or not, based on *some of the proposed principles* in *Secure Driving Techniques* and *Traffic Regulations.*

For diagnosis purposes, the selected variables are: speed, horizontal acceleration and yaw angle rate, which placed in this framework, give important information about driver's maneuvers while driving. For all of these it is also presented a proposed normalization, taking into account set parameters which allow the entire systems to work in several scenarios.

Based on the above, driving diagnosis results would give a quantitative estimation of how safe is the driving process while someone drives in real time and driving conditions. Both, diagnosis results and video register information are analyzed to establish possible data misunderstanding while someone drives and is being evaluated.

Chapter 5

Intelligent Driving Diagnosis Agent Implementation

This chapter presents the implementation of the proposed approach in real environment. Both developed computational tool and driving diagnosis algorithm are described. Scenarios, assessment parameters, and driving intelligent diagnosis approach are described below. It describes some specifics considerations about intelligent driving diagnosis software and scenarios characteristics. A new proposal related to an intelligent driving diagnosis task based on GPS data acquisition is presented. Also, proposed algorithms for fuzzy inference engine approach are presented.

5.1 General Implementation Overview

The proposed approach known as an "Integrated Vehicular System with Black Box Capability and Intelligent Driving Diagnosis" is possible by hardware and software integration. While the nuclear focus of this Thesis lies in the presentation of the proposed design of intelligent agent for the diagnosis task, it is also important to describe the data acquisition methodology that will make the diagnosis (see Section 4.2 Fig. 4.2-2).

5.2 Prototype Adapted with Black Box Capabilities for Vehicle Telemetry Data Acquisition and Video Recording

The adopted prototype for diagnosis task satisfies two main functions:

- Acquisition and transmission of vehicular telemetry data: Acquired data, by implementing GPS technology for monitoring related variables to the vehicle’s movement, are registered –because of a black box’s utility- and sent by Internet for their remote processing. All the needed information is stored in a specific database designed for this purpose. For this Thesis, the selected signals are velocity, horizontal acceleration and yaw angle rate.
  Below, Fig. 5.2-1 presents the proposed data format developed for the *in situ* data registration.

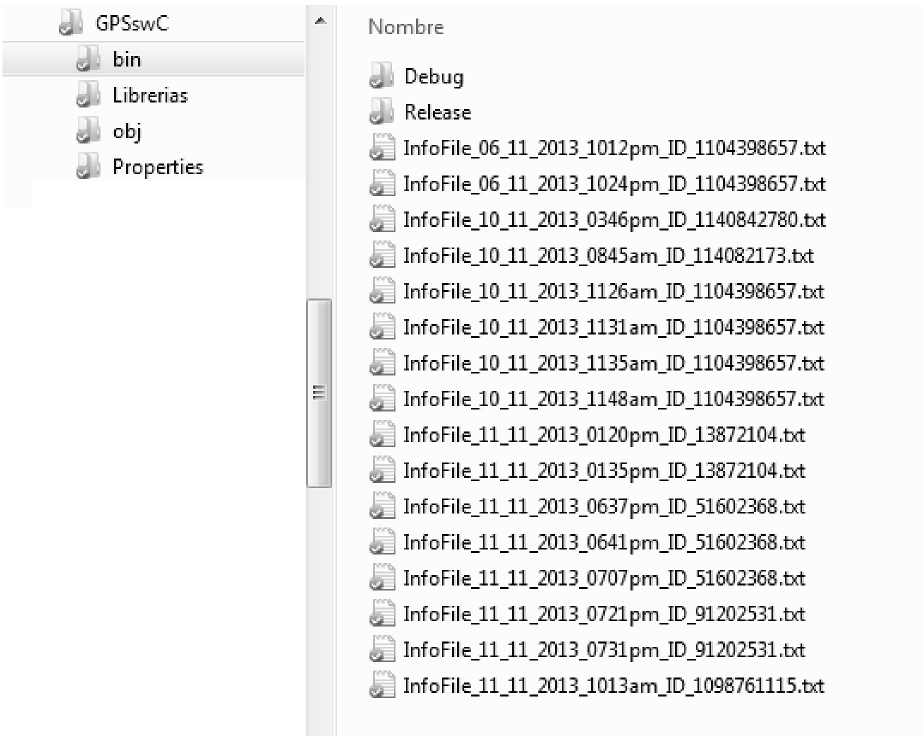


Fig. 5.2-1 - Proposed Data Format Developed for Vehicle Telemetry Data Acquisition

This file is generated automatically and contains all telemetry information according to car movements.

```
InfoFile_11_11_2013_0135pm_ID_13872104.txt
```

Name file, contains itself important information about drivers as shows Table 5.2-1:

File Name (Route):	InfoFile
Date:	11_11_2013
Time:	0135pm
Driver ID:	ID_13872104

Table 5.2-1 – File Name Format

A sample of the information registered into the proposed format is presented in Fig. 5.2-2.

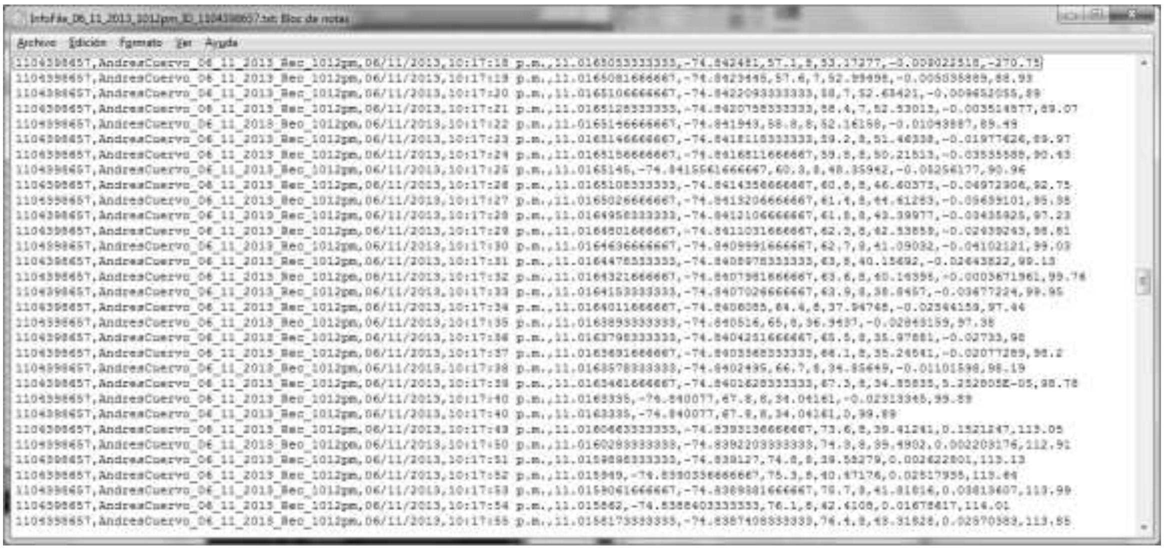


Fig. 5.2-2 – Telemetry Data - Register Scheme

Picking up one line of the proposed protocol in Fig. 5.2-2, now it is presented the registered information explaining each registered variable, as follow (see Fig. 5.2-3):

1104398657,AndresCuervo_06_11_2013_Rec_1012pm,06/11/2013,
10:17:18 p.m.,11.0165053333333,-74.842481,57.1,8,53.17277,-0.009022518,-270.75

1	**Driver ID**	13872104
2	**Route file identifier:**	AndresCuervo_06_11_2013_Rec_1012pm
3	**Date:**	06/11/2013
4	**Time:**	10:17:18 p.m.
5	**Longitude:**	11.0165053333333
6	**Latitude:**	-74.842481
7	**Altitude:**	57.1
8	**Satellites in view:**	8
9	**Velocity:**	53.17277
10	**Acceleration:**	-0.009022518
11	**Yaw Angle:**	-270.75

Fig. 5.2-3 – Explanation of Proposed Format for Telemetry Data Registration

- Video register of indoor and outdoor panoramic of the vehicle (Fig. 5.2-4): this task can be implemented using a video recorder. Video recorders allow analyzing the driver behavior and his environment influence during an implemented route. The video records can only be accessed by physical means and after the route has finished. The purpose of this registers is giving a context for the intelligent agent diagnosis.

Fig. 5.2-4 - Adapted Prototype for Vehicle Telemetry Data Acquisition and Video Recording

The Adapted Prototype has the following advantages:

- ✓ It has compatibility with the vehicle technology, so it can be installed in any vehicle.
- ✓ Its installation does not interrupt the driving process of the test driver.
- ✓ It does not interfere with driver focus. He must not take care of the Adapted Prototype.
- ✓ Satisfies requirements for "Black Box Systems" as allow to record samples *in situ* which could be analyzed once the route has been finished.

5.3 Developed Computational Tool

The developed computational tool for this Thesis takes information from vehicle telemetry for the diagnosis. It allows the intelligent agent diagnosing the driver based on received signals.

The development tool was designed to diagnose driving of a single driver at a time, regardless of driver type, the route place or the vehicle in which adapted Prototype is installed. It also presents general information of the driver test, regardless of whether the evaluation was made or not. At the same time, information about driving diagnosis made by the intelligent agent is shown point-by-point in the interface. In addition, the designed tool allows performing two analysis classes:

- ✓ Online analysis: it is implemented when is required to evaluate in real-time a driver during his driving process.
- ✓ Offline analysis: it is implemented when is required to check driving registers of any driver after his test.

In any case, information referred to the vehicle movement state, to the driver and to the intelligent diagnosis is available from the tool. Finally, using geo-references and by means of a *Google Maps* request, it is possible to show its location in a map.

Information processing for intelligent diagnosis is obtained from each one of the signal acquired values in a time instant. For this reason, each sample is divided in discrete signals at spaced intervals one second between two consecutive samples.

5.3.1 Assessment Parameters

In the previous chapter it was explained that the proposal for the normalization of the variables, taking into account the maximal parameters as limits not to be exceeded:

$$V_{Norm} = \frac{v(t)}{V_{limit}}; \qquad HA_{Norm} = \frac{a(t)}{HA_{Limit}}; \qquad YAR_{Norm} = \frac{\Delta\theta(t)/\Delta t}{YAR_{limit}}$$

Where V_{limit}, YAR_{limit}, HA_{Limit} are constant values calculated from the following criteria:

- Maximal allowed velocity V_{limit}: this variable can be modified according to the route features the driver can take. It can be applied to different road frameworks, so that it adapts to the route features. For example, the maximal velocity is 35 km/h for urban roads, while in highways the maximal velocity is 75 km/h.
- Horizontal Acceleration Limit HA_{Limit}: Considering horizontal acceleration measurement, this work proposes an acceleration or deceleration of 0.35 g when –for example, velocity changes from 40 to 20 km/h- in one second (based on performed tests) as a risk maneuver marker. However, this event[10] is not strictly a dangerous maneuver from the driver, but it can also be a reaction by the driver in the evasion of an obstacle, another vehicle or a pedestrian. For every

[10]In this case, the word *event* refers to any acceleration or deceleration detected by the system can be diagnosed as a dangerous maneuver of the driver.

monitored variable, the video support allows to distinguish among these unusual data.

- Yaw Angle Rate limit YAR_{limit}: According to measurements performed in routes, the Yaw Angle Rate is read as a rate of change of steering angle of the vehicle. When a driver makes a turning maneuver with the steering wheel, it should not be more than 0.5 normalized degrees per second. It is known a vehicle must turn by reducing the velocity in order to avoid possible accident events.

5.3.2 Interface

With previous considerations, a proposed software interface for this study is shown in Fig. 5.3.2-1. Each number in the text corresponds with the respective section in the figure.

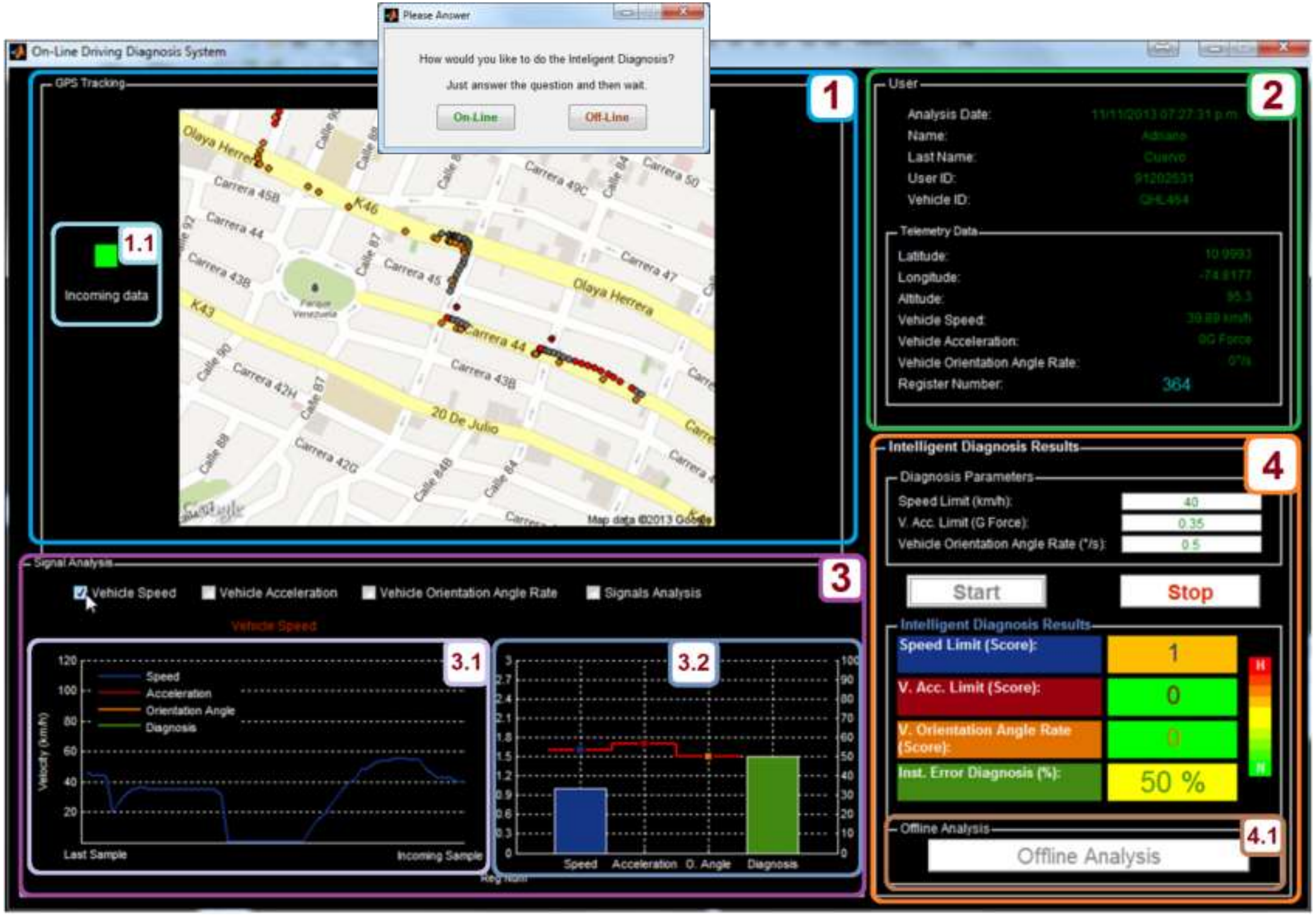


Fig. 5.3.2-1 - Software Interface for Driving Intelligent Diagnosis (Online)

1. GPS tracking: in this section, the vehicle position in the test place is identified. With the knowledge of the road features in a place, it is possible to give a context for the approximated diagnosis from the intelligent system.

1.1 Incoming Data: during online analysis, the data sending status from vehicle telemetry is monitored from the vehicle to database, so that it is possible to know whether or not a driver has finished his test.

2. User: information of each driver test and each sample and its corresponding time is shown in this section. Monitored variables for the analysis and geographic coordinates for vehicle location are shown here too.

3. Signals Analysis: Time analysis for variables and their evolution can be graphically monitored.

3.1 Vehicle Signals Analysis: the evolution of each variable over time is shown here as magnitudes. The signal is going to view must be selected. Signals correspond to made maneuvers by the test driver in an instant time.

3.2 Score Signals Analysis: with the proposed normalization, the score is monitored during the route, in order to allow the intelligent agent making the driving diagnosis. Levels, in a range from zero (0) to three (3), show the degree of danger for a variable, where zero (0) is the lowest danger level and three is the highest danger level during driving maneuvers. Diagnosis score made by the intelligent agent is shown as a green bar, where 0% is a free-risk maneuver and 100% is a risky maneuver.

4. Intelligent Diagnosis Results: this section contains information concerning driving diagnosis made by the intelligent agent for each instant time. A colored scale illustrated the degree of risk in general and for each variable, where red scores are the highest ones, according to dangerous maneuvers, and green ones are the lowest values referred to non-dangerous maneuvers. At the same time, diagnosis parameters are configured according to the covered route's features.

4.1 Offline Analysis: once completed the route, register files containing as monitored informed as driving intelligent diagnosis are available to be viewed any time. The purpose of these registers is organizing the driving diagnosis information by user, date, time and route. The interface presented in Fig. 5.3.2-1 also allows performing the offline analysis using each box. Fig. 5.3.2-2 shows how this feature works once the route has been completed. In this case, the interfaces draw the performed route on Google Maps (Box 1) and also marks the vehicle position with a blue round marker in order to shows the registered score and magnitude of each monitoring variable (Boxes 3 and 4). This feature allow to explore all monitored variables per sample, in that sense it is possible to analyze driver performance and the intelligent diagnose issue by the intelligent agent.

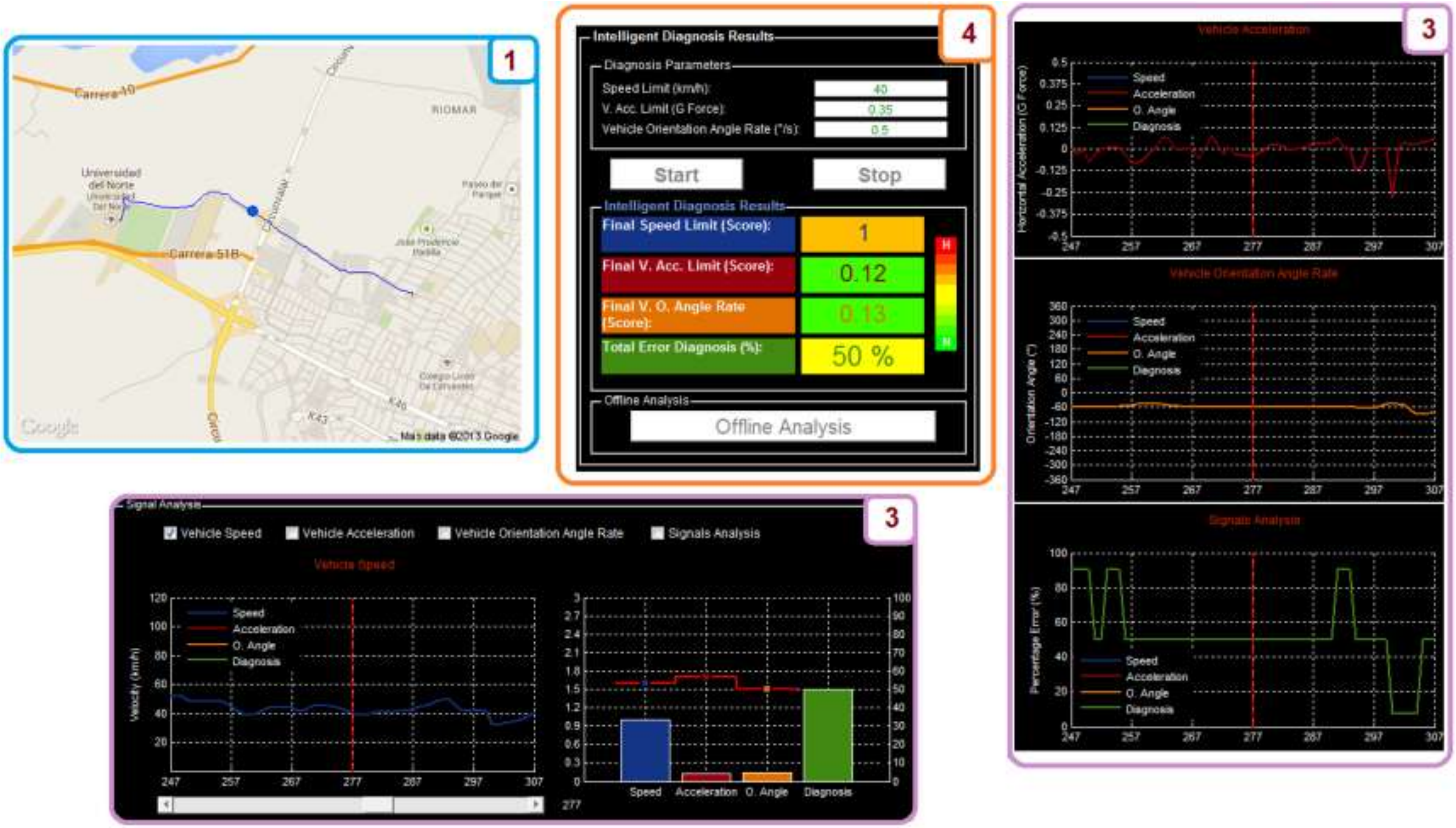


Fig. 5.3.2-2 - Software Interface for Driving Intelligent Diagnosis (Offline)

5.4 Driving Diagnosis Algorithm

The proposed algorithm for driving intelligent-diagnosis assessment task and the intelligent agent design with its characteristics properties are shown in this section.

The proposed approach implements Fuzzy Logic for the design of the intelligent agent responsible for the task of driving diagnosis. The proposed fuzzy inference engine for signal analysis from vehicle telemetry processes each monitored signal independently, so that it is finally possible to get a qualitative diagnosis of the driving process.

In *fuzzy inference engine* terms, each block diagram shown in Fig. 5.4-1 is explained in the following subsections.

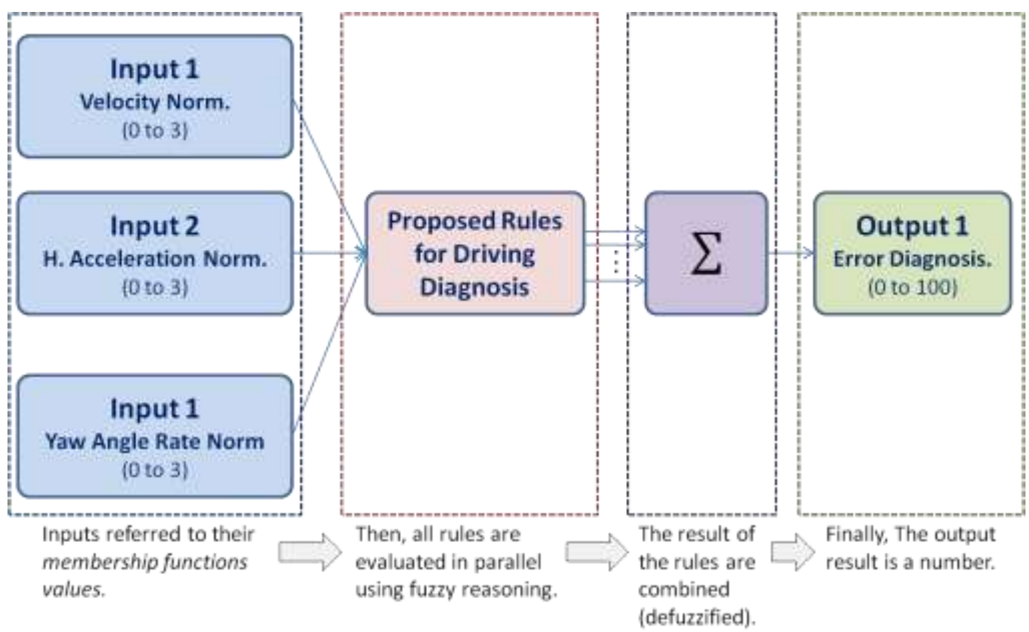


Fig. 5.4-1 - *Fuzzy Inference Engine* Design

Each block which characterizes the proposed algorithm will be explained below:

5.4.1 Inputs

Each normalized input of the monitored variables passes through each Membership functions' group that characterizes, so it is possible to define how each point is mapped to a membership value between zero (0) and one (1). In a general way, an equation for each fuzzy set is defined as follows:

$$A = \{x, \mu_A(x) | x \in X\}$$

Where $\mu_A(x)$ is the membership degree of x, being x a member of a set for each possible value for the X variable, so a $\mu(x)$ exists for each analyzed variable (velocity, horizontal acceleration and yaw angle rate). For example, it is possible to solve the problem of how high can be the variable velocity considering its magnitude at different levels as discussed below.

A function set for each variable is defined as follows.

Velocity: it is analyzed by three evaluation levels –low, normal, high. For this case, x value for the degree of membership evaluation $\mu_A(x)$ is the normalized value previously described as V_{Norm}. Its membership functions set are shown in Fig. 5.4.1-1.

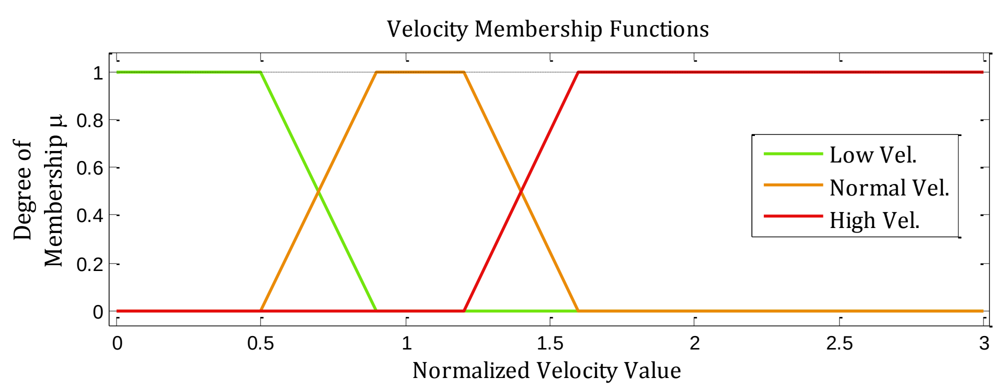


Fig. 5.4.1-1 - Velocity Membership Functions

Horizontal Acceleration: it is analyzed by three evaluation levels –Low H Acce, Normal H. Acce, Strong H Acce. For this case, x value for the degree of membership evaluation $\mu_A(x)$ is the normalized value previously described as HA_{Norm}. Its membership functions set are shown in Fig. 5.4.1-2.

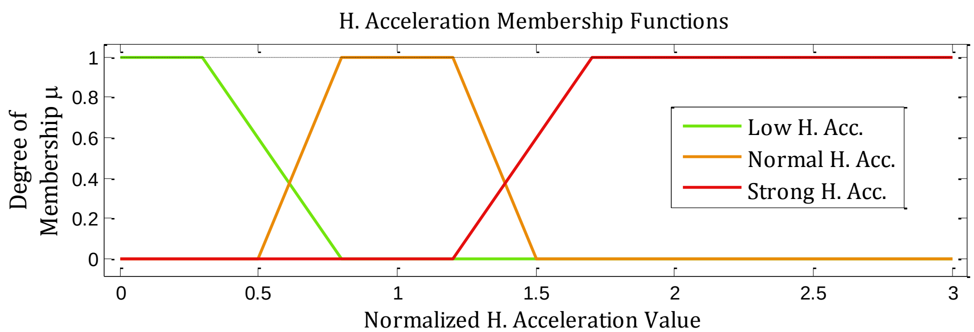


Fig. 5.4.1-2 - Horizontal Acceleration Membership Functions

Yaw Angle Rate: it is analyzed by two evaluation levels –Normal YAR, Excessive YAR. For this case, x value for the degree of membership evaluation $\mu_A(x)$ is the normalized value previously described as YAR_{Norm}. Its membership functions set are shown in Fig. 5.4.1-3.

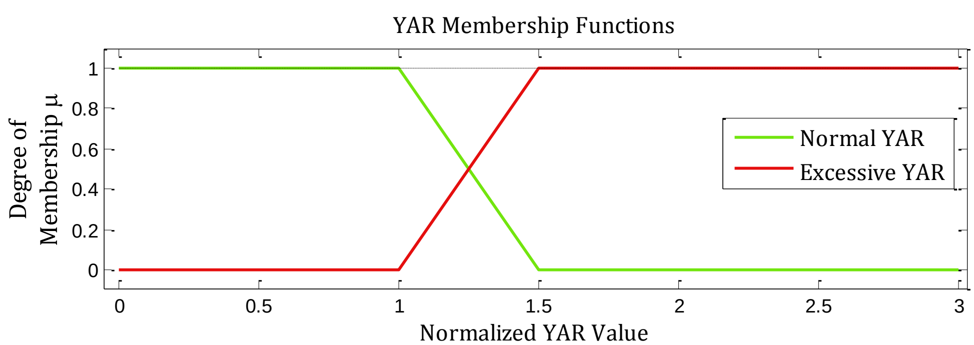


Fig. 5.4.1-3 - YAR Membership Functions

5.4.2 Fuzzy Inference Type and Rules

Fuzzy Inference Type: The proposed algorithm for the task of intelligent diagnosis of driving has two important features:

- *To abstract linguistic knowledge about traffic regulations and safe driving techniques for quantitative diagnosis of driving.*

- *To perform an intelligent diagnostic process of driving through rules from human experience on driving topics.*

For this reason a fuzzy inference ***Mamdani*** type is used (MARTIN DEL BRíO, Bonifacio; SANZ MOLINA, 2007), for satisfying design criteria that solves this problem.

Rules: based on International Driving Regulations –described in Chapter 2 a rules set for the fuzzy inference engine is proposed in order to approximate the expert knowledge of safe driving techniques and international driving regulations, for intelligent driving diagnosis. This set is shown in Table 5.4.2-1:

Rules	**Input**			**Output**
	Norm. Velocity	**Norm. H. Acce**	**Norm. Yaw Angle Rate**	**Erroneous Diagnosis**
1	High Vel.	None	Excessive YAR	Highly Risky
2	High Vel.	Strong H. Acc.	None	Highly Risky
3	Normal Vel.	Strong H. Acc.	Excessive YAR	Risky
4	Normal Vel.	Normal H. Acc.	Normal YAR	Moderate
5	Low Vel.	Normal H. Acc.	Normal YAR	Low
6	Low Vel.	Low H. Acc.	Normal YAR	Without Error
7	Low Vel.	Low H. Acc.	Excessive YAR	Without Error

Table 5.4.2-1 - Proposed Rules for Intelligent Diagnosis Approach

The proposed approach for the rules covers the following instances:

a) *Detection of highly dangerous maneuvers:* rules one to three describe the instances where potentially risky behaviors are evaluated in the driving process. Velocity excess (speeding), aggressive acceleration or deceleration and inappropriate or risky movements of the steering wheel are described here, as well as interaction among input variables in potential events that can lead an accident (as explained in Section 2.1.2 and 2.1.3).
b) *Detection of moderate risk maneuvers:* rules four to six describe some events could become risky events (as Section 2.1.2).
c) *Not dangerous or risky events:* these events occur when driver maneuvers are considered as right ones, according to the monitored signals analysis. Rule seven could contemplate a singular event in which a driver must make very tight junctions, maintaining control of the vehicle in terms of velocity and acceleration, according to the route features.

At this point, it is important to note that each rule seeks to represent Driving Rules and Secure Driving Techniques as shown in sections 2.1.1, 2.1.2 and 2.1.3. In that sense, definition such as *position on the carriageway, passing of the oncoming traffic, speed and distance, maneuvers, slowing down, intersections and obligation to give way* are represent on each of the proposed rules.

5.4.3 Defuzzification

Defuzzification allows getting a magnitude in order to determine the erroneous driving diagnosis from its fuzzy set. After result of aggregation from the combination of Membership Functions' input and output variables, a driving diagnosis is obtained for the instant time a sample is being evaluated. Output

Membership Functions –Percentage of Erroneous Diagnosis- are shown in the next subsection.

Because there is a Mamdani type fuzzy inference, defuzzification is implemented by the *centroid method* (MARTIN DEL BRíO, Bonifacio; SANZ MOLINA, 2007).

5.4.4 Output

Percentage of Erroneous Diagnosis is analyzed by five (5) evaluation levels – Without Error, Low, Moderate, Risky and Highly Risky. For this case, x value for the degree of membership evaluation $\mu_A(x)$ is set from 0% to 100%, according to given rules. Its membership functions set are shown in Fig. 5.4.4-1.

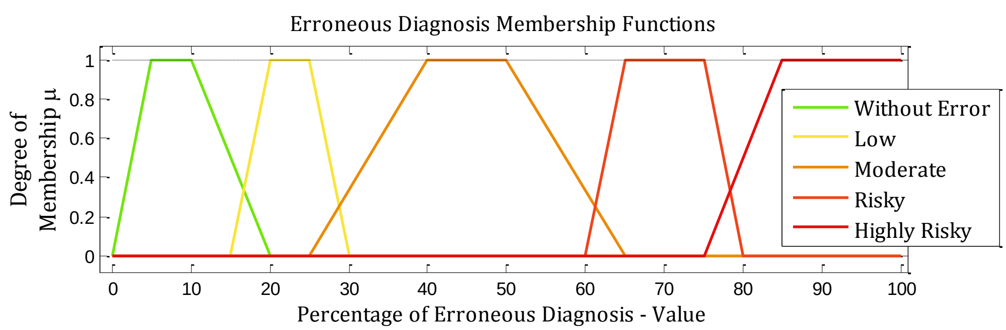


Fig. 5.4.4-1 - Percentage Erroneous Diagnosis Membership Functions

5.5 Limitations of Proposed Implementation

It is worth mentioning this Thesis does not aim to design and implement (at this early stage) a communication scheme for vehicular telemetry, and its performance during acquisition and data transmission. However, this dissertation analyzes the variables from a system of this type for perform an intelligent driving diagnosis. Therefore, the three variables monitored and used for this analysis are ***velocity*** (in *km/h units*) ***horizontal acceleration*** (in *G Force units*) ***yaw angle rate*** (in *°/s units*) available for GPS NMEA protocol or other vehicular telemetry device (see Section 2.2 .2).

It should be noted that the proposed acquisition and implementation for data transmission is susceptible to errors throughout communication, because in all cases the GPS must have line of sight to the sky for satellite tracking. For this reason, this study ignores the erroneous data due to lack of satellites in view, because they may contain wrong information (in these cases, recorded video would allow to validate incoming information).

Regarding video records, it is important to mention that video analysis will be performed manually, which means that using *video-time-tags* and *records number (in the development tool)* it is possible to match both video scenes and analysis.

In future work, it is expected that intelligent diagnosis system perfections acquisition stage towards the development of new researches or studies (more details will be given in Section 7).

PART III: EXPERIMENTAL RESULTS AND CONCLUSIONS

Chapter 6

Experimental Results Analysis

This chapter presents the discussion and analysis of the experiments on real scenarios that have been carried out. The results depicted in this chapter demonstrate the utility and feasibility of the overall proposed approach presented in the previous chapters.

6.1 Experimental Design

The set of experiments conducted in order to properly assess the monitoring system by detection of the potential dangerous events based on the analysis of monitored variables and diagnostic criteria (point to point) performed by the intelligent agent.

To do this, based on these experiments tested in a real environment a correct driving process, the one which is in between the allowed limits established in the place where experiments are performed (according to traffic regulations), was verified. By itself, the results at this stage of the research confirmed the accuracy of the intelligent agent diagnosis base on an abstraction of expert knowledge that was properly applied for this task (based on the background information regarding international harmonization of traffic regulations

(Organización Mundial de la Salud (OMS), 2013)). It is important to note that all tests are performed safely, so that the driver is always focused on driving safely and responsibly. Only some of the tests that create a degree of difficulty will be conducted in controlled environments (e.g. an empty parking).

As support for validation, the results of the diagnostic interface will be complemented by manually review of video records *in situ* in order to verify the performance of intelligent agent diagnosis, as well as the driver's perspective and direct influence of the traffic over all data.

Considering the above, for the experiments will take into account the following issues:

- ***Different scenarios:*** Routes contain different features from each other. The factors contemplated for design of the routes are namely:
    - *Traffic:* On route traffic density is defined based on the number of vehicles at a certain time of day. The reached speed could differ. It would depend on the allowed speed limit and the density of cars on the road.
    - *Turns:* Number of times the driver must perform intersections or make turns (as road) to complete the route. The speed limit is reduced in such scenarios.
    - *Straight line:* Routes through places without any crossings. In these places, typically, the speed limit may be higher than in those areas where intersections occur.

The proposed scenarios allow the proposed system evaluating the performance of the intelligent system and the driver, using the magnitude of the monitored signals as directly related to the actions performed while the driver test executes his actions.

- ***Categories of drivers:*** Drivers will be classified taking into account the criterion of age, and will be as follows:

    - *Drivers up to 20 years:* Drivers with driving license below 20 years.
    - *Drivers between 21 and 40 years:* Young and mature adults with driving license.
    - *Drivers over 41 years:* Mature adults and seniors with driving license.
- ***By gender:*** Drivers will be classified taking into account the criterion of gender:
    - *Men*
    - *Women*
- ***Times of the day:*** the testing shall also taking into account the tree times of day, be categorized as:
    - *Morning:* Any journey between 6:00 am and 10:00 am.
    - *Afternoon:* Any journey between 11:00 am and 4:00 pm.
    - *Night:* Any journey between 5:00 pm and 9:00 pm.

Any other time of day can be ruled out because the traffic flow would not be representative for the experiment.

In order to evaluate the performance of the intelligent driving diagnostic system is necessary to verify video records and route features to see if the proper alert signal is activated when it has to. This took into account the evaluation criteria pre-configured and diagnostics issued by the intelligent agent. For this reason the analysis of the three monitored variables (speed, horizontal acceleration, and vehicle yaw angle rate) was proposed considering the same route. At the same time, it will be possible to perform a detailed analysis of the diagnosis made by the intelligent agent in each of the cases.

The following is the outline of routes used to perform the experiments:

6.1.1 Route 1 –Straight Line

At route number one speed limits vary according to road conditions. In the first 1.5 km of the route the permitted speed limit is 35 km/h while the remaining 1.7 km, the average speed limit is 50 km/h, on the understanding that that the allowed limit is only a maximum and must not be exceeded under any circumstance.

This is the shortest route performed. However, its own characteristics allow carrying out important tests about driver performance using the intelligent system. The following table contains the most significant characteristics of this route:

Route details:	
Approximate Distance Traveled:	3,2 km
Speed limits:	40-60 km/h
Approximate Number of Turns:	3
Approximate Number of Straight Line:	7
Approximate Number of intersections:	2

Table 6.1.1-1 - Route 1 Characteristics

This tour has three important sections. The most common is "Straight line" section, in which it is expected drivers would almost reach speed limit. Also "Turns" and "Intersection" will allow verifying whether the driver performed a safe maneuver. Fig. 6.1.1-1 shows the route and the three sections.

Fig. 6.1.1-1 - Route 1 Barranquilla, Atlántico – Colombia

6.1.2 Route 2–Intersections, Straight Lines and Turns

At route number two Speed limits vary according to road conditions. The first 4.4 km of the route the speed limit is 35 km/h while the remaining 4 km, the average speed limit is 50 km/h, on the understanding that the limits are only permitted maximum, they must not be exceeded under any circumstance. For this route there are seven (7) different types of rotation and some steps through intersections.

This is the longest route performed. However, its own characteristics allow carrying out important driver performance tests using the intelligent system. The following table contains the most significant characteristics about this route:

Route details:	
Approximate Distance Traveled:	8,4 km
Speed limits:	40-60 km/h
Approximate Number of Turns:	7
Approximate Number of Straight Line:	5
Approximate Number of intersections:	Several

Table 6.1.2-1 - Route 2 Characteristics

This tour has three important sections. In the “Turns” section it is expected that the driver would perform a secure maneuver slowing down before a turn. Also, the “Straight line” section allows assessing whether the driver maintains secure speed limits without reaching it. Particularly, “Intersection” will allow verifying whether the driver performed a safe turn maneuver and also break performance. Fig. 6.1.2-1 shows the route and the three sections.

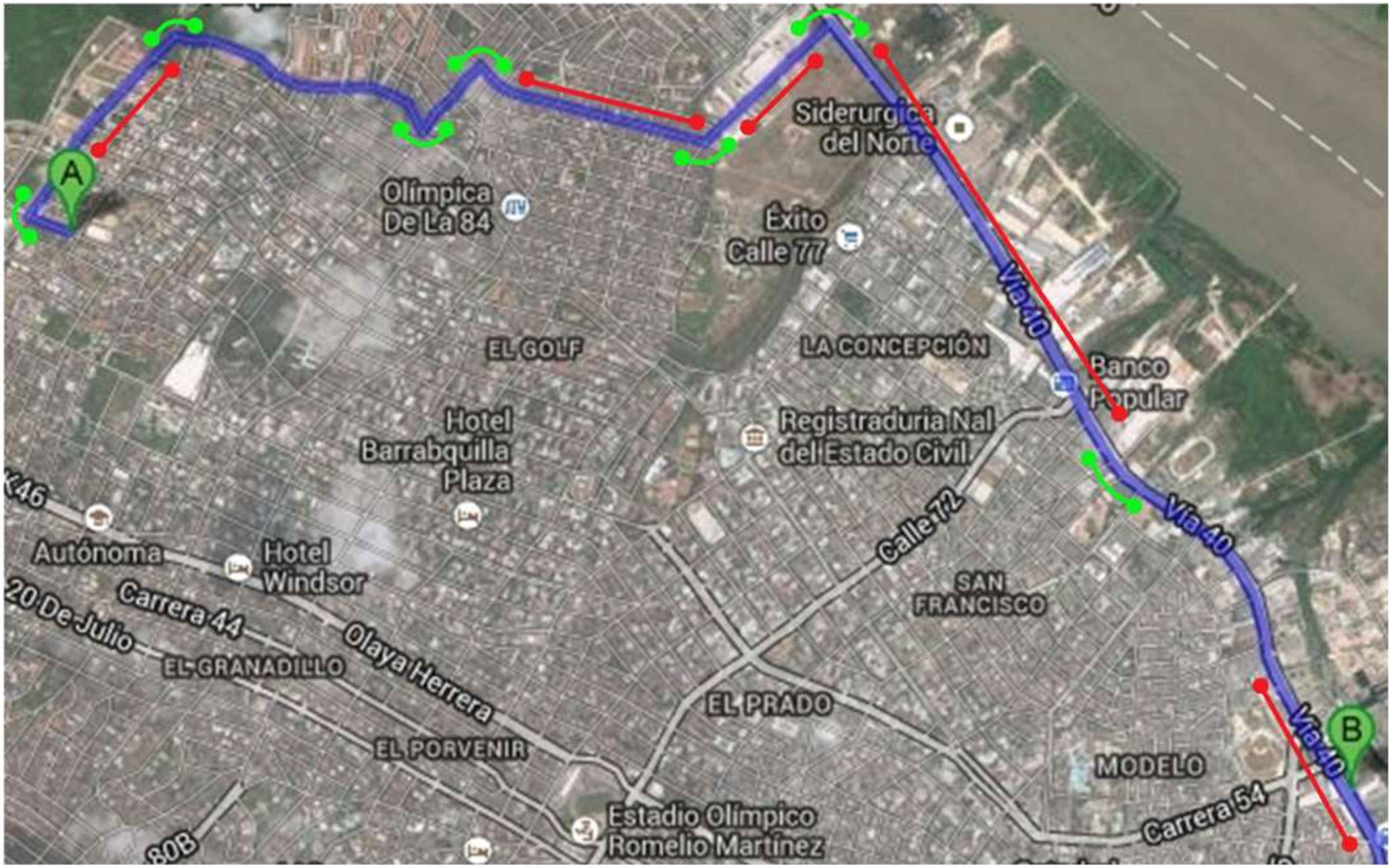


Fig. 6.1.2-1 - Route 2 Barranquilla, Atlántico – Colombia

6.1.3 Route 3 –Low Speed Limits and Intersections

At the third route speed limit is 40 km on average in urban areas in which this tour is performed. The average speed limit is 35 km/h, on the understanding that the limit is only allowed and the maximum should not be exceeded under any circumstance. For this route there are three different types of rotation and some steps through intersections. Compared to route 1 and route 2, this particular route has a greater number of signals and lights which are important for the whole trip and is also important in the intelligent agent diagnostic criteria.

This route has the lowest speed limits. However its own characteristics allow carrying out important tests about driver performance using the intelligent system, such as driver performance on each variable. The following table contains the most significant characteristics about this route:

Route details:	
Approximate Distance Traveled:	3,3 km
Speed limits:	40 km/h
Approximate Number of Turns:	3
Approximate Number of Straight Line:	4
Approximate Number of intersections:	Several

Table 6.1.3-1 - Route 3 Characteristics

This tour has three important sections. In the "Turns" section it is expected the driver would perform a secure maneuver slowing down before a turn. Also, the "Straight line" section allows assessing whether the driver maintains secure speed limits without reaching it. Particularly, "Intersection" will allow verifying whether the driver performed a safe turn maneuver and also break performance. In all these section the speed limit is lower than the others. Fig. 6.1.3-1 shows the route and the three sections. Notice how, this particular route has several stop signs and traffic lights.

Fig. 6.1.3-1 - Route 3 Barranquilla, Atlántico – Colombia

All experiments will be recorded inside and outside the vehicle as shown in Fig. 6.1-1 using telemetry data acquisition vehicle. GPS data will be sent via Internet to the storage database. Diagnostic analysis issued by the intelligent system will be validated using the information recorded by video accessing it manually.

Fig. 6.1-1 - Video Recording Format for Driving Tests

6.2 Analysis of Results

With the methodology of the experiments presented above, the results of the experiments performed are now described in detail.

The results will be shown according to the proposed routes. On each of these, there will be particular emphasis on the diagnostic performance of the intelligent agent. Based on the video records, the final diagnosis made by the intelligent system will be verified.

6.2.1 Intelligent Driving Diagnosis Verification

Once the experiments were performed, it is quite important to verify the intelligent diagnosis on each route. Below, it is presented some samples of each route. Each scored signals and the intelligent diagnoses number would be presented.

- **Route 1 - Straight Line**

Here it will be shown a sample of this route. In this run, each of the signals monitored in terms of the degree of membership (*score*)[11] for diagnosis process are presented. Also, the diagnosis performed by the intelligent agent is presented at this point.

The following are the results of Intelligent Diagnosis System:

Driver A - Drivers until 20 years (NC)				
Place (latitude, longitude)	**Velocity (Score)**	**H. Acceleration (Score)**	**Yaw Angle Rate (Score)**	**Inst. Error Diagnosis (Percentage)**
Cr 53 C. C. Price Smart (11.0151,-74.8304)	0,39	**0,59**	0	13,8%

Table 6.2.1-1 - Diagnosis Results for a Driver for Route 1

In this case, the diagnosis performed by the intelligent system during the route for one driver identifies anomalies in the variable “horizontal acceleration" in the section of the route with “straight line” shape. The video record indicates a slightly irregular acceleration at which the system decides it is not a risky maneuver and calls "Without Error" with 13.8% (See Fig. 6.2.1-1).

[11]The word *score* would be referred to the degree of membership on each variable. It would indicate (as was mentioned above) how the normalized variable fits on proposed membership levels.

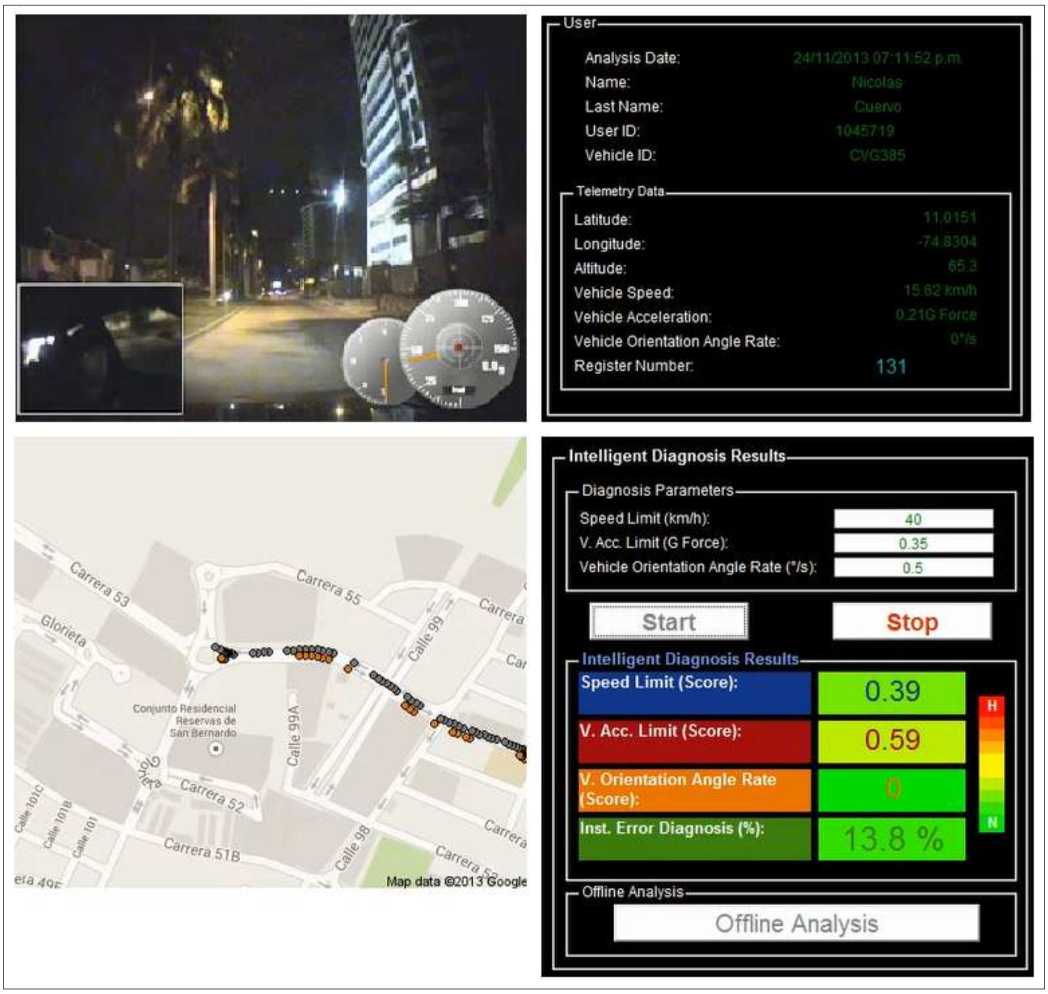


Fig. 6.2.1-1 - Interface Diagnosis Results for Route 1

- **Route 2 - Intersections, Straight Lines and Turns**

Here it will be shown a sample of this route. In this run, each of the signals monitored in terms of the degree of membership (*score*) for diagnosis process are presented. Also, the diagnosis of the intelligent agent is presented at this point.

The following are the results of the Intelligent Diagnosis System:

Driver A - Drivers until 20 years (DO)				
Place (latitude, longitude)	**Velocity (Score)**	**H. Acceleration (Score)**	**Yaw Angle Rate (Score)**	**Inst. Error Diagnosis (Percentage)**
Cr 59 Centro Bíblico (11.0075,-74.8036)	**1,12**	0,05	0,05	50,0%

Table 6.2.2-1 - Diagnosis Results for a Driver for Route 2

In this case, the diagnosis performed by the intelligent system during the route for one driver identifies an important speed increase, in this case the system called "Moderate" with a 50%. The video record suggests that the speed limit is being exceeded in an inappropriate way (See Fig. 6.2.1-2) considering that this route has many turns and intersections.

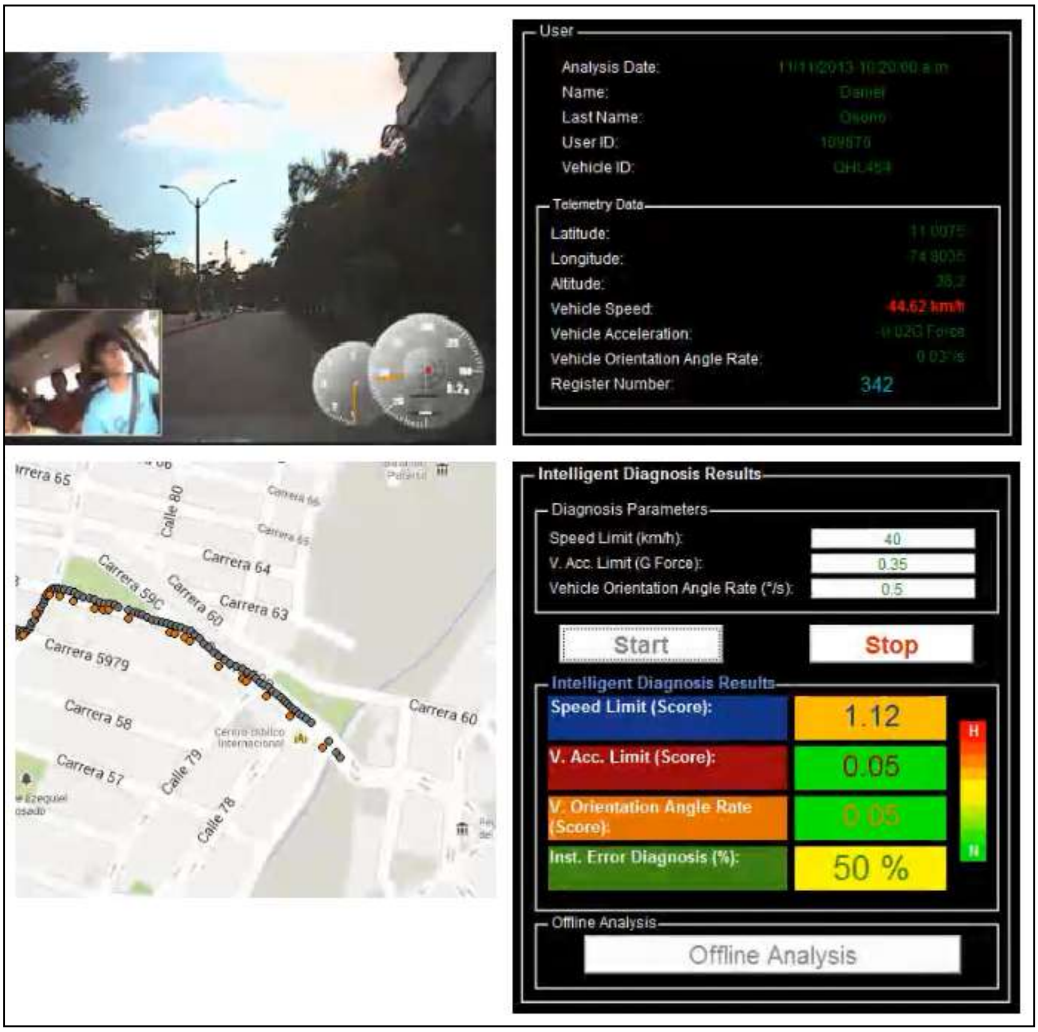


Fig. 6.2.1-2- Interface Diagnosis Results for Route 2

- **Route 3 - Low Speed Limits and Intersections Road**

Here it will be shown a sample of this journey. In this run, each of the signals monitored in terms of the degree of membership (*score*) for diagnosis process are presented. Also, the diagnosis of intelligent agent is presented at this point.

The following are the results of Intelligent Diagnosis System:

Driver A - Drivers over 40 years (LP)				
Place (latitude, longitude)	**Velocity (Score)**	**H. Acceleration (Score)**	**Yaw Angle Rate (Score)**	**Inst. Error Diagnosis (Percentage)**
Cr 46 and Cll 91 (11.004,-74.8253)	0,27	0,26	**1,16**	7,5%

Table 6.2.3-1 - Diagnosis Results for a Driver for Route 3

In this case, the diagnosis performed by the intelligent system during the route for one driver identifies an important yaw angle rate increase, in this case the system called "Without Error" with a 7.5%. The video record suggests that the high yaw angle rate score is because of a left turn (See Fig. 6.2.1-3).

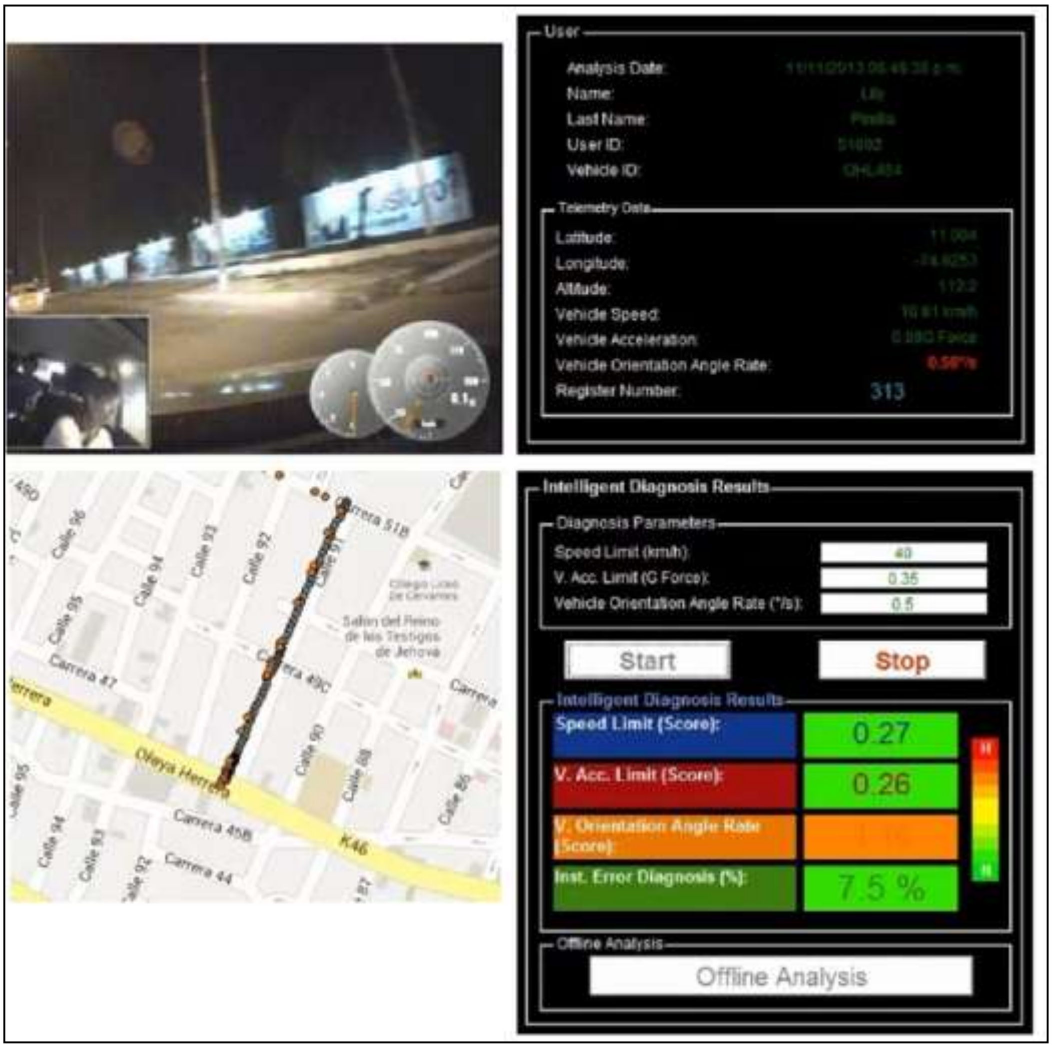


Fig. 6.2.1-3 - Interface Diagnosis Results for Route 3

6.3 Driver Diagnosis Analysis

It is presented now an analysis about driving performance taking into account the following criteria:

- **Analysis by categories and route characteristics**
- **Analysis by time of the day and route characteristics**
- **Analysis by gender and route characteristics**

Different persons agree participating in this test. They were grouped into categories so the system could conduct an orderly information analysis. The following table shows the percentage of participants in each category:

Categories	Participants (%)	Participants
Drivers until 20 years	29%	4
Drivers between 21 and 40 years	43%	6
Drivers over 41 years	29%	4
Total	100%	14

Table 6.3-1 – Percentage of Participants by Category

Gender	Participants (%)	Participants
Masculine	57%	8
Feminine	43%	6
Total	100%	14

Table 6.3-2 – Percentage of Participants by Gender

6.3.1 Analysis by Categories and Route Characteristics

Notice that participants in this experiments fit into the proposed categories, such categories are (see Section 6.1):

- *Drivers until 20 years:* Drivers with driving license.
- *Drivers between 21 and 40 years:* Young and mature adults with driving license.
- *Drivers over 41 years:* Mature adults and seniors with driving license.

Now, analysis based on *scored signals* and *error diagnosis* is presented. The next table shows the average of total scores per variable (Velocity score, H. Acceleration score and YAR score) and also the total error diagnosis result per category. Notice that the three different routes would be analyzed.

The results below show the percentage of error (averages) detected in the scores of each of the signals. In here 0% represents no error detected and 100% the maximum error. This convention will be maintained for the three variables analyzed and also for the intelligent diagnosis of driving. The colors represent three different levels:

- White: the lowest error percentage
- Dark blue: the highest percentage error

- Light blue: the percentage of intermediate error

Route 1 - Straight Line Road				
Categories	**Vel. Score (%)**	**H. Acce. Score (%)**	**YAR Score (%)**	**Total Intelligent Diagnosis (%)**
Drivers until 20 years	44,17	7,10	38,25	25,29
Drivers between 21 and 40 years	42,57	13,59	29,95	17,67
Drivers over 40 years	37,39	9,53	31,81	18,32

Table 6.3.1-1 – Average Scores and Average Total Intelligent Diagnosis for Route 1

For route 1, the Table 6.3.1-1 shows that drivers over 41years do not drive fast compared to those drivers less than 20 years, suggesting that teenagers tend to drive with a higher velocity. In addition, drivers between 21 and 40 years tend to perform more abruptly acceleration or deceleration maneuvers. Finally, drivers under 20 years have a higher percentage of yaw angle rate, suggesting that frequently perform lane changes, while drivers between 21 and 40 years do not perform this action so often. This route does not have many turns and intersections. The intelligent system diagnosed the three categories and yield results that indicate that drivers under 20 years have the highest error score. Note that the total percentages issued by the intelligent diagnosis are not considered risky taking into account driving conditions; however, it is possible to find some more erroneous behaviors in this category.

Route 2 - Intersections, Straight Lines and Turns Road				
Categories	**Vel. Score (%)**	**H. Acce. Score (%)**	**YAR Score (%)**	**Total Intelligent Diagnosis (%)**
Drivers until 20 years	38,19	14,60	36,17	19,94
Drivers between 21 and 40 years	40,58	6,67	39,49	19,24
Drivers over 40 years	38,34	9,48	34,79	21,38

Table 6.3.1-2 – Average Scores and Average Total Intelligent Diagnosis for Route 2

In Route 2, the analysis for Table 6.3.1-2 shows that drivers between 21 and 40 years tend to drive slightly faster than the other categories. On this route, drivers under 20 years reached lower velocities. However, drivers under 20 years tend to perform more abrupt acceleration or deceleration maneuvers while drivers between 21 and 40 years do not. Finally, drivers between 21 and 40 years have a higher percentage of yaw angle rate, suggesting that frequently perform lane changes, while drivers over 41 years do not perform so often this maneuver. The intelligent system diagnosed that over 41 years have the higher error score. Note that the total percentages issued by the intelligent diagnosis are not considered risky taking into account driving conditions; however, it is possible to find some more erroneous behaviors in this category.

Route 3 - Low Speed Limits and Intersections Road				
Categories	**Vel. Score (%)**	**H. Acce. Score (%)**	**YAR Score (%)**	**Total Intelligent Diagnosis (%)**
Drivers until 20 years	40,85	13,15	35,09	18,68
Drivers between 21 and 40 years	38,06	14,72	38,68	19,29
Drivers over 40 years	42,49	7,90	32,65	18,01

Table 6.3.1-3 – Average Scores and Average Total Intelligent Diagnosis for Route 3

In route 3, the table 6.3.1-3, the analysis shows that drivers over 41 years tend to drive slightly faster than the other categories. On this route, drivers between 21 and 40 years reached lower velocities. However, drivers between 21 and 40 years tend to perform more abrupt acceleration or deceleration maneuvers while drivers over 41 years do not. Finally, drivers between 21 and 40 years have a higher percentage of yaw angle rate, suggesting that frequently perform lane changes, while drivers over 41 years do not perform so often this maneuver. The results of intelligent system diagnosis indicate that drivers between 21 and 40 years have the higher error score. Note that the total percentages issued by the intelligent diagnosis are not considered risky taking into account driving conditions; however, it is possible to find some more erroneous behaviors in this category.

Finally, when analyzing all route characteristics, in routes with more straight lines (as route 1) the drivers are more likely to maintain high velocity levels or very close to the limit. However, on routes with less straight lines, the drivers tend to decrees the velocity. Also, in all routes a slightly increase of yaw angle rate score were detected, suggesting in many cases drivers tend to perform frequently lane changes. Some of the reasons which could motivate this behavior are traffic density and the need to keep on moving in order to avoiding traffic jam. Taking into account the mentioned above, it is important to remark that the intelligent system diagnoses the highest error score in route 1 and the fewer score in route 3. This behavior was expected because high velocity levels increase the probability of a risky situation also considering the other variables.

6.3.2 Analysis by Times of the Day and Route Characteristics

Maintaining the proposed conventions, comparisons of the intelligent driving diagnosis by times of the day and route characteristics will be presented as follows:

Route 1 - Straight Line Road				
Time of the day	**Vel. Score (%)**	**H. Acce. Score (%)**	**YAR Score (%)**	**Total Intelligent Diagnosis (%)**
Morning	44,72	12,11	26,74	12,73
Afternoon	39,20	7,29	35,40	22,25
Night	38,86	11,32	36,59	24,90

Table 6.3.2-1 - Average Scores and Average Total Intelligent Diagnosis for Route 1

Analyzing the different categories at a time of day (Table-6.3.2-1) on route 1 is possible to note that evaluated drivers tend to increase velocity in the morning, however, at night it is not so common. This may be due to traffic density in the morning was not so high compared to the night. Moreover, in the morning a slight change in acceleration or deceleration maneuvers is also registered, although it is not very high, is higher compared to the night and afternoon. The score variable corresponding to the yaw angle rate is higher at night than in the morning, suggesting drivers perform more frequent lane changes on this route at this time of the day. The intelligent system diagnosed the three times of day tested, at night more error occurs. Note that the total percentages issued by the intelligent diagnosis are not considered risky taking into account driving conditions; however, it is possible to find some more erroneous behaviors in the night than in any other times of day.

Route 2 - Intersections, Straight Lines and Turns Road				
Time of the day	**Vel. Score (%)**	**H. Acce. Score (%)**	**YAR Score (%)**	**Total Intelligent Diagnosis (%)**
Morning	45,91	8,94	37,47	24,81
Afternoon	34,43	7,02	36,43	24,48
Night	37,04	14,74	36,47	13,00

Table 6.3.2-2 - Average Scores and Average Total Intelligent Diagnosis for Route 2

In route 2, (Table 6.3.2-2) similarly to the route 1, it is possible to note that the evaluated drivers tend to increase velocity in the morning, however, at afternoon it is not so common. This may be due to the fact that traffic density in the morning was not so high compared to the afternoon. Moreover, in the night a slight change in acceleration or deceleration maneuvers is also registered, although it is not very high, is higher compared to the morning and afternoon. The score variable corresponding to the yaw angle rate is higher at morning than in the afternoon, suggesting drivers perform more frequent lane changes on this route at this time of the day. The intelligent system diagnosed the three times of day tested, at mornings more error occurs. Note that the total percentages issued by the intelligent diagnosis are not considered risky taking into account driving conditions; however, it is possible to find some more erroneous behaviors in the morning than in any other times of day.

Route 3 - Low Speed Limits and Intersections Road				
Time of the day	**Vel. Score (%)**	**H. Acce. Score (%)**	**YAR Score (%)**	**Total Intelligent Diagnosis (%)**
Morning	39,09	10,73	35,63	17,11
Afternoon	41,11	9,86	37,04	14,47
Night	41,45	13,73	33,53	23,13

Table 6.3.2-3 - Average Scores and Average Total Intelligent Diagnosis for Route 3

Finally, in route 3 (Table-6.3.2-3) is possible to note that evaluated drivers tend to increase velocity in the night, however, at morning it is not so common. This may be due to traffic density in the night was not so high compared to the morning. Moreover, in the night a slight change in acceleration or deceleration maneuvers is also registered, although it is not very high, is higher compared to the morning and afternoon. The score variable corresponding to the yaw angle rate is higher at afternoon than in the night, suggesting drivers perform more frequent lane changes on this route at this time of the day. The intelligent system diagnosed the three times of day tested, at night more error occurs. Note that the total percentages issued by the intelligent diagnosis are not considered risky taking into account driving conditions; however, it is possible to find some more erroneous behaviors in the night than in any other times of day.

6.3.3 Analysis by Gender and Route Characteristics

Maintaining proposed conventions, now it is going to be compared the intelligent driving diagnosis by gender and route characteristics.

Route 1 - Straight Line Road				
Gender	**Vel. Score (%)**	**H. Acce. Score (%)**	**YAR Score (%)**	**Total Intelligent Diagnosis (%)**
Feminine	39,94	10,07	40,50	18,02
Masculine	41,79	10,39	26,27	21,66

Table 6.3.3-1 - Average Scores and Average Total Intelligent Diagnosis for Route 1

Comparing gender, men drivers in this route (Table 6.3.3-1) increased the velocity more often than women. Similarly, men present a slight change in acceleration or deceleration maneuvers, being higher than in women. However, the score variable corresponding to the yaw angle rate is higher in women than in men, suggesting women perform more frequent lane changes on this route. The intelligent system diagnosed that men performed some more errors than women.

Route 2 - Intersections, Straight Lines and Turns Road				
Gender	**Vel. Score (%)**	**H. Acce. Score (%)**	**YAR Score (%)**	**Total Intelligent Diagnosis (%)**
Feminine	39,04	9,88	39,05	13,90
Masculine	38,92	11,02	35,34	24,09

Table 6.3.3-2 - Average Scores and Average Total Intelligent Diagnosis for Route 2

Table 6.3.3-2 shows Comparing gender, women drivers in this route increased the velocity more often than men. Similarly, men present a slight change in acceleration or deceleration maneuvers, being higher than in women. However, the score variable corresponding to the yaw angle rate is higher in women than in men, suggesting women perform more frequent lane changes on this route. As in route 1, the intelligent system diagnosed that men performed some more errors than women.

Route 3 - Low Speed Limits and Intersections Road				
Gender	**Vel. Score (%)**	**H. Acce. Score (%)**	**YAR Score (%)**	**Total Intelligent Diagnosis (%)**
Feminine	40,77	9,81	37,06	15,68
Masculine	40,49	13,16	33,72	21,13

Table 6.3.3-3 - Average Scores and Average Total Intelligent Diagnosis for Route 3

Table 6.3.3-3 shows Comparing gender, women drivers in this route increased the velocity more often than men. Similarly, men present a slight change in acceleration or deceleration maneuvers, being higher than in women. However, the score variable corresponding to the yaw angle rate is higher in women than in men, suggesting women perform more frequent lane changes on this route. Similarly to route 1 and route 2, the intelligent system diagnosed that men performed some more errors than women.

According to the studies performed by (Fondo de Prevención Vial, 2013) "Fondo de Prevención Vial" in Barranquilla, men are more frequently involved in traffic accidents than women. Comparing those statistics with results issue by proposed intelligent driving diagnosis systems it is important to note that men were also detected as the gender which performs more inadequate maneuvers while driving.

6.3.4 Route Analysis and Hazardous Areas

Finally, it is presented the most hazardous areas and routes according to the data analyzed. Table 6.3.4-1 it is possible to note that route two (2) has the highest total intelligent diagnosis percentage of error. That suggests that drivers perform more inadequate maneuvers in this route than in the other routes. However, this percentage is not considered risky taking into account driving conditions; but it is the highest comparing route one (1) and route three (3).

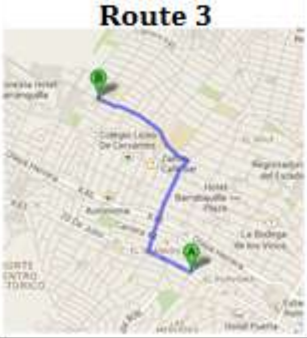
Route Analysis and Hazardous Areas				
Route	**Vel. Score (%)**	**H. Acce. Score (%)**	**YAR Score (%)**	**Total Intelligent Diagnosis (%)**
Route 1 	40.93	10.24	32.91	19.96
Route 2 	38.97	10.58	36.77	20.17
Route 3 	40.62	11.62	35.26	18.61

Table 6.3.4-1 - Average Scores and Average Total Intelligent Diagnosis per Route

According to the studies performed by (Fondo de Prevención Vial, 2011) “Fondo de Prevención Vial” in Barranquilla, some of the most hazardous areas (taking into account traffic accidents between 2003 and 2009) are “Vía 40” and “Carrera 51B”. By analyzing this study and comparing those statistics with results issued by the “Intelligent Driving Diagnosis System” it is important to note that “Via 40” was also detected as one of the most risky area according to the performed driver’s assessment.

6.4 General Analysis

Generally the Intelligent Agent executes correctly the driving diagnose for any kind of drivers. However, in none of these cases a corrective support for the driving process of the person is provided.

Also, this system allows comparing the result with those provided by “Fondo de Prevención Vial”. In this proposed experiments intelligent driving diagnosis is consistent and comparable with the study presented by “Fondo de Prevención Vial”. This comparison suggests that this system could by also implement for supporting this kind of studies but providing online driver assistance.

It is possible to notice that sometimes the yaw angle rate variable is misunderstood by the system. This is because the data taken for this variable may be inaccurate due to the availability of satellites in view. It means that it is possible to have some measuring mistakes due to obstacles standing between the GPS antenna and the sky (e. g. buildings, tall constructions or trees).

It can be noted that in the straight-line paths some drivers exceed or nearly exceed the speed limit. However, the intelligent diagnosis correctly interprets whether this represents a non-dangerous maneuver or not.

The horizontal acceleration variable has a high impact on the physiology of the driver. This variable was not exceeded in any of the tests since an excessively high acceleration or deceleration could be achieved only in collision events. However, slight increases in this variable were noted during acceleration or abrupt deceleration in cases where high speed levels were reached.

Chapter 7

Conclusions and Future Works

This chapter summarizes the main conclusions arisen from the analysis and discussion of the results reported in this work. The chapter also reviews the dissertation's scientific contributions and then discusses promising directions for future research and applications in certain topics in which this research can be extended. Finally, some concluding remarks are drawn.

7.1 Analysis and Discussion of Results

The work and the results presented in Chapters 4, 5, and 6 shows it is possible to present the proposal of an “integrated vehicular system with black box capability and intelligent driving diagnosis" based on the presentation of the characteristic properties of an intelligent diagnosis agent, getting accurate results from the intelligent driving diagnosis according to proposed quantitative assessment levels. These results show the relevance and importance of the implementation of vehicle safety systems, contributing to the research of ITSS in Safety Systems as was presented in Chapters 2 and 3.

The proposed intelligent diagnosis agent allows diagnosing different types of drivers in different case of studies (scenarios) (see Section 6.2, 6.3 and 6.4). Based on the records of vehicular telemetry data and the Adapted Prototype for Vehicle Telemetry Data Acquisition and Video Recording, it is possible to note that in all cases where there was a line-of-sight for satellite tracking, the intelligent diagnosis was possible.

This new proposal contributes to the presentation of the characteristic properties for the intelligent diagnosis agent. This seeks presents a structured approach to make possible the driving diagnosis task (see Section 4.2).

7.2 Main Contributions

Based on motivation presented in Chapter 1 and the problem statement presented in Chapter 4, this Thesis contributes with a computational tool that performs an intelligent driving diagnosis based on related vehicle motion signals. Specifically, it presents a structured design of the characteristic properties for the intelligent diagnosis agent developed for this purpose.

The main contributions of this Thesis are summarized as follows:

- *An intelligent approach of an expert agent implemented by fuzzy logics capable of analyzing, using different criteria, information related to driving maneuvers using signals referred to vehicle movement (velocity, horizontal acceleration, yaw angle rate). The expert agent approach design takes into account both Secure Driving Techniques and Driving Rules seeking to diagnose potentially hazardous maneuvers while driving.*

This Thesis presents the proposal for the intelligent driving diagnosis based on: a) the formal presentation of an intelligent agent implemented in "Fuzzy Logic" which takes into account both Secure Driving Techniques and Driving Rules (see Section 4.2), and b) the proposal for the driving diagnosis based on the selection of three signals Referred to vehicle movement (velocity, horizontal acceleration, and yaw angle rate) (See Section 5.2).

- *To diagnose the driving process, a computational tool, which integrates online and offline diagnosis adaptable to different kind of scenarios, was* *developed. In addition, a scheme of integrated vehicular systems with black box capabilities was implemented.*

Here, the requirements of an adapted prototype for acquiring vehicular telemetry signals and video recording register (with black box properties) were presented (See Section 5.2). The implementation of this prototype allowed the whole system to evaluate several case studies.

7.3 Future Research and Directions

The development and introduction of an intelligent agent, focused on driving diagnosis as a real environment application, represents an interest on the evolution of driver assistance systems and especially remote driving assistance. In this sense, this Thesis contributes in the field of Security Systems given by the ITS Scheme (see Figure 2.4-1). On the other hand, this proposal allows future research implementing soft computing techniques or analysis signals, but maintaining the given structure in this work.

The results obtained in this dissertation show the utility of an intelligent driving diagnosis for evaluating and comparing the performance of drivers in different scenarios. Furthermore, this works allows performing other important researches such as driver characterization, characterization of high-risk areas while driving, among others.

Finally, these results need to develop improvements in many aspects before mentioned require further study. So, below are some topics to be reviewed for future work:

- Characterization of drivers (Drowsiness effect of psychoactive substances, etc.)
- Characterization of high-risk areas while driving
- Digital image processing for intelligent driving diagnostic support
- Online Intelligent Driving Assistance

7.4 Concluding Remarks

This Thesis addresses the issue of intelligent driving diagnosis as a need to know whether a driver commits mistakes while driving or not, and to determine the degree of risk in a specific situation (see Section 6.2, 6.3 and 6.4). The faculties of the intelligent driving diagnosis approach based on a proposed intelligent agent, at its early stage, certainly satisfied a remote driving assessment process, allowing knowing the performance of various drivers in different scenarios. Also, this Thesis contributes to the field with a diagnostic scheme for real situations; which means that system itself can be used in any kind of roads and also under different frameworks (as speed limits, road conditions, traffic regulations, among others).

The advantages that this research presents are still subject to future exploration (in its first phase as a real-time and real-conditions proposed approach). Since the efforts of Research in the field of Security Systems area look for safe processes.

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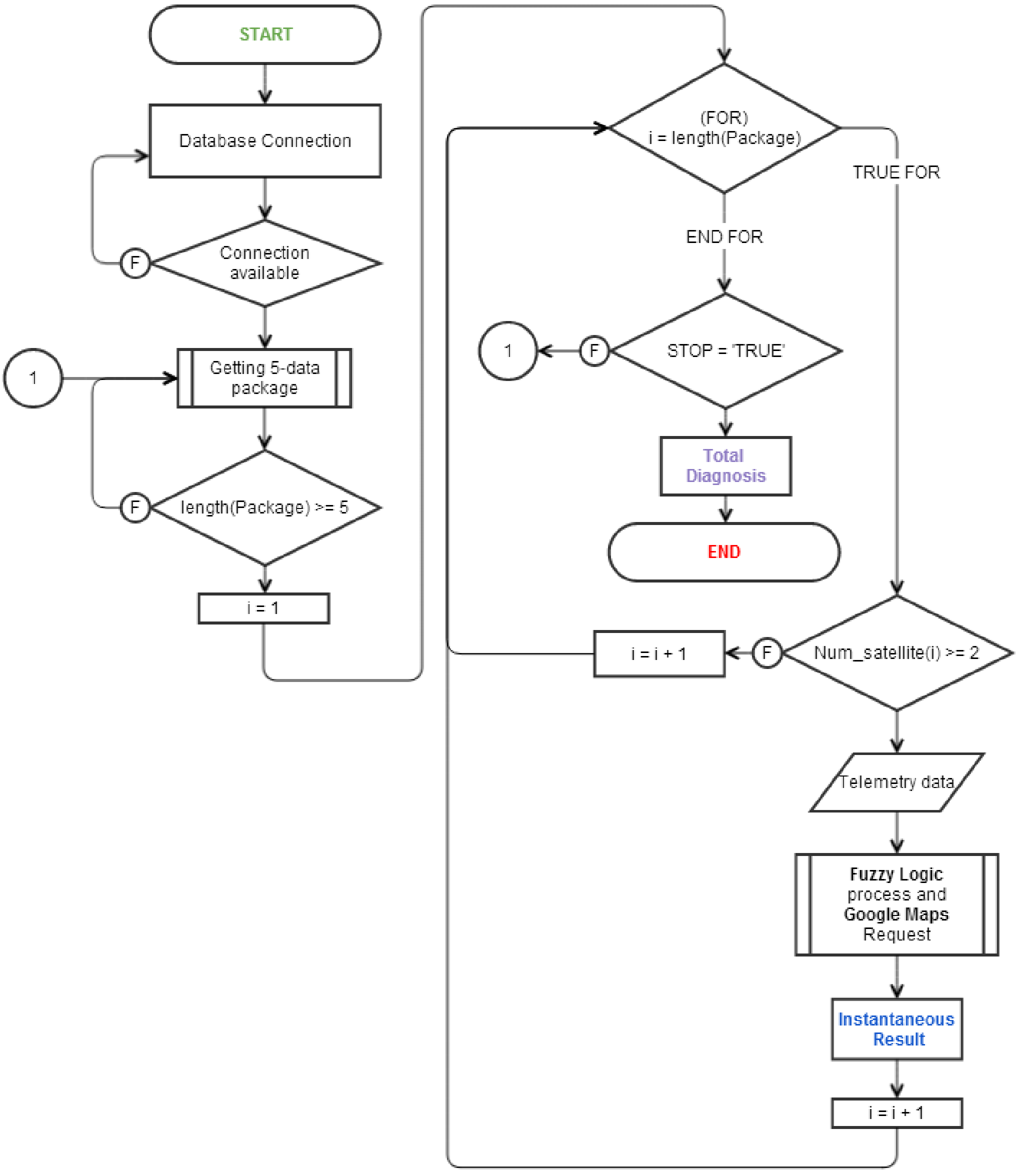
ANNEXES

A 1 – Driving Diagnosis System Flow Chart



A 2 – FIS MATLAB Toolbox Configuration