Germán LaRA: An Autonomous Robot Platform Supported by an Educational Methodology

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Abstract. This article presents the evolution of a learning methodology, from its conception ten years ago until its maturity, grounded on Robotics. This methodology is based on building robots within long term projects, which involves key features to encourage students to engage in research and development. This work identifies two phases in the Tec de Monterrey Campus Cuernavaca Robotics' history. In the first one, students assimilated commercial platforms and worked on programming tasks and some adaptations of control systems. In the second phase, students design, develop and integrate mechanical parts, hardware architectures and programming modules. The current work within this educational framework is presented as Germán Lara, an autonomous robot platform developed by undergraduate students, as part of a Greenhouse Automation project. Finally, an assessment based on a qualitative analysis of the student's skills shows the difference between both phases.

1 Introduction

A practical approach, as a didactic technique, is a simple way to introduce the challenge of describing insights about real-world problems to students. With some basic principles, a teacher can provide convenient heuristics so that students actually build artificial systems (e. g. robots). Building systems is crucial because we, as researchers and scientists in computer science, want to design and construct

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intelligent artificial systems so that we can understand intelligent systems in general: this is the synthetic methodology [9].

As a basic methodology of the new artificial intelligence (also mentioned in literature as nouvelle or embodied artificial intelligence [6]), it can be summarized as learn by building. For example, if we are trying to understand human spatial navigation, the synthetic methodology requires that we build an actual navigating robot with sensors and actuators that enable it to move and interact within an environment.

Building a real physical system always yields the newest insights. A real-world navigating agent, like a human or a physical robot, has to somehow deal with the inaccuracy of its actions and the unpredictability of the real-world environments, while these problems can be partially or totally ignored in a simulation.

By actually building agents (i.e., real robots) students can learn about the nature of the phenomenon, develop an analytical sense about the problem and understand the applicability or making meaning [4] of the possible solution(s) with a synthetic or integrative criteria in fields so diverse as computer or cognitive science.

In the Laboratory of Robotics and Automation (LaRA), we have followed the methodology of learning by building. This has been possible thanks to professors like Dr. Fernando Ramos Quintana that in the last 15 years has greatly encouraged students to engage in research. Project after project the grade and majors of the students have come from Ph. D. students to first-year undergraduate students.

The success of this approach could be said to reside in the robots themselves. They allow concrete testing of ideas in a very objective way: a robot either works or it does not. Moreover, robots serve as excellent platforms for transdisciplinary research [8] and cooperation between people with different backgrounds and ages.

The most relevant Robotics achievements of the Tec de Monterrey Campus Cuernavaca are presented in Section 2. Then, the educational and academic framework of LaRA as well as the Program for Undergraduate Research Encouragement with the current Greenhouse Automation project, are described in Section 3. After that, the research on computer science that is using Germán Lara, an autonomous robot, as platform is introduced in Section 4. Finally, conclusions and a qualitative assessment are presented in Section 5, and future work is discussed in Section 6.

2 Related Work

The Tec de Monterrey, as an institution of higher education and research, was funded in Mexico more than 60 years ago. Tec de Monterrey Campus Cuernavaca is relatively younger, almost half the age of the first campus in Monterrey. However, it took half of this time, 15 years, to consolidate a strong group of researchers in electronics, control and computer science to start a fresh 15-year history in Robotics.

This group of researchers and academic leaders started in 2000 to establish two-year projects, increasingly involving younger undergraduate students. The most trascending difference between the projects, besides the degree of the students, is the nature of the platform used. There is a general division between the projects that

Table 1 Smart Hexapods project's output: Ph. D. and Master in Computer Science theses

Author	*Year*	*Type*	*Title*
Edgar E. Vallejo C.	2000	Ph.D.	Evolución del comportamiento en agentes autónomos: una contribución a la locomoción de insectos. [15]
Alejandro Vargas H.	2001	Master	Aprendizaje por refuerzo en línea para la locomoción de un hexápodo.
Arnulfo Martínez P.	2002	Master	Locomoción de un hexápodo combinando andaduras en superficies planas e irregulares.

used commercial robotic platforms (students as users) and those that used prototype platforms (students as designers and developers).

Navigation algorithms need to handle multiple and varied information to develop proper behaviors. Since the interaction in the real-world is time-constrained, an agent cannot generate a completely new behavior for every situation. Rather, it shall exploit its experience in order to adapt its behavior based on prior knowledge.

The **Smart Hexapods** project used a Lynxmotion[1] Quadropod and Hexapod robots to compare and develop insect-inspired locomotion models. Ph. D. and Master in Computer Science students approached locomotion as an emergent property of the interactions between the control mechanisms of individual legs [5]. Table 1 summarizes the scientific production of this project that lasted two years.

Navigation algorithms need to cope with the intrinsic uncertainty of the real-world in order to increase the behavioral diversity of the agent overtime. Master in Computer Science students developed architectures that enabled artificial agents to explore novel characteristics of a situation. Thus, the agents could react appropriately to certain situations in real-time **Robot Soccer** matches.

After the Smart Hexapods project, a new platform came onto scene: Yujin[2] Mirosot Robot. Table 2 summarizes the theses obtained from the research effort of this dynamic and competitive challenge. Additionaly, to their effort, students were encouraged to participate in international events. Which resulted in a 5^{th} place in simulated and 6^{th} place in real, both Mirosot League at the 2002 FIRA[3] Cup Korea, and a 4^{th} place in simulated Mirosot League at the 2003 FIRA Cup Austria.

A combination of the machine learning algorithms from the Smart Hexapods project, the multi-agent approach from the Robot Soccer project, and the empowerment of the students, as well as the entire Campus, with the FIRA Robot Soccer World Championship, brought another platform: ZMP[4] E-Nuvo Walking robot.

Nine Mechatronics Engineering fourth-year students were integrated in two teams each with a humanoid robot. By taking advantage of the mobile robotics

[1] http://www.lynxmotion.com
[2] http://www.yujinrobot.com
[3] http://www.fira.net
[4] http://www.zmp.co.jp

Table 2 Robot Soccer project's output: Master and Ph. D. in Computer Science theses

Author	*Year*	*Type*	*Title*
A. Dizan Vázquez G.	2002	Master	Soccer robótico: análsis crítico del área y diseño e implementación de una arquitectura para robots.
Huberto Ayanegui S.	2002	Master	Una arquitectura multicapas para el control de agentes de soccer robótico.
David A. Gómez J.	2004	Master	Desarrollo de algoritmos robustos para el sistema de visión de Mirosot FIRA.
Moisés Memije R.	2005	Master	Desarrollo de un módulo de estrategias para un equipo de fútbol robótico.
Huberto Ayanegui S.	2008	Ph. D.	Reconocimiento y descubrimento de patrones de comportamiento en sistemas multi-agente cooperantes. [1]

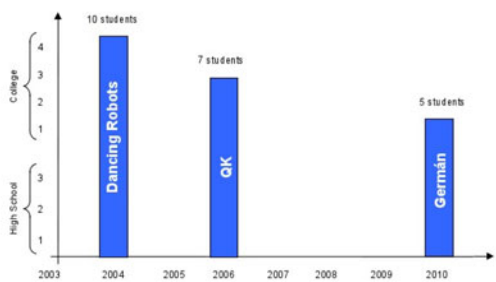


Fig. 1 Undergraduate students' projects. X axis shows the year in which each project was started. Y axis represents the average grade year of the students from each project.

specialization[5] of the students, an attractive and challenging project was proposed: **Dancing Humanoids** for the 6^{th} International Robot Olympiad[6] 2004, in Korea.

Even though there were no graduate theses involved in this project, the fourth-year students could collaborate and cooperate with the research faculty. A simulator [10] was developed in order to analyze the motion behavior of the humanoid robots while dancing. From this interaction, the students successfully programmed different dancing routines for each robot. Both teams participated at the Robo League in the RoboDancing category of the IRO 2004, achieving the 1^{st} and 3^{rd} places.

With the inertia from the International Robot Olympiad and the fact that undergraduate students could perform outstandingly, fulfilling the requirements and exigencies of a researcher, a final dare was pending: to design and develop a robot platform. Another difference from the previous project was that instead of graduate or fourth-year students, the project would be undertaken by third-year students.

[5] E.g. mathematical methods for rigid bodies kinematics, and dynamics and control of robots.

[6] http://www.iroc.org

The 8^{th} International Robot Olympiad 2006, was held in Gold Coast, Australia. A team of seven Mechatronics Engineering third-year students designed, manufactured, developed and tested the 18-Degrees-Of-Freedom lab prototype robot, named **QK**, for forest fire surveillance. Encompassing from the design of the mechanics and electronics, to the manufacturing and printed circuit boards construction, from the wireless and vision sensors selection, to the algorithms and protocol testing. The team won the 1^{st} place at the Robo League in the Creativity category of the IRO 2006. This, matured a Robotics laboratory as well as an educational framework.

3 LaRA

The Laboratory of Robotics and Automation (LaRA) is part of the facilities of the Tec de Monterrey Campus Cuernavaca. In contrast with other laboratories that support the academic life, there are no scheduled courses during the semester in LaRA.

In other laboratories, like the Manufacturing or Electronics, there are classes related to, or that need resources from them. Each teacher assigns a final project as part of the evaluation of the course. The students have to develop a project related to a subject of the course and deploy it by the end of the semester. In the worst case, during the semester the students could have up to six different projects.

This approach has the disadvantage that, the next semester, the students will work in different short-time projects. Also, the students only have the opportunity to work with students from the same class, that mainly are of the same major and age.

LaRA, aside from supplying resources to teachers and students like the other laboratories, has long-term projects, giving advice and support to the students about technology and projects, and offers a full-time available workplace where students can collaborate and interact with people of different ages, majors and professional interests. LaRA serves students from high school, college and graduate school that study, or are interested in, careers in engineering, management or design. Most of them are curious about mechanics, electronics, programming or entrepreneurship.

Most of the students working in LaRA are enrolled in a long-term project, where they match the requirements of their course projects to the needs of the LaRA's projects. Also, there are students that work in LaRA as a scholarship-service. Generally, they match their projects (personal or from a course) to the LaRA's projects needs as well, but they are required to work in the lab at least five hours per week.

3.1 PROFIL

The Program for Undergraduate Research Encouragement (PROFIL [11], according to its initials in Spanish[7]) emerged as part of the academic framework of Tec de Monterrey Campus Cuernavaca. The main goal is to boost a research culture in the scholastic community based on innovation, technological development and applied research, within an educational framework in LaRA.

[7] Programa para el Fomento a la Investigación en Licenciatura.

PROFIL has been the key to change from commercial platforms to functional prototypes. Thus, younger students have engaged in long-term and ambitious projects, becoming designers and developers, instead of users. Robotics is particularly effective because of the complexity of mechanics, electronics and software development. The activities involved with the design and development, interact with the curiosity of the students giving an unique experience to any student and team. The learning processes happen more effectively when the students build a prototype using their own ideas, ingenuity and creativity.

PROFIL involves the students within an enviroment of self-learning, advanced topics and long-term projects with a transdisciplinary approach. This constrasts with most universities that offer research opportunities to students [13], which mainly comprise working in a research lab during the summer, internships or occasionally during the academic year, with intense and focussed research work.

These are fundamental aspects that have changed the perspective of the undergraduate students' capacities and roles. In addition to this enrichment of the students' experience, this program is a scaffolding for students that are interested in or could become future researchers. The educational framework is based on:

- **Long Duration Projects:** A two-year duration gives the students the opportunity to get closer to a graduate-level aim and aspiration.
- **Participation in International events:** Motivation enables the students to be autonomous, so an international context pushes their creativity and enthusiasm.
- **Attractive and Challenging Projects:** Robotics is a dynamic field proper for technological development, which animates the students and makes them feel part of something important, allowing a high level of commitment.
- **Adaptation of the Curriculum:** Students need to match their course requirements, as well as their professional interests, with the project needs.
- **Adoption of a Formal Learning Model:** Understanding by building is a learning strategy that frames the academic and educational frameworks.

3.2 Germán

As a natural evolution of PROFIL and with an environment, health and safety focus of the LaRA, the current project recruited second-year students and seeks for a field robot prototype for greenhouse automation. A greenhouse enviroment, from a Robotics perspective, is a dynamic and challenging place. The irregular terrain and the hallways make it complex to navigate. The weather and the chemical products have to be considered when designing a device for greenhouse automation.

Germán is a cheap field prototype that intends to cover all of the requirements for working in a greenhouse. Additionally, Germán is intended as a research platform, which requires modularity, flexibility, to be easy to modify and adapt to different tasks. The project is organized in four areas:

- **Mechanics**
  Design, manufacturing and testing of the robot structure and mechanisms. This involves chosing the materials in order to cover needs such as strength, chemical or water-resistance, heat transfer, availability and cost.

Fig. 2 Students working in different projects as part of LaRA's support to the academic life (top, left). Third-year student with a rapid-prototyped robot for navigation algorithms validation (top, right). Field robot chasis assembly (left).

- **Electronics**
  Design, building and verification of circuits and PCBs for sensors (e.g. laser, infrared and sonar range finders), actuators (e.g. motors), controllers (e.g. Microchip[8] dsPIC), and power supply.
- **Software Development**
  Design, development and validation of the architecture, programs and routines for motion control, sensor data adquisition and analysis, motion planning, communication between software layers, and information about the state and goals.
- **Business Plan**
  A field robot must be competitive, not only technically, but also commercially. The price of the components, the working time of the team, as well as advantages such as energy saving, multipurpose design and a robust platform, are considered into a sales strategy to position Germán in a commercial market.

The main idea is to design and build as much as possible, considering the resources and limitations of the LaRA. In several previous projects, one major problem was that at certain stage of the development it was necessary a change in the software, electronical or mechanical module. Most of the time these kinds of adjustments were not possible due to a lack of technical experience, issues with warranty policies, or because of the functional design of the platform itself.

[8] http://www.microchip.com

The learning process of the students who work on Germán enables them to have a more effective understanding because the know-how is being developed by the students themselves. Younger students commonly approach the engineering aspects of project work with enthusiasm, but often only pay lip service to the methodologies, procedures, materials and use of tools and machinery. The most interesting part of the process is when the experienced students show and teach younger students [2]. This is more natural than classic approaches that immerse undergraduate students to already consolidated graduate research programs [3].

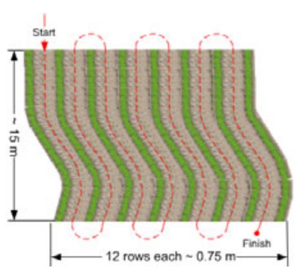
The main contribution of Germán, as a robotic platform, is that the same students are able to repair, modify and replicate it. This work in progress is the base for future field and entrepreneurial developments in LaRA and PROFIL projects.

Fig. 3 Germán LaRA with a thermonebulizer for Greenhouse fumigation.

3.2.1 Current Work

Germán is in the development and building phase. The mechanical structure has been manufactured and assembled (see Figure 3). Germán was designed to weigh 40 kg maximum in order to carry 40 kg. The team working in mechanics is formed by three second-year, five first-year and two high-school students.

The electronic design for power supply and motor control has been protoyped and tested. The controller for velocity is being tested. This work has been done by four second-year students. The business plan, done by two second-year students, has



http://ilf.rz.tu-bs.de/index.php/tasks.html

Fig. 4 The robot navigation between crop rows is a classic task for greenhouse automation evaluated the strenghts and weaknesses of the project, and it is being benchmarked against other automation products and services for greenhouses.

4 Incremental Learning for Autonomous Navigation

One of the most challenging goals in Robotics lies in the area of autonomous navigation. This research field aims for an artificial agent (e.g. robot) moving in the real world, which includes reasoning about uncertainty to build reliable sensory-based motion strategies [7]. In order to plan its motions, the agent must compute collision-free paths among possibly moving objects, which requires to:

To cope with the complexity and to integrate the constraints concerned with real-world situations, there are machine learning techniques like Reinforcement Learning [12] (RL) that stress learning from interaction. Interaction endows an agent with a wealth of information about cause and effect, about the consequences of actions, and about what to do in order to achieve goals. Recent research efforts [14] focus on RL, together with optimal stochastic tools, for motion control learning.

Interacting with the environment also involves uncertainty in sensing because of noise, signal delay and range limitations. As well as inaccuracy of the agent's actions and unpredictability of the real-world environments. Altogether make the information regarding the current situation to be partially accesible or incomplete. Probabilistic models, in this case, are appropriate to learn and predict, allowing to refine prior knowledge on the basis of the available observations.

A proposal for designing and building agents that autonomously plan and control their own motions, while reasoning about the uncertainty in control, sensing and prediction, is an hybrid system capable of learning from its experience about the environment, and to increasingly develop and perform more sophisticated behaviors.

The current research will develop a ”learn and predict” structure integrated to an onboard sensor-based motion planning. The aim is to enable an agent to improve RL policies based on the same observations that are used to predict motion as it happens, thus, contributing to the autonomous navigation improvement.

This work is part of a Ph. D. thesis, and will be using Germán as a platform for testing navigation algorithms. This collaboration between graduate and undergraduate students will benefit the participation of Germán in international contests for agricultural robots, such as the Field Robot Event[9]. This agricultural robot with autonomous navigation capacities shall be able to perform more complex tasks like fumigating, pollinating, harvesting and diagnosing crops.

The collaboration between graduate an undergraduate students, besides the technical basis and the educational framework, has helped to manage the continuity of Germán with a student population that changes from semester to semester.

The Ph. D. thesis and PROFIL have been the bridge in LaRA to have permanent personal support for the students to ensure the maintenance of the focus on Germán.

[9] http://www.fre2011.dk

5 Conclusions

In this paper we have reviewed the evolution of an educational framework until its consolidation. As a result, Germán is a robot platform designed and developed in LaRA, and grounded on the PROFIL methodology. PROFIL has evolved naturally to engage younger students in applied research.

During the first phase, undergraduate students teamworked with graduates in Computer Science. The projects were developed using commercial platforms and focusing on programming tasks (e.g. simulators). Some technical, but not challenging, adaptations were made in mechanical and electronic parts.

The second phase was characterized by an important motivational factor: students became designers and developers in order to meet the challenge of building robots for solving real-world problems. Also, funds were provided to the undergraduate teams, which needed to manage the available resources. The transition from the first phase to the second one required the development of skills, which are the essential difference between both phases.

Such skills are qualitatively described as follows: 1) students understood the relevance of the *integration* process, immersed into a transdisciplinary environment, for a project; 2) they worked *collaboratively*; 3) improved *problem-solving* skills e.g. analysis, synthesis, abstraction and structuring; 4) undergraduate students were responsible of *administrative* tasks for managing funds; 5) they developed *self-directed* learning attitudes.

Although major teaching institutions, as Tec de Monterrey, have developed different didactic techniques as academical frameworks, such as Problem-based learning, Collaborative learning, Project-oriented learning, Cases, Service-learning, and Research-based learning. The real technological developments need more time and effort than what an undergraduate student can dedicate to a single course project.

Laboratories as LaRA that follow a synthetic methodology as understanding by building, and educational frameworks as PROFIL, allow the students to enhance their experience with applied research. Consolidating a laboratory or organizing the research faculty is not an easy task, but is a long-term investment for an Academia committed to high quality education.

Every year new generations arrive to universities, and it is more difficult to encourage them to develop an analytical and critical sense. This paper describes the case of Tec de Monterrey Campus Cuernavaca that after ten years consolidated an educational framework. Since QK, five years ago, there have been three generations involved in PROFIL, which means an average of five students per generation.

From the first generation, four are graduate students participating actively in research and technological developments. It is hard to evaluate quantitatively the difference between PROFIL students and standard ones since PROFIL is a Campus program, open to any student, and not specific for a group of classes.

Those students that have been enrolled in PROFIL show stronger abilities in problem solving, communication, cooperation and general technical knowledge.

This can be more clearly seen in the interest and success of the second generation on more ambitious programs such as international stays at the Massachusetts Institute of Technology and at Texas A & M, both in U.S.A, and at the Université du Maine and at Grenoble INRIA research centre, both in France. Also, they have been motivated to contribute to scientific articles as in the present work.

The third and second generation are working together in Germán, which has been vinculated with at least 12 courses in three semesters, raising the standards of the courses and the expectations of the professor. Finally, what is most important, students work in these kinds of projects because of curiosity and ambition, not for a grade, which results in a more natural experience of learning and understanding.

6 Future Work

The cycle that follows long-term projects together with the inclusion of younger students has been a complete success. Novice students get enrolled in a project, and they learn from the experienced ones and understand useful concepts for their courses. Then they become experienced and teach new students. A system to track this cycle for continuity is needed.

Also, younger people, as high school students, is required to be involved for the next project. The first step has been taken giving specialization courses like Robotics, Biomechatronics and Automotive Mechatronics. Just as it happened five years ago with fourth-year Mechatronics students.

Even that PROFIL is a campus program, it has lacked of a formal adoption in the curricular structure of the university. There should be classes and courses marked as candidates for PROFIL projects, so professors from different subjects know in advance what is going to be the semester project. This way, the research faculty will focus on specific characteristics of the long-term project, while they adapt the course material for the students in the present semester.

Greenhouse and agricultural robots must be able to learn new motion strategies while interacting with the environment in order to relate and cooperate more naturally with other robots and people. Germán shall be capable of incrementally learning new behaviors, toward an online adaptation within the environment dynamics.

References

1. Ayanegui, H., Ramos, F.: Recognizing patterns of dynamic behaviors based on multiple relations in soccer robotics domain. In: Ghosh, A., De, R.K., Pal, S.K. (eds.) PReMI 2007. LNCS, vol. 4815, pp. 33–40. Springer, Heidelberg (2007)
2. Chin, C., Spowage, A.: Project Management Methodology Requirements for use in Undergraduate Engineering Research Projects. In: IEEE ICMIT (2008)

3. Dahlberg, T., Barnes, T., Rorrer, A., Powell, E., Cairco, L.: Improving retention and graduate recruitment through immersive research experiences for undergraduates. In: SIGCSE (2008)
4. Ditcher, A.: Effective Teaching and learning in higher education, with particular reference to the undergraduate education of professional engineers. Int. J. of Engng. Ed. (2001)
5. Ferrell, C.: A Comparision of Three Insect-Inspired Locomotion Controllers. Robotics and Autonomous Systems 16, 135–159 (1995)
6. Iida, F., Pfeifer, R., Steels, L., Kuniyoshi, Y. (eds.): Embodied AI. Springer, Berlin (2004)
7. Latombe, J.-C.: Robot motion planning. Kluwer Academic Publishers (1991)
8. Moulton, B., Johnson, D.: Robotics education: a review of graduate profiles and research pathways. World Transactions on Egineering and Technology Education (2010)
9. Pfeifer, R., Bongard, J.: How the body shapes the way we think. MIT Press (2007)
10. Ramos, F., Salinas, S., Rebón, J.C., Arredondo, A.: A Simulator for Learning Symbolically about the Behavior of Motions in Bipedal Robots. Int. J. of Engng. Ed. (2009)
11. Ramos, R., Zárate, V., Álvarez, J.: PROFIL: the development of robotics projects to introduce the applied research culture in the undergraduate level of the engineering area. International Journal of Human Welfare Social Robots. KAIST, South Korea (2005)
12. Sutton, R.S., Barto, A.G.: Reinforcement learning: an introduction. MIT Press (1998)
13. Taraban, R., Blanton, R.: Creating effective undergraduate research programmes in science: The transformation from students to scientist. Teachers College Press (2009)
14. Theodorou, E., Buchli, J., Schaal, S.: Reinforcement learning of motor skills in high dimensions: A path integral approach. In: ICRA, pp. 2397–2403 (2010)
15. Vallejo, C., Edgar, E., Ramos, F.: Evolving Insect Locomotion using Non-uniform Cellular Automata. In: Genetic and Evolutionary Computation Conference, vol. 869 (2000)