Plug and Play with a QoV Model
A Research Based Learning Approach

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Abstract: An application that allows and encourages the *Research-Based Learning* (*RBL*) was developed. This facilitates students the interaction with a real prototype under the *Plug & Play* approach. Students with minimal knowledge of hardware, low-level programming, signal processing or control design, intuitively could discover and build your knowledge based on a generic guide. The system is based on instructional design for the student to: establish a link between theory and practical solutions, internalize the knowledge, exploit critical thinking, and high motivation by the intellectual challenge of solving a real problem. The experimental platform includes a prototype scale (1:5) *Quarter of Vehicle* (*QoV*) model with an *Electro-Rheological* damper that represents a vehicle semi-active suspension system. The *QoV* model is equipped with several sensors for measuring: the positions on the motor base, the suspended mass and between the rim and the sprung mass, the acceleration in the tire and the sprung mass, and the damper force of the system. An *Human Machine Interface* talks with a *DSpace* data acquisition card that communicates with the sensors/actuators system and works directly with *Matlab/Simulink*. Early results have been found more efficient teaching-learning for several reasons: (1) students concentrate efforts on the learning objective (minimum programming), (2) a real scale prototype is available, (3) students can share their designs seamlessly and reuse software accelerating , and (5) high motivation because the research and easy use of the system.

1 MOTIVATION

México ended 2014 as the largest vehicle producer in Latin America and 7^{th} worldwide. Mexican automotive industry saw its consolidation as one of the top countries in vehicle production and export, as a result of Nissan, Honda and Mazda's new facilities opening in central México. During 2014 the automotive industry was close to 3.5 million produced vehicles; without considering the launch Daimler/Nissan, together with the foreseeable arrival of new investment from the existing brands in México, plus a couple of companies reassuring its investment this year (Elie, 2013).

Mexico will be close to 5.0 million produced vehicles in 2020. This will demand more successful professionals in this field. automotive industry. The distribution requirements in terms of total employment are: (1) Manufacturing components: 52 %, (2) Assembly: 21 %, (3) Logistics and storage: 8 %, (4) Administration: 8 %, (5) Design and development product: 6 %, (6) Sales and Service customer: 3% and (7) Industrial safety: 2 %. The employment in the sector is concentrated in manufacturing and assembly (73 %); but, the activity with greater value-added is *Design*. The Mexican automobile sector has the most modern and efficient installed capacity for vehicle production worldwide. Production capacity is highly technical and very flexible, which makes it possible to manufacture several types of models. Mexico must increase its focus on *Design* and *Development Product* to enhance the value-added sector.

Higher education has a crucial role in this opportunity. Higher education seeks to develop graduates with a wide range of intellectual and practical knowledge and skills, such as critical and creative thinking, written and oral communication, quantitative literacy, information literacy, teamwork and problem solving, civic knowledge and engagementlocal and global, intercultural knowledge and competence, ethical reasoning and action, and foundations and skills for lifelong learning, (n.d., 2011). *Tecnológico de Monterrey* is working on these needs through different initiatives in undergraduate programs such as *Intership Program in Research and Innovation*, (Galeano-

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Sánchez et al., 2011) (Galeano-Sánchez et al., 2012). Students for the automotive sector with better credentials and skills using innovative teaching-learning techniques such as *Research Based Learning* (*RBL*) are been graduated every year.

This paper is organized as follows. Section 2 briefly reviews the *RBL* approach and how is going to be exploited in this study case. Section 3 describes the opportunities in the control system of semi-active suspensions to justify the development of educational technology. Section 4 presents some preliminary results. Finally, section 5 concludes the paper.

2 RESEARCH BASED LEARNING

The term undergraduate research and its integration into the curriculum grows out of *US* practice; in particular through innovations pioneered at the *Massachusetts Institute of Technology* (*MIT*) through the leadership of Margaret MacVicar, *MIT*s Dean of Undergraduate Education. In 1969, *MIT* started the *Undergraduate Research Opportunities Program*. This developed as a cross-institutional initiative that supported selected students to work on student initiated and faculty-supported research projects.

The Boyer Commission on Educating Undergraduates in the Research University called for ten key changes in undergraduate education, four of which demand to strengthen the undergraduate experience of research: (1) Make *Research-Based Learning* (*RBL*) the standard, (2) Construct an *Inquiry-Based Freshman* year, (3) Build on *Research-Based Strategies* to characterize the whole of a research university education, and (4) Culminate with a capstone experience. After this report, all types of US institutions of higher learning were transformed based on the principle that research-based learning should inform all levels of undergraduate education, (n.d., 1998).

At higher education level, you cannot be a good teacher unless you are also a good researcher. The quality which makes higher education *higher* and quiet different from training is that it is grounded in a deep understanding of the provisional nature of knowledge, (Baldwin, 2005). Linking research and teaching has several advantages in enhancing student learning. Immersing students in the relevant disciplinary and research cultures and the process of doing research and enquiry can be of wider benefit. Research strategies develop important skills. Additionally, students who are actively involved in research are more engaged.

(Healey and Jenkins, 2009) organized the ways of engaging students in research in a two-axes map, Fig. 1. One axis classifies the ways students may be engaged in research according to the extent to which students are treated primarily as the audience or as participants, while the other axis classifies the approach as emphasising research content or research processes and problems. All ways are valuable and interdependent. Effective programmes incorporate all these different modes.

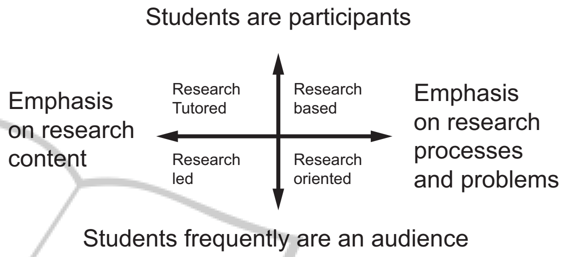

Figure 1: The nature of undergraduate research. *Research-led*: learning about current research in the discipline; *research-oriented*: developing research skills and techniques; *research-based*: undertaking research and inquiry; and *research-tutored*: engaging in research discussions.

- *Research-led*: learning about current research in the discipline. Students can be engaged through lectures, academic staff-led seminars, laboratories and course work.
- *Research-oriented*: developing research skills and techniques. Course lectures, practical and laboratory classes and course work are common modes of teaching in which research skills and techniques are particularly developed.
- *Research-based:* undertaking research and inquiry. The most obvious way for students to engage in research is to undertake research projects (or capstone research) and inquiry projects, both within the curriculum and outside it.
- *Research-tutored*: engaging in research discussions. Engaging in discussion is a key way to develop understanding.

In much of higher education programs relatively too much teaching and learning is in the bottom half of this model, and most students would benefit from spending more time in the top half. The way the four approaches are interlinked together is important in the design of effective courses.

3 EDUCATIONAL TECHNOLOGY

The primary functions of an automotive suspension system are to (Gillespie, 1992): (1) isolate the chassis motion from road irregularities, (2) keep the tire-road contact with minimal load variations, and (3) resist roll of the chassis. They depend on the vehicle vertical force that it must transmit from the tires to the chassis. According to the capability to adjust the damping force, the automobile suspensions can be classified as: passive, active or semi-active. Passive suspensions are only able to dissipate the energy and their damping characteristics are time invariant, while active ones are able to store, dissipate and generate energy through a variable damping coefficient but they are very expensive to apply because require an external power supply.

Semi-active control has recently been an area of much interest because of its potential to provide similar performances of active actuators; but, without a significant external power supply (Fijalkowski, 2011). The semi-active suspensions consist on a spring and damping component; its continuous variable damping coefficient adjusted by external control signals offers much better performance .

There are 4 main technologies of semi-active dampers: *Electro-Hydraulic*, *Pneumatic Actuators*, *Magneto-Rheological* and *Electro-Rheological* (*ER*). *ER* dampers are used in this application, they contain a rheological fluid, the semi-activeness is manipulated by adjusting an electric field.

Four topics will be considered with this educational technology: (1) *Quarter of Vehicle* (*QoV*) model, (2) Damper modeling, (3) Control systems, and (4) Data-based control algorithms.

QoV Model. The *QoV* model is the most basic system to represent an automotive suspension, Fig. 2. Its use assumes an equivalent load distribution among the four corners and a linear dependency with respect to the translational and rotational chassis motions. The system considers a sprung mass (m_s) and an unsprung mass (m_{us}). A spring with stiffness coefficient k_s and a semi-active damper represent the suspension between both masses. The semi-active damping force (F_{SA}) depends on a control input variable and it is highly nonlinear with respect to the suspension motion. The stiffness coefficient k_t models the wheel tire. The vertical position of the mass m_s (m_{us}) is defined by z_s (z_{us}), while z_r corresponds to the unknown road disturbance, Fig. 3.

Damper Modeling. To characterize all rhelogical phenomena, an efficient experimentation is needed. Different experiments allow to explore the damping force in the Force-Velocity characteristic map. Each experiment consists on a displacement sequence that analyzes the mechanical properties and an electric sequence that explores the transient response between the magnetic field and damping variation, (Lozoya-Santos, 2013).

Control Systems. An extensive classification of different control strategies for semi-active dampers according to the type of manipulation (continuous or on-off), control goal (comfort, road holding or both), type of control law to include the semi-activeness (clipped, frequency adaptive, frequency switched, measurement-based), type of control design (model-based or free of model), etc. is presented in (Lozoya-Santos, 2013).

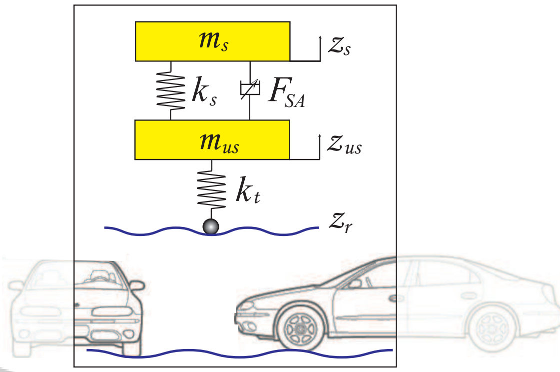

Figure 2: Quarter of Vehicle (QoV) Model.

The interest in semi-active suspensions derives from the potential for improvements to vehicle ride performance with no compromise in handling, without considering its type of control design. It is necessary to assume a balance in the controller design goals.

Data-based Control Algorithms. Only measurements and analytical estimations are used to monitor the suspension behavior to adjust the damping force according to the desired performances. The most representative control approach for comfort is the *Sky-Hook* (*SH*) controller, which has been successfully applied on commercial vehicles. The principle of this algorithm is to *link* the chassis to the *sky* by a virtual damper and put a controlled damper among the masses, in order to reduce the vertical oscillations of the chassis.

Based on the acceleration measurement instead of the velocity of the sprung mass, the named *Acceleration Driven Damper* (*ADD*) control (Savaresi et al., 2005) and its improved version have become new efficient comfort-oriented controllers. In the sense of reducing the number of measurements that are used to control the damping force, (Spelta et al., 2011) proposed the *Mix-1-stroke* algorithm that shows similar performance as the *SH-ADD* controller, but with only one measurement.

In a dual way to the *SH*, the *Ground-Hook* (*GH*) controller has been proposed to reduce the road holding by including a virtual damping between the *wheel* and *road* and a controllable semi-active shock absorber. This is the most representative control strategy

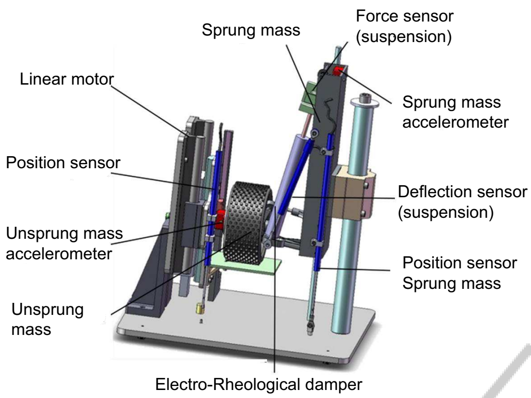

Figure 3: Quarter of Vehicle (QoV) Model.

fully oriented to road holding, (Valasek et al., 1997).

This *ER* shock absorber is adjusted using a manipulation voltage between *0* and *5* kV. Below the wheel lies an linear servomotor that mimics the desired road profile. The servomotor have a bandwidth of *0-20* Hz with a maximum velocity of *1.5* m/s. The motor has its own servo-driver and is operated from a computer by sending the desired road profile through the *Dspace*^{TM}. This platform is equipped with a wide variety of sensors as is shown in Fig. 3. A photo is shown Fig. 4.

Figure 4: Experimental *QoV* Model, manufactured by *SOBEN*^{TM}.

A *Human Machine Interface* (*HMI*) was developed to easily interact with the *experimental QoV model*. This *HMI* is the fundamental platform for the *RBL* proposal. Basically, this represents a *Hardware-in-the-Loop* (*HiL*), that is used in the development and test of complex real-time embedded systems, Fig. 5.

Figure 6 shows how a *Dspace* card talks with the experimental platform and *Matlab/Simulink* on real time. The *HMI* running on *Matlab* has configured a general control system with different options for each

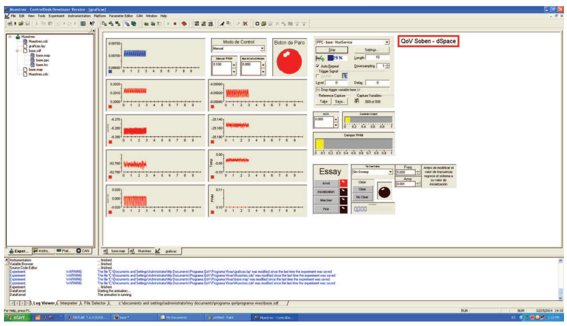

Figure 5: Human Machine Interface (HMI).

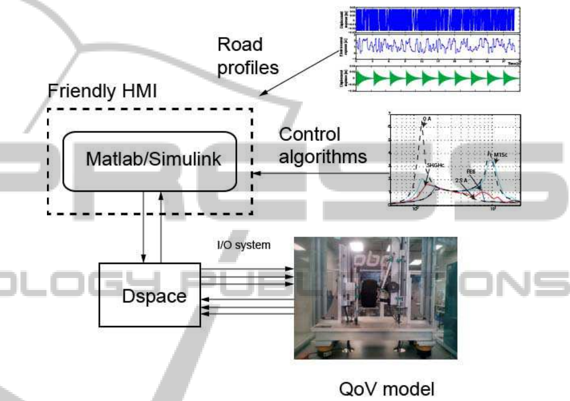

Figure 6: Communication system.

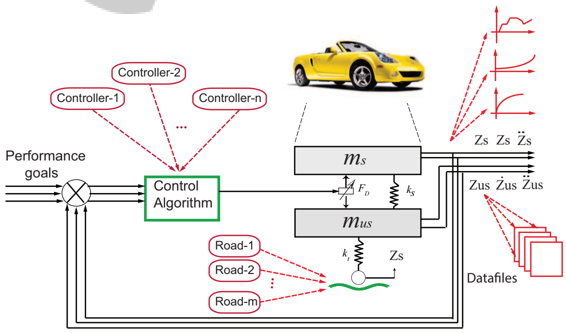

Figure 7: Plug and play system.

block/signal, Fig. 7. Based on this flexibility, the *HMI* allows:

- Design a control system as if you were drawing a block diagram (*Drag and Drop*), Fig. 8.
- Reuse software such as: road profile, control algorithms, etc.
- Online plotting and registering.
- Online access to the *Matlab* and toolboxes platform.

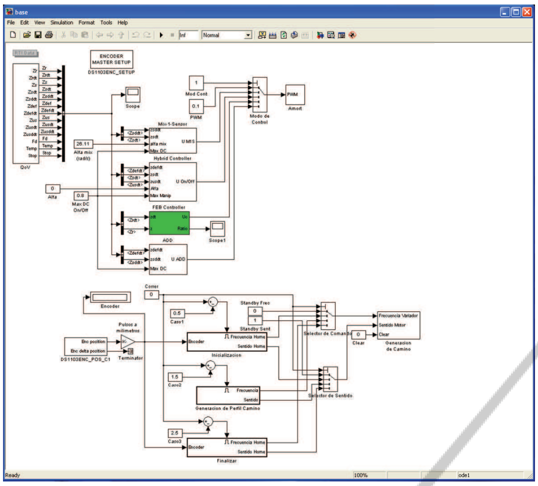

Figure 8: Simulink interface. Configure a control system is as easy as drawing it.

4 EARLY RESULTS

Early results could be discussed in 3 great points: (a) *HMI*, (b) *RBL* and (c) Academic results

4.1 HMI

A *Vehicle Dynamics* course provides a fundamental understanding of vehicle ride and handling behaviour and links this understanding to the practical implications for chassis and suspension design. Mechanical Engineering students have a low background in control systems, instrumentation, low-level programming, etc. The main goal of the *HMI* is to allow students an easy and friendly operation of the experimental *QoV* model. To design , implement and test in a prototype vehicle (in minutes) is a great learning experience and motivation. This *HMI* opens a number of opportunities in active learning, problem-based learning and research-based learning , allowing students so extremely easy to live a practical experience. Practice on a prototype has some disadvantages as some dynamic phenomena can not be reproduced accurately; however, also has important advantages such as time efficiency and overall safety of experimentation. Additionally, students will have a repository of several elements to design (to draw) a control system such as different profile of the roads, type of standard tests, data-based control algorithms, model-based control algorithms, etc.

Students will be focus in the academic goals, without consuming time on implementation details (it is not the objective of this course). Eventually, students will be able to design and contribute with new toolboxes to the *Vehicle Dynamics* repository with new ideas and code.

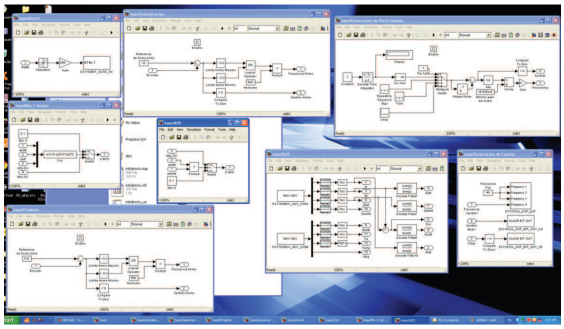

Figure 9: Vehicle Dynamics Repository: control algorithms, road profiles, etc.

4.2 RBL

The *Vehicle Dynamics* course was re-designed in three teaching-learning activities: (1) *Lectures*, (2) *Experiments* and (3) *Reports*, Fig. 10. The novel activities to this course are *Experiments* and *Reports*. *Lectures* were more conventional but focus in the *Experiments*.

Three modes of inquiry were exploited in the *Lectures*: *structured* providing a problem and an outline for addressing it; *guided* providing questions to stimulate inquiry, but students are self-directed as regards exploring these questions; and *open* where students formulate the questions themselves. Also during the *Lectures*, special emphasizes was given to different strategies for linking teaching and research, (Baldwin, 2005):

- *Draw on Personal Research in Designing and Teaching Courses*. Own research was incorporated into the course to motivate students. Graduate students participate and discuss their current research results as a part of *Automotive Consorcium Research Group*.
- *Place the Latest Research in the Field Within Its Historical Context in Classroom Teaching*. The lastest damping theories and control algorithms are included. The technological advances in the automotive industry are discussed.
- *Design Learning Activities Around Contemporary Research Issues*. Students were asked to explore cutting-edge research problems, i.e. the tradeoff of comfort and road-holding for semiactive suspension systems (which is an open question).
- *Teach Research Methods, Techniques and Skills Explicitly Within Programs*. *ER* damper modeling demands both model equation and experimental

data. Representative data comes from a special *Design of Experiments*. Students must learn these research methods.

- *Build Small-scale Research Activities into Undergraduate Assignments*. This is the main application of this proposal.
- *Infuse Teaching with the Values of Researchers*. Through different activities the following values of researchers are discussed: openness, scepticism to received theories, honesty with oneself as well as others, respect for evidence, respect to others, tolerance of ambiguity, respect for the subjects of study, persistence, analytical rigour, accuracy, humility, willingness to admit error, and creativity.

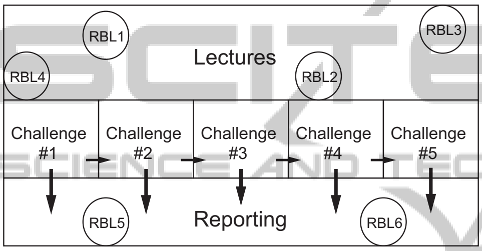

Figure 10: Vehicle Dynamics course. Teaching design based on RBL.

Experiments are possible because the new experimental *QoV* (*HMI*). Five experimental sessions were designed as *challenges* for the students. Different assignments were considered through each of the four ways of engaging students in research around each *challenge*. A balanced distribution of time and teaching-learning techniques should give better results to different learning styles and academic topic. Teaching new material in manageable amounts, through five *challenges*, modeling, guiding student practice, helping students when they made errors, and providing for sufficient practice and review. Also, with experiential and hands-on activities after the basic material was learned. A review is an important component of instruction between each *challenge*. Review can help students strengthen the connections among the material they have learned. The review of previous learning can help them recall words, concepts, and procedures effortlessly and automatically when they need this material to solve problems or to understand new material. The development of expertise requires thousands of hours of practice, and daily review is one component of this practice.

An example of teaching design for *Challenge # 2*, based in Fig. 1, will be described. Students are organized in collaborative teams of five members.

1. *Research-led*: Spent some lectures outlining a research problem (*ER* Damper experimental modeling) and setting it in a theoretical context based on the state-of-the-art.

2. *Research-oriented*: Students must read some papers to learn about: design of experiments, damper models and model identification. Also, students read the *QoV* manual to learn how these ideas can be implemented.

3. *Research-based*: Students undertake research by implementing the experiments in the experimental *QoV* model through the *HMI*.

4. *Research-tutored*: Students must discuss the used methods/algorithms to solve this challenge, the main findings and unresolved issues.

Reporting includes some activities as consequences of the *Experiments/Challenges*. There are several important process that students must complete with the experimental results of the *challenges*, the most important are: (1) analyze, (2) discuss, (3) learn/validate concepts, (4) communicate and (5) write a report. As a result of experimentation to solve the *challenges*, analysis of the results to understand the phenomena and/or generate knowledge. Students must write a technical report (i.e. abstract, introduction, state of the art, experimental design, results, discussion, conclusions, and bibliography). The writing of this report is justified by several reasons. For learning, the act of writing provides a chronology of thoughts, they can then label, objectify, modify, or build on; and it engages in becoming invested in ideas and learning. Writing-to-learn forms and extends thinking and thus deepens understanding.

Learning is a complex and dynamic process involving interactions between previously acquired levels of understanding and the conceptualization and incorporation of new material. Writing a report encourages a level of cognitive activities which maximizes the potential of the students to modify and restructure knowledge. Students improve their learning by constructing and evaluating the knowledge to acquire, students gain ownership of knowledge by asking their own questions about existing knowledge. Writing a report definitely plays the key role in the process of student knowledge-construction.

Learning through writing activities and experiences that interest and stimulate students is usually inherently motivating. The writing a report activities included conceptual understanding, procedural knowledge and logical thinking is a means for transforming concepts and skills. Writing engaged all students actively express and explain meaning at their own abilities.

4.3 Academic Results

The early results of this work should be analyzed from two perspectives: (1) the academic outcomes and (2) the results of the didactic proposal using the *HMI*. Although the results are preliminary, they are motivating.

Figure 11 presents an example of experimental results that students obtained. Top plot shows the transient response of a suspension system using different damping coefficient. Students can test manually the *ER* damper for different electric current and evaluate the results. Bottom plot shows an road profile estimation system, this experiment is very easy for implementation, but it is a really complex problem for undergraduate students, (Tudón-Martínez, 2014). All students can complete the five *challenges* and make the experience.

About the didactic proposal, based in a survey with 42 students, the main comments are:

- *HMI - Use*. Students with basic background in *Matlab/Simulink* indicate the *HMI* is very ease of use. Students without this background said it is a good *HMI*.
- *HMI - Academic Purpose*. Some students think they lost the implementation details because the *Plug & Play* concept.
- *Debugged Software*. Students can design, develop, debug and validate their assignments off line. The experimental implementation was very short.
- *Motivation - QoV Model*. All students showed high motivation; however, some of them are skeptics to the real vehicle behavior. Even the *QoV* model is an accepted framework for practical applications; but certainly there are some limitations/constraints because only the vertical dynamics of the vehicle is considered. The scaled prototype represents the main concern.
- *Motivation - Academic Topic*. All students showed high motivation for being part of a real problem with an open question.
- *Software Reuse*. All students appreciated the available code; some students modify it. Students recognized some values: advantage of collaboration, recognition of authorship, recognition of standards procedure as documentation of software.

4.4 Related Work

The *Institut National Polytechnique de Grenoble* (*INPG*), France has a similiar *QoV* experimental test bench. They are using the *XP Windows HMI*, but is restricted to: (1) limited number of road profiles, (2) General state space based controller, and (3) there are not real time plots. They have 4 test benches for academic purposes. Given the restrictions on use, these equipments are used in a limited way to validate results.

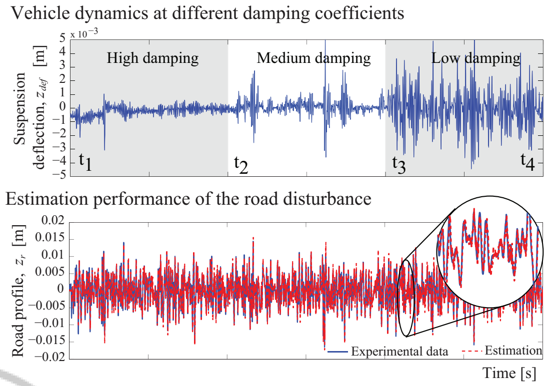

Figure 11: Some experimental results.

Also, *Gipsa-Lab* at *INPG* has a 1:5-scaled *baja* style racing car, which represents a full vehicle including wheels, engine, steering, breaking system, and the key element a *SA* uspension system, Fig. 12. This experimental platform has two computers: (1) *Host computer* where the user sets the initialization parameters, configures the desired road profile, implements the suspension control algorithms, and records the acquired data; and (2) *Target computer* where the control algorithms are compiled and executed in a *RT* operating system (*xPC target*^{TM}). This is an excellent experimental system for research purposes with a open software. Similar experiments can be done to our proposal, but the needed time for learning the use of experimental platform and the needed time for developing and implementing the tests is excessive high for educational purposes.

The *University of Bundesweher* at Munich, Germany has a similar experimental *QoV* model to us.

Figure 12: 1:5-scaled *baja* style racing car.

They are researching about chasis control systems looking for optimal solutions in rough roads. They developed an *HMI* based on *C++*. This platform has an open code: (1) to interact with sensors and actuators, (2) to implement non conventional controllers, (3) to design new road profiles, (4) to plot simultaneously several signals, and (5) to compare real and simulated results on real time. Similar to *Gipsa-Lab* approach, the main purpose is research only.

The essential difference of these related works to us is: (1) the *HMI* which was designed for academic purposes (*Plug & Play Approach*) based on a teaching technique and (2) the software that support the *HMI*, which is the result of two *PhD* dissertations: (Lozoya-Santos, 2013), (Tudón-Martínez, 2014). An important constraint of our proposal is the cost of the *Dspace*^{TM} card; however, there are cheaper options.

5 CONCLUSIONS

he proposed educational technology is based on both: *Plug & Play* approach and *Research Based Learning* (*RBL*). Early results show the *Plug & Play* approach simplifies the used of the experimental *QoV* model allowing an efficient teaching-learning system

Preliminary results are: (1) high motivation of students, which greatly facilitates the teaching-learning process, (2) the *HMI* allowed for experimentation very efficiently, (3) unlike the original course (i.e. only in a classroom), practical experience taught the students to ”see”, ”feel”, ”listen” various phenomena of vertical vehicle dynamics, (4) although we have no evidence to prove the results of the writing reports, we believe that the students internalized the concepts they learned to better understand, organize and communicate their ideas (orally and in writing). Our only evidence is that test scores were substantially higher.

As future work, we will begin to statistically measure and compare the performance of students through the terms. Designing rubrics to validate the benefits of *HMI* in terms of efficiency during the teaching-learning process.

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