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Multidisciplinary Practicals in Satellite Navigation Systems in Road Vehicles for Subjects Taught in Different Engineering Schools*

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Aimed at giving students training in transversal skills, such as multidisciplinary group work or putting acquired knowledge into practice, a series of practical sessions has been developed involving teachers and students from two different areas of expertise in two Schools of Engineering (School of Industrial Engineering and School of Computer Science of the Polytechnic University of Madrid). The ultimate objective of the practical sessions is to develop a driving assistance system (ADAS) based on satellite positioning. It is hoped that this integrative experience will make full use of each group's knowledge so as to be able to offer students a global view of both theory and practice. In this way, a synergy will be promoted between mechanical engineering and computer science, a true technological reflection of the automobile sector where a fusion of disciplines is essential.

Keywords: multidisciplinary teaching; practicals; navigation system; road vehicle

1. INTRODUCTION

THE TEACHING OF ENGINEERING has undergone a change of focus as to which aspects should have the greatest emphasis. The traditional approach focused mainly on knowledge and specialist skills, whereas the modern approach lends greater importance to problem-solving skills, understanding and other transversal skills [1].

Nevertheless, the current trend in the accreditation of engineering degrees is based on the assessment of outcomes of students on completion of their studies, and not so much on the number of hours devoted to teaching the subjects [2]. Numerous studies can be found that attempt to identify the desirable skills that students should acquire [1, 3–17]. Based on these studies, lists of skills that students should acquire through engineering curricula commonly include:

- ability to apply a knowledge of mathematics
- ability to design and conduct experiments, as well as to analyse and interpret data
- ability to work in multidisciplinary teams
- ability to identify and solve engineering problems
- understanding of professional and ethical responsibility
- ability to communicate effectively
- knowledge of contemporary issues
- ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

Along the same lines, as part of the Tuning project [10, 18], the most relevant general skills were identified and these were rank-ordered by employers, students and teachers. Among the most relevant skills identified from this work were the ability for analysis and synthesis, the ability to learn, the ability to solve problems and the ability to put knowledge into practice. In addition, Nguyen [19] emphasised that engineering is a very wide field that takes in aspects of business/management, science, mathematics, social science and computer technology. These studies demonstrate that to prepare engineers for professional practice in a changing environment, training must be global, regardless of the technical specialisation.

One common denominator identified by the students was a need to acquire the skills to work as a team. In addition, the need was raised to expand this concept to working in multidisciplinary groups since employment in engineering usually includes tasks that require teams of persons with different areas of expertise [20, 21]. Therefore, in the interdisciplinary work experience set out in [21], one of the objectives identified is that students should be given the chance to deal with problems

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from disciplines that are not theirs, as well as to understand how their discipline is related to others.

Given the segregated nature of different engineering programmes, students have few opportunities to participate in activities that encourage this skill, which suggests that the ability to work in multidisciplinary teams is not sufficiently developed [22]. Martin, Maytham, Case and Fraser [15] analysed graduate perceptions of how well they are prepared for work in industry and found that, in general, graduates consider themselves well prepared and highlighted strengths such as technical background, problem-solving skills, formal communication skills and lifelong learning abilities. However, one of the main weaknesses identified was work in multidisciplinary groups.

Another deficiency identified in Martin et al. [15] was a lack of practical preparation, in spite of its importance being frequently acknowledged [23, 24]. However, practical training is costly and takes up a considerable amount of time. For this reason, alternatives have been sought, such as computer simulated experiences and virtual laboratory [25–30]. However, as pointed out in [23], simulated experiences should not be considered to be a replacement for laboratories and real experiences.

Aimed at mitigating some of the deficiencies found in normal teaching practice, numerous actions have been planned, forming a basis for convergence towards the European Space for Higher Education [31]. Some of the lines of work are as follows:

1) Implementing new teaching methodology oriented towards skills acquisition (e.g. [32])
2) Promoting b-learning and e-learning (e.g. [33–35])
3) Developing new teaching materials to supplement the new methodology, for continuous training, for publication in Open Course Ware [36, 37],
4) The co-ordination of subjects as to the content and skills pursued, as part of the same syllabus, between different syllabuses,
5) The application of new assessment methodology (e.g. [38]).

The learning experience includes the plan of a sequence of common practical sessions as part of the subjects taught in different degree courses in different Schools of Engineering in the UPM, to encourage multidisciplinary group work. To be precise, the subjects involved are:

- Transport Technology, taught as part of the Industrial Engineering degree (ETSII), which deals with the main advances currently being introduced into road vehicles
- Digital Maps and GPS Navigation, taught as part of the Computer Engineering degree (EUI), which attempts to introduce the student to satellite navigation technologies and systems, as well as their current applications.

The practical sessions sought to make full use of each group's experience in certain disciplines in order to provide students with a global, practical and applied view, precisely in the field of road vehicle technology where mechanics, electronics, communications and computing are being ever more frequently brought together.

The experience described in this paper exemplifies a number of priorities set out in the European Space for Higher Education and is situated in the five lines of work articulated above in its efforts to:

- coordinate subjects with respect to content and skill development
- develop new teaching materialsthat develop self-study
- foster learning not only of knowledge skills but also specific, transversal skills
- develop an assessment plan aligned with the new learning experience.

2. OBJECTIVES PURSUED

The project's main objective consists of the joint development of practical sessions at the core of two different degree subjects taught in different centres with the purpose of providing students with a global, practical perspective. The goal was to make the best use of issues most strongly dealt with in both programmes so that students will acquire a holistic understanding of the complete system. Moreover, it should be pointed out that this joint focus is carried out in practicals, and in line with the guidelines of the European Space for Higher Education.

The project involved three phases:

1) coordination between two subjects taught in different centres
2) preparation of common practical sessions to give students a shared view of specific aspects of the subjects
3) development of an individual and multidisciplinary group work plan, before, during and after the practicals.

The goal of the project was to develop a learning experience that would provide an opportunity to integrate knowledge in the following areas:

1) Generic skills. Based on the skills identified in the Tuning project [10], the project integrated teaching and learning strategies aimed at strengthening generic skills required across the engineering disciplines, including the ability to put knowledge into practice, basic computer handling skills, and above all, the ability to work in a multidisciplinary team.
2) Transversal skills in the field of engineering. Because each subject in a programme is often considered to be independent of the others, the general skills intrinsic to engineering are frequently ignored because they are not deemed to be specific to a particular subject. These transversal skills must form a solid foundation for

students as they complete their studies because more complex concepts and skills will be built on this foundation. Of the skills those considered most important in the experience are the abilities to:

- connect varied concepts [39]
- make estimates as to the magnitude of typical problems [40]
- test process control: preparation, data acquisition control, outcome acceptance criteria, results analysis [41].
- subject-specific skills. Finally, there are skills that are specific to each of the subjects involved in the experience.

3. SUBJECTS INVOLVED

3.1 Transport technology

Traditionally, the automobile sector has absorbed a large number of engineers (mainly industrial engineers, although also civil and telecommunications engineers, and others), on design, research, commercial and production tasks.

Although the basic concept of a road vehicle has not changed substantially with the passing of the years, the technology incorporated most certainly has. So, if the main demands required of these vehicles are examined, such as safety, comfort, performance, a reduction in consumption and emissions [42], it can be seen that the development and introduction of disciplines like electronics, systems control, computing and telecommunications have led to significant progress in achieving these objectives, giving rise to the so-called Intelligent Transport Systems (ITS).

By way of example, Figure 1 shows a comparison between how active safety systems (orientated towards reducing accident risks) and passive safety systems (orientated towards reducing the consequences of accidents) have evolved. To a greater or lesser extent, the active safety systems are based on data capture and processing, which means some of the aforementioned disciplines are involved and offer a far greater future potential relative to the traditional methods of the passive safety approach.

This is aimed at giving a general view of technology which is being introduced in the world of road vehicles. However, as we are dealing with a highly dynamic and changing environment, a detailed study of specifics was not appropriate for this project. Therefore, three basic lines of inquiry are emphasised:

1) how to approach basic specifications and their implications on systems design
2) applied technologies, showing how they are linked to other subjects already studied
3) guidance in document processing, necessary for the updating required by the rapid changes being introduced in the sector.

3.2 Digital cartography and GPS navigation

The synergy between satellite navigation systems and computer environments currently represents one of the most promising fields of development for new applications. Systems to guide us to our destination, the most usual navigator system, topography applications, in-vehicle safety systems or automatic navigation systems for ships and planes, are just some of the applications that can now be found in use in the market.

This subject aims to introduce students to the use of satellite-based navigation technologies, popularly known as GPS (Global Positioning System) or GNSS (Global Navigation Satellite Systems). The different positioning systems currently available are reviewed, as well as their interaction with cartographic databases for the creation of navigators and electronic maps. The

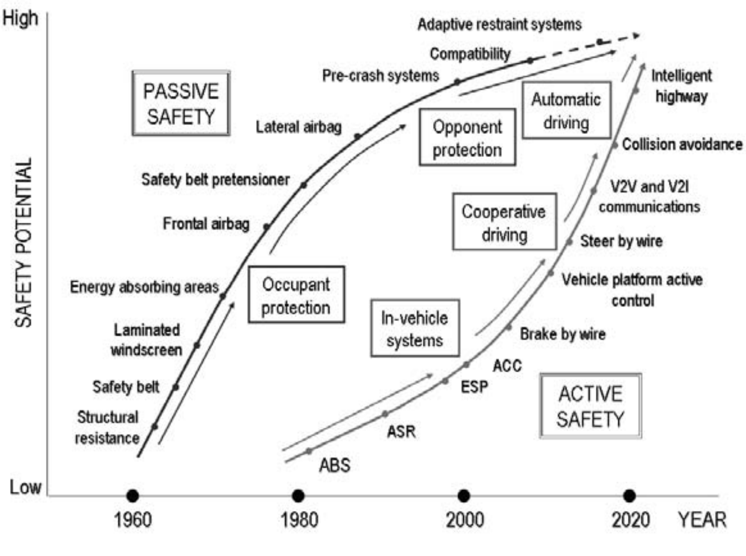

Fig. 1. Evolution of safety systems.

different algorithms used to calculate position are also studied, displayed in different types of coordinates. One of the basic aspects of the subject is how it relates to the field of mobile robots and intelligent vehicles [43, 44], thereby opening up a wide range of applications in the computing field where this technology is becoming absolutely essential.

In sum, the final objective is for students to become skilled at handling different satellite navigation devices and at gathering information through computer applications and software and design applications used by GNSS together with digital maps, how geolocation using GNSS works, the development of geolocation-based software applications, the mastery of Map-Matching techniques for digital cartography and the use of peripherals for the implementation of GNSS applications.

3.3 Common core

Road vehicle positioning is a tool that has become widespread in recent years. Although it was initially conceived to guide vehicles to the point of destination chosen by the driver, its applications are at present much broader. These, among others, are security applications, safety applications, fleet management, and traffic management and supervision [45–47].

These applications are part of the ITS dealt with in the subject called 'Transport Technology', whereas the hardware and software involved in many systems, at least in part, is approached in the subject called 'Digital Maps and GPS Navigation'. Figure 2 shows the disciplines that are part of each degree and subject involved in the experience.

4. PRACTICAL SESSIONS

4.1 Topic

The set of common practicals was approached with the purpose of developing a driver assistance system based on vehicle satellite positioning. Thus, a series of sessions was arranged so that every component could be developed and/or examined. It was hoped that this would establish a common theme for all the practical sessions.

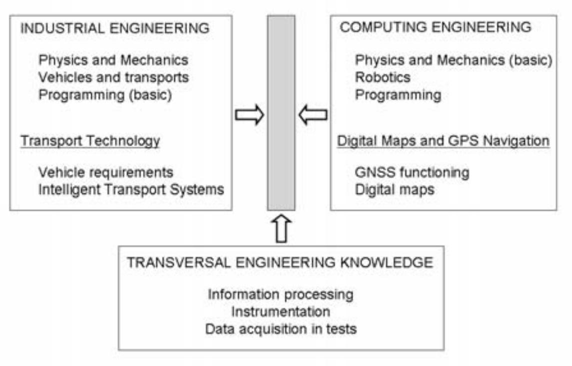

Fig. 2. Disciplines dealt with in joint experience.

An Intelligent Speed Adaptation system (ISA) was selected. ISA systems is the generic name given to all systems where the vehicle 'knows' the speed limit and is capable of using this information to warn the driver, if need be, or limit the top speed by acting on the vehicle. The system comprises the following elements:

- a speed measuring system
- satellite positioning, although beacons could also be used
- digital map with the necessary attributes
- control unit
- user interface.

ISA systems can be classified according to different criteria [48]. According to system permissiveness with driver actions, we can distinguish the following categories:

- informative: the system only informs of the speed limit on the section the driver is on, the driver can heed the advice or not.
- voluntary: the driver can connect or disconnect the vehicle's speed control system.
- mandatory: the system at all times limits the vehicle's speed in line with its control criteria.

Another classification is made in accordance with the frequency with which speed limits are updated and the variables used to do this, which results in the following categories:

- fixed: the vehicle is informed of certain pre-set limits
- variable: the vehicle is informed of certain concrete points where the limit is lower, for example, such as pedestrian crossings, dangerous bends, etc.
- dynamic: more restrictions are imposed because of environmental conditions (rain, fog, slippery road surface, etc) so that updating is continuous over time.

There are numerous prior experiences with fixed limits systems [49–57]. However, variable and dynamic limits systems have been much less studied, despite their potential benefit being much greater [58]. The system chosen for the practical sessions was a variable limits system given that it involved more advanced digital maps than those currently used for navigation. This, at present, represents both an obstacle and a challenge to obtaining such maps [59, 60], an issue that students need to approach.

4.2 Sequencing practical sessions

Developing the driver assistance system was planned in three stages, with each practical based on the previous one.

1) Practical session PS1: developing the vehicle positioning system
2) Practical session PS2: developing the detailed digital map

3) Practical session PS3: integrating and testing the driver warning system.

The first practical included installation and the algorithms needed to achieve the GPS positioning of the vehicle. So that performance in the face of different working conditions could be compared, two types of receiver were used. Since the receivers provide information on latitude, altitude and longitude, if positioning on cartographic maps is to be obtained, the information needs to be transferred to Cartesian coordinates, so that they possess the different possibilities existing for projection. From these, the Universal Transverse Mercator projection was chosen. The change in coordinates was performed using Gauss-Krüger equations.

The second practical developed the detailed digital map. To this end, an instrumented vehicle was used that included the aforementioned satellite positioning system and an inertial measurement system comprising a non-contact speed sensor and a gyroscopic platform. The inertial system allows every point on the path to be calculated in Cartesian coordinates in respect of the preceding point in accordance with the following expressions:

$$x_n = x_{n-1} + \Delta x_n = x_{n-1} + v_n \cdot \Delta t_n \cdot \cos(\theta_{zn})$$
$$y_n = y_{n-1} + \Delta y_n = y_{n-1} + v_n \cdot \Delta t_n \cdot \sin(\theta_{zn})$$
$$z_n = z_{n-1} + \Delta z_n = z_{n-1} + v_n \cdot \Delta t_n \cdot \sin(\theta_{yn})$$

where (x, y, z) are the Cartesian coordinates, v is the longitudinal circulation speed, Δt is the time between measurements and (θ_x, θ_y, θ_z) are the angles turned about the axes defined in the test vehicle, where the X axis is the longitudinal axis and Z the vertical axis. To be able to compare the paths obtained by both methods a rotation and a translation of the path obtained by the inertial system is required, as this does not provide an absolute reference. However, the road grade and the superelevation can be directly deduced from the angles recorded by the gyroscopic platform about the X and Y axes respectively. Taking the geometric road data, the safe driving limits are defined.

Finally, the third practical session included the integration of the global system, including positioning on the digital map and the generation of warnings. Positioning the vehicle on the digital map was accomplished using the GPS signal, and the speed signal was used to estimate the position from the last position given by the GPS in the zones where the signal was lost. The purpose of the driver warnings is to provide the driver with an objective and understandable indication of the greater or lesser proximity of a hazard situation taking account of driving speed and road characteristics in the sections ahead. The safe speeds map fixes the driving speed that should not be exceeded, which means the warnings will be those that inform the driver when and with what intensity they should reduce speed when approaching a singularity. Taking a uniform deceleration, we get:

$$a = \frac{v^2 - v_s^2}{2 \cdot (d - tr \cdot v)}$$

where v is the vehicle's speed at that instant, v_s is the safe speed at the next road singularity, d is the distance to the next road singularity and tr is the reaction time. So, as the level of deceleration required increases, the warnings must intensify.

Figure 3 illustrates the layout of the practical sessions arranged for developing the driver warning system. Figure 4 summarises the operations performed by the final application program that must be completed throughout the 3 sessions.

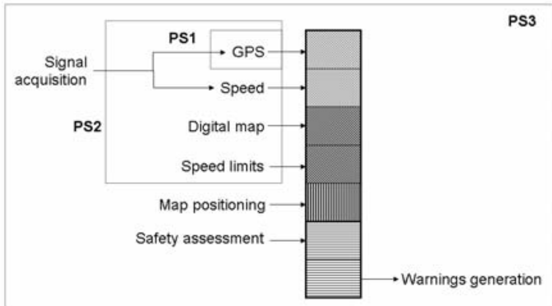

Fig. 3. Elements diagram of final application developed.

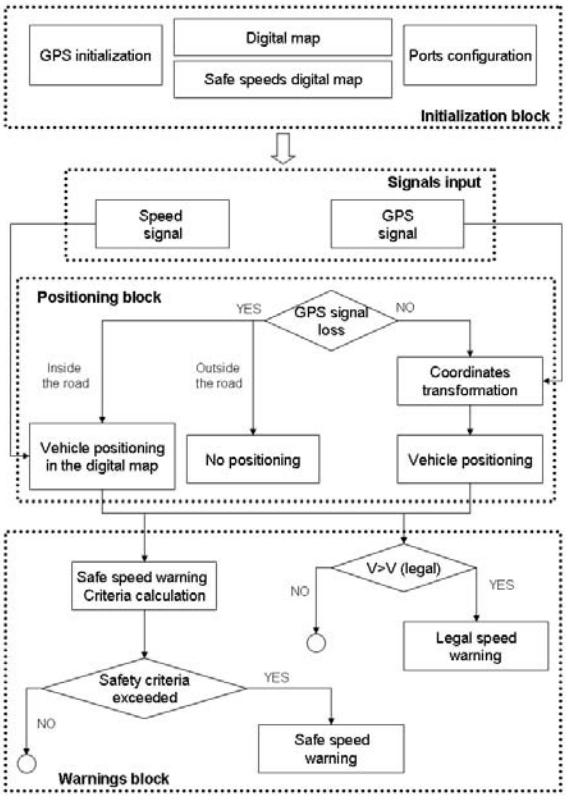

Fig. 4. System functionality diagram.

4.3 Task distribution

The practicals were prepared to be done in groups of 4–5 students, two from the School of Computer Science and 2–3 from the School of Industrial Engineering. The project was designed to eliminate the traditional approach perceived by students where theory and problem-solving classes are separate from practicals. The integration of theory and problem solving in the practicals was intended to achieve a better understanding of theory and to exploit the theoretical concepts in greater depth in the practicals. To this end, each practical was organised into pre-tasks (which included documentation work and specific software preparation, among others), test development and subsequent tasks (data processing and completing the stages required for successive practicals). As Figure 5 shows, before the practical session, pre-tasks are reviewed in a preliminary presentation, as these are essential for the success of the practicals. When final processing of the experimental data had been completed, each group presents the main conclusions reached.

In order to make full use of the multidisciplinary

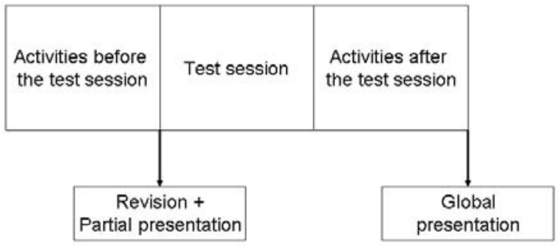

Fig. 5. Work structuring of each practical session.

Table 1. Tasks to be performed in practical sessions

	Before the test session	**Test session**	**After the test session**
Practical session 1: Development of a method for vehicle positioning			
ETSII	– Software for GPS coordinate transformation (Cartesian and geographic)	– Positioning of a vehicle on a route with multiple receiver models. Use of C++ software for positioning information capture.	– Analysis of the results following the features of each GPS receiver.
EUI	– Software for GPS signal acquisition in C++. (1) – Analysis of the GPS signal: time, latitude, longitude, altitude. (1) – Storage in a file of the position information (1)		
Practical session 2: Development of a digital map			
ETSII	– Software for digital map development using inertial measurement systems (speed sensor and gyroscopic platform)	– Measurement of the road geometry.	– Documentation on the calculation models of safe driving speeds. – Safe speed calculation on road singularities (3) – Development of a digital map with the road geometry. (3) – Comparison of the results of the inertial system, GPS signal and Google Earth information
EUI	– Application in C++ for receiving analog signals and the GPS position (2)		
Practical session 3: Integration of the driver assistance system			
ETSII	– State-of-the-art of ISA systems	– Test with drivers	– Analysis of the warning signals provided by the system to the drivers. – Final report – Survey
EUI	– State-of-the-art of the map-matching algorithms. – C++ application that compares the position of the car on a digital map together with the safe speed and generates safety warnings		

(1) Used in practical sessions 1, 2 and 3.
(2) Used in practical sessions 2 and 3.
(3) Used in practical session 3.

Table 2. Equipment used in practical sessions

Equipment	Type	Used in practical session no.
GPS receivers	Astech G12	1, 2, 3
	Garmin GPS eTrex H	1
Non-contact speed sensor	L-CE Correvit	1, 2, 3
Gyroscopic platform	RMS FES 33	2
Customized keyboard for event positioning		2
Laptop		1, 2, 3
Data acquisition system (acquisition cards)	DAQCard-6062E (National Instruments)	2, 3
	Advantech USB-4711A-AE	2, 3
Driver interface	7” screen	3

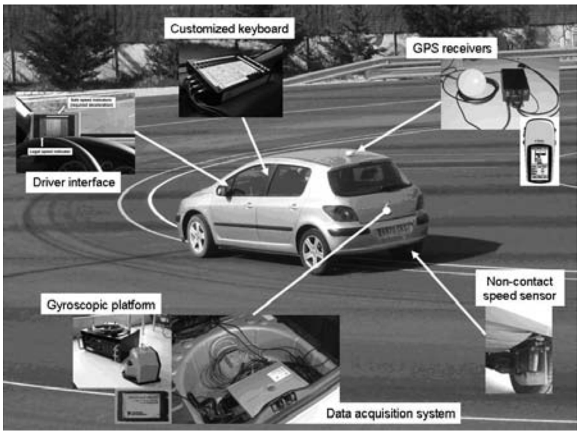

Fig. 6. Vehicle and instrumentation used in practicals.

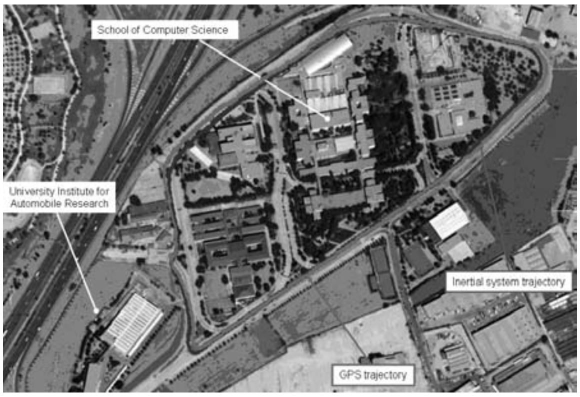

Fig. 7. Comparison of different information sources for positioning on University campus.

aspect of the student groups from two different engineering schools, the work they had to carry out in each session involved shared knowledge and knowledge exclusive to the two degrees as Table 1 shows. Regardless of their contributions, all group members had to be able to defend any part of the work developed in the final presentation.

4.4 Equipment used

During the practical sessions, different instrumentation equipment was used (Table 2) which was fitted in the vehicle shown in Figure 6. To have an open architecture easily accessible by students, the control unit used was a laptop computer.

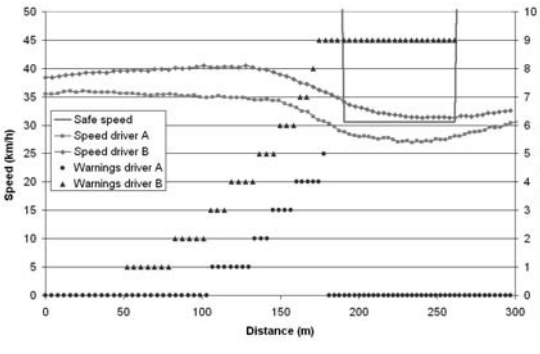

Fig. 8. Comparison of warnings provided to two drivers on approaching a road singularity.

4.5 Summary of results

The practical sessions were conducted on a test track of the University Institute for Automobile Research of the UPM and on the University campus. Thus, it was possible to obtain results under real driving conditions, but in a controlled environment that students has to analyse in the final stages of the practical sessions. So, for example, the concordance of the resulting digital map was compared with the inertial measurement system and with the positioning provided by the GPS receiver and easily accessible maps like those included in Google Earth (Figure 7).

Since the driver speed and warning information was stored during the tests, the behaviour of different drivers can be compared when faced with the warnings. By way of example, Figure 8 shows the case of an approach to a road singularity by two drivers, including the warning levels provided on a 10-level scale (from 0 to 9) according to the growing need to decelerate to adapt the speed to a safe one. It can be observed that driver B does not do so, although they do reduce speed on approaching the road singularity. The study on how the developed system influences driver behaviour is also illustrative for students.

5. EXPERIENCE ASSESSMENT

After completing the experience, students were asked to write down their opinions about it. The questionnaires were anonymous and items such as positive and negative aspects and aspects that should be changed in the future were tackled.

The main conclusions of the students were:

- The practical sessions were approached as development stages in a driver assistance system. Thus, through the tasks developed before, during and after the practicals, the modules needed for the system to work were completed and analysed. This fact had a motivating effect on the students, who perceived the final objective pursued from the very beginning.
- The students judged the experience to be positive because they obtained new knowledge that hardly could be achieved without collaborative work in a multidisciplinary team.
- Teamwork was considered interesting and satisfactory, with close relationships between students being established and between students and teachers
- Some students considered that they studied more than necessary to pass the subject, but they found this additional workload satisfactory and useful.
- Some coordination difficulties were found between students from the two Engineering Schools, because of the different timetables and the distance between Schools and the test track where the practicals were carried out.

6. CONCLUSIONS

Within the lines of priority work in educational innovation, linking subjects in order to give students a more global and holistic perspective is fundamental. Drawing up joint plans turns out to be an arduous, complex task since it involves numerous teachers and various departments. Additional complications arise if it is wished to make use of the resources of different engineering schools. In the experience described we sought to find synergies in two subjects, (Transport Technology and Digital Cartography and GPS Navigation) from different degrees (Industrial Engineering and Computer Science) through a plan involving practical sessions and multidisciplinary group work.

The general opinion of the students involved in the experience has been positive because they obtained new knowledge that hardly could be achieved without multidisciplinary teams. Furthermore, some of them have continued working in these topics after the course and decided to do their final project improving and completing their previous work in the subjects.

Finally, it is worth pointing out that two fundamental aspects came together to create a successful learning experience. On one hand, it enabled students to broaden their training in vehicle technology, from mechanical as well as information and communication technologies standpoints, but never losing sight of a practical approach. On the other hand, a synergy was brought about between mechanical engineering and computer science, a true technological reflection of the automobile sector where a fusion of disciplines is essential.

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