Mobile Robots Development: A Case Study from Robotics Competitions and Course Projects

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***Abstract*—In this paper, we present a proposal for a practical course on mobile robots at undergraduate level in engineering programs. The aim is to complement the theoretical concepts acquired in mechatronics, electronics and computer science in a practical manner with hand-on- experience with real robotic applications. The proposal is based on the lessons learned from robotic competitions and final year projects of student at Pontificia Universidad Católica del Perú (PUCP). The projects comprise: i) a mobile robot for a beach cleaning competition, ii) an improved version of the cleaning robot for an inventions contest, and iii) a mine detecting mobile robot. As a result, the products of these practical developments are reflected in functional prototypes that serve as research platforms, patents generation, research papers, and undergraduate theses, along with recognition at national and international level. The results and lesson learned from these case studies are presented and discussed for the mobile robots course proposal.**

Keywords— education; robotics; mobile robots; mechatronics,

I. INTRODUCTION

In the last decades, robotic systems were only seen as industry-oriented because their major contribution was the automation of assembly lines. However, with new advances in technologies and the necessity to develop innovative solutions for modern problems, their scope of use has started to change paradigms. Recently, low-cost and feasible new technologies at the reach of most users have started to shape the basis of a not so distant society that will include robots in our daily life. This transition is characterized by the progressive development of personal robot assistants, such as commercial domestic robots, and within, the redefinition of industry-oriented robots into human-robot collaboration systems [1].

Those mentioned changes together with challenges identified years ago, such as response to natural disasters and human assistance [2], are now the focus. Thus, it is necessary to prepare future professionals with a wide technical perspective and the capacity to bring integrative solutions. Under this regard, the field of robotics has started to influence the curricula of academic institutions by shaping students according to technological trends [3]. In order to complement this new paradigm, non-traditional events, such as robotic competitions, have started to acquire an important role. Initially forged to test students and roboticists technical abilities, robotic contests have educational and entertainment purposes.

Despite their broad popularity, its goals were usually repetitive tasks. Nevertheless, as a response to current worldwide problems, robotic contests have taken a serious role by showing the cutting edge of robotics technologies. As an example, The DARPA Robotic challenge [4], sponsored by the Department of Defense of United States, encourages institutions and universities around the world to develop robots for disaster response, an initiative that took a serious role after the Fukushima disaster in 2011. At the undergraduate level, there also exist international competitions oriented to real-world problems, among them, underwater robotics competitions, and mobile robots contests. The challenges are oriented to real-world problems such as beach pollution, sea contamination and even rovers design for Mars explorations. These types of events give undergraduate students a third learning environment, one between classes and laboratories where they can test their technical abilities, but most importantly, their critical thinking.

In this paper, three cases of the participation of undergraduate students in robotics contests are presented. Section two, introduces a group of the most competitive robotics contests, along with their importance and contribution for the undergraduate engineering curricula. Section three presents the projects developed by undergraduate engineering students at PUCP. In section four, the lessons learned from the experiences are presented. Finally, in section five, the conclusions and discussion are shown.

II. ROBOTIC COMPETITIONS

Nowadays, robotics competitions are gaining a strong presence by complementing the curricula of young students in the path of engineering. The topic of the competitions have started to aim real-world problems. At school level, the First Lego League (FLL) [10] has gained a strong popularity among young students. Its challenges are based on practical applications such as climate change, assistive technology, and transport [8]. Some private institutions, such as The Marine Advanced Technology Education (MATE) [11], in partnership with the Marine Technology Society ROV Committee created the annual MATE ROV Underwater Competition [5], which aims to inspire and challenge students to learn and apply STEM by using marine technology in order to solve real-world problems.

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(a) (b) (c)

(d) (e) (f)

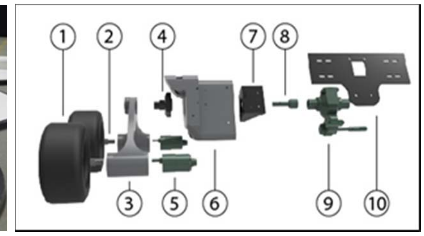
Fig. 1. a) First Lego League (FLL), b) Marine Advanced Technology Education (MATE), c) University Rover Challenge (URC), d) RoboCup , e) Humanitarian Robotics & Automation Technology Challenge [13], f) Latin American Robotics Competition (LARC).

Robotics Contests contextualized on aerospace applications, such as the University Rover Challenge (URC) [12], sponsored by the Mars Society [6], and the European Rover Challenge (ERC) [9], have recently increased in popularity, fostering Mars exploration and allowing students to propose innovative solution through interdisciplinary experiences along with project and team management. Another major event is RoboCup, an international contest which promotes robotics and AI research. It has different categories, such as Robot Soccer, Rescue, Home Support, Industry. IEEE RAS–SIGHT Humanitarian Robotics & Automation Technology Challenge (HRATC) focuses on promoting the development of new strategies for autonomous landmine detection using mobile robots. This event connects students with experts of the industry to discuss alternatives ways to clear post-combat regions of landmines, enriching their robotic solutions with qualified insights from the experts. In addition, Landmine Free World - Minesweepers Competition, challenge different students robotics solutions and compare their effectiveness. Through this validation, the participants can discuss and share their knowledge with other international competitors and expose the quality of their proposal among their international peers with different backgrounds.

III. Case of Studies: Robotic Projects at PUCP

A. Case I: Sunaya - Sand Cleaner Mobile Robot

The mobile robot Sunaya was designed as a social cleaning robot to rise pollution awareness on beaches. For this purpose, Sunaya was designed to perform cleaning tasks on beaches and establish communication with humans using in-built interaction characteristics. Some of the most significant features are: a modification of Rocker-Bogie suspension system for movement over uneven terrain; a collector and dis-charge system for garbage, and interaction capability through visual and dynamic features, in order to enhance communication with the people. This project was presented at the Latin American Robotic Competition IEEE LARC 2013 [7]. The goal was to develop a beach cleaner robot, and clean a simulated beach by picking up cans and avoiding obstacles.



(a) (b)

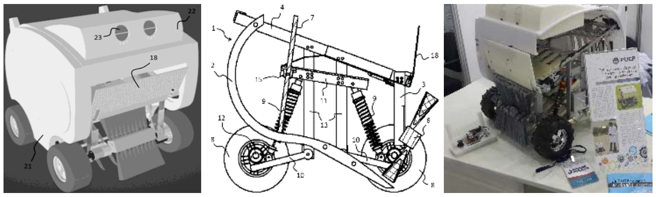
Fig. 2. Sunaya: The Social Cleaning Robot, b) Exploded view of Rocker-Bogie Suspension System: 1) wheels, 2)joitns, 3) rocker-bogie arm, 4) base joint, 5) motor, 6) rocker-bogie base, 7) bearing, 8) joint, 9) differential mechanism, 10) aluminum fitting.

(a) (b)

Fig. 3. a) Competition Area, b) Sunaya's during competition.

During the robot's design process, the morphological aspect was an important factor in the implementation of the robot [14]. In this project, the following premises were considered: a friendly visual appearance, an all-terrain locomotion system and capacity to collect and discharge light waste material. For the manufacturing process, 3D printing technology was used, using Polyetherimide (ULTEM) and Polycarbonate (PC), along with aluminum and steel. The all-terrain suspension and locomotion system was achieved with a Rocker-Bogie differential structure simplified with a four-wheeled design, allowing the robot to maintain a stable position on uneven terrain. The control system is composed by an embedded computer as the main processing unit, mainly for the vision algorithm computing. Additionally, an Arduino board was selected for the control of motor drivers and sensors.

At the competition, the robots attested to be an eye-catching all-terrain cleaning robot vehicle, shown in Figure 3. During survey, the robot performed successfully the cleaning task inside a simulated beach area. However, control algorithms for obstacle avoidance should be improved due to the dynamic environment and variety of light conditions in which the robot operated. Additive manufacturing offered a solution of rapid prototyping even with almost same tensile strength than conventional material such as aluminum or sheet steel. On Sunaya's public experience at LARC, seven students got the opportunity to participate in an international event in robotics. They assembled an interdisciplinary team, combining students from engineering and arts. In addition, they received diffusion in technical magazines and videos at national level. Moreover, they established contact with international experts who had more experience and knowledge on the field. Furthermore, the students submitted a patent request of Industrial Design Registration (expedient 001931-2013-DIN, INDECOPI-Perú, title 3763).



(a) (b) (c)

Fig. 4. **Fig.** Sullkapata, Isometric view, B: Lateral view of a longitudinal section of the vehicle, C: Sullkapata on National Invention Contest.

B. Case II: Sullkapata - Beach Cleaner Mobile Robotic

In many cases, the teams at the competitions do not document in detail their work due to the tight schedule to build a functional prototype. As result of the experiences gained at LARC 2013, the robot design and lessons learned were properly documented. With the gained experience and results obtained, one member of the group decided to translate this project into an improved version of Sunaya, named Sullkapata. The goal was to develop a solution that could solve the competition survey applied at LARC 2013. The present innovation is about an Unmanned Ground Vehicle for cleaning and security of beach on uneven terrain in general, which involves a main structure having waved rails, a case for protection, and a suspension system for traction power that rest on the main structure. One of the main improvements in the robot was the garbage collector system. This newer version had two bristle brush rollers to recollect the garbage and dispose it on the top of the vehicle. In addition, those rollers purged the waved rails dispersed sand from solid objects, hence, permit be purged the sand recollected.

In addition to the mechanical design, the navigation was autonomous. The system was equipped with sensors for obstacle avoidance, including a mobile phone as tool for image recognition and communication. In the tele-operated mode, video streaming was available through Wi-Fi network provided by the smartphone. The control system of Sullkatapa is composed by an Arduino Control Board for the sensors, motor drivers, and it is connected directly to the smartphone device via an USB port. Furthermore, the main structure was designed with lightweight constructions materials, including Polycarbonate (PC), ULTEM and aluminum. Problems presented at Sunaya, such as CPU time consumption for image processing and garbage system were overcome.

The new design was written on a thesis submitted to the engineering faculty at PUCP and afterward defended to obtain the degree of Mechatronic Engineer developed by an undergraduate student based on lessons learned on the first version. It involved technical knowledge on manufacturing, structural design, electronic and programming in order to present an autonomous vehicle for cleaning beach with constructive features that respond to a quality balance between compatibility, and efficiency during recollection and disposal garbage and power consumption. Furthermore, the students contested with this project at the National Invention Contest by submitting an invention patent (expedient 001675-2014 INDECOPI-Perú), shown in Figure 4.

(a) (b)

Fig. 5. a) Competition field, including the borders, grid, surface and buried simulated mines; b): MinedetexBot Robot.

C. Case III: MineDetextBot - Mine Detection Robot.

In contrast to the several improvements that landmine technology received during the last years, landmine detection technology has not received drastically changes. Amputations, burns, among other severe injuries, are the consequences of human landmine detection and deactivation. Acknowledging this humanitarian issue, worldwide academic institutions are currently fostering research in this field. The proposed objective for seniors undergraduate students of Mechatronics Engineering at PUCP was to develop a mobile robot which detects landmines. This project was realized under the rules of the Minesweepers Competition organized by Hadath and IEEE Robotics & Automation Society-Egypt Chapter. With this proposal, it was intended to develop a solution on their field of studies that may reduce the risks of demining post-combat areas under the frame of last year undergraduate project course.

This mechatronic system, named MineDetexBot, shown in Figure 5, was equipped with a sensor to detect a magnetic field induced on metallic landmines and with navigation sensors, such as ultrasounds, 2D LiDAR, and a camera to detect and idetinfy obstacles on the surface. It has a mechanical structure to drive through an uneven off-road terrain with a maximum 5° inclination. For operating the vehicle remotely, ZigBee communication protocol between a computer and the vehicle was implemented. In order to execute the measurements and the autonomous mine detection and identification, an Arduino Mega communicated with a BeagleBone Black were used. Through the development of this project, the students applied their theoretical engineering knowledge and competences learnt during their studies, such as critical thinking, problem solving, project management and teamwork.

As outcome, a functional prototype was elaborated and detailed in a technical documentation, including a technical report, blueprints and an operating manual. Through it, all the engineering calculations and components selections were clearly presented and justified. Moreover, the functionality and accomplishment of all the goals were presented and reviewed by an evaluation committee on the final presentation day of the course, obtaining a successful approval. Furthermore, an indexed publication was presented and published at the IEEE 8TH International Conference on Engineering Education (ICEED2016). At this conference, the students received feedback from international experts who evaluated the applied methodology, enriching their experience. In addition, the students developed the necessary skills to work in teams and obtained hands-on practice to develop further projects with a higher complexity. This experience backed the application of some students the program of Professional Development at the U.S., in 2017, offered by the program CIENCIACTIVA from the Peruvian National Council for Science, Technology and Technological Innovation (CONCYTEC).

IV. Discussion: Lessons Learned

As an overview, robotics competitions can play a major role complementing undergraduate students skills and education. In addition to foundational skills like literacy and numeracy, students require a mix of soft and technical skills to thrive world economy based on innovation. Some developed soft skills including teamwork, people management time management, creativity, judgement and decision making, and communication which are currently demanded in professionals. During the development of Sunaya and MineDetexBot, several students needed to coordinate between them, assigning tasks and distributing properly their time in order to succeed. Moreover, the students needed to communicate actively complex ideas clearly and effectively to professors and colleagues with solid arguments in order to obtain support, reviews and, in case of Sullkapata, secure funding. Digging into the technical skills, acquiring practical experience in an international environment, being exposed to the latest state-of-the-art technology, and obtaining reviews from international experts enhanced the students perspective. Furthermore, the students obtained important academic accomplishments as undergraduates: publishing conference papers and submitting patents.

Senior engineering course projects require students to develop a major project in a team, applying the knowledge and skills acquired in their undergraduate studies. We propose a practical course that offers hands-on experience, a characteristic that will improve the quality of the solutions with a reduced complexity. In addition, the proposed practical course aims a real application with a positive impact to the society, covering a humanitarian issue. With the experience obtained from the three analyzed cases, the covered academic topics of the practical course are presented in Table 1.

V. Conclusions and Future work

In conclusion, it was possible to demonstrate the positive impact that the combination of Robotics Competitions and senior year Course Project generates on undergraduate engineering students. Based on the described experiences, it was possible to identify enough elements to propose a practical course on mobile robotics for the mentioned student group.

Following this exposed work and continuing implementing the proposed course, it is expected that undergraduate students will obtain practical experience prior to undertake an integrative senior year project; so the quality of the developed projects in courses will be improved. In addition, it will aim a current issue to be solved, and it will encompass mechanical, electronic, programming and control theory topics. This content will be tested and tuned in the laboratory. Finally, it will be expected, the students to carry on their careers with practical experience, ready to face unexpected circumstances with a wider perspective to arrive to a suitable solution.

TABLE I. Practical Course Topics by Areas

<table>
<tr><th></th><th></th><th>Case I:</th><th>Case II:</th><th>Case III:</th></tr>
<tr><td rowspan="5">Mechanical Features</td><td>Suspension</td><td>Rocker Bogie</td><td colspan="2">Independent suspension</td></tr>
<tr><td>Steering</td><td colspan="3">Skid-steer</td></tr>
<tr><td rowspan="2">Structure Material</td><td colspan="2">ULTEM and PC</td><td>Steel</td></tr>
<tr><td colspan="3">Aluminum</td></tr>
<tr><td>Joints/Shaft Couplings/ Wheels.</td><td colspan="3">Detachable / Bronce, set screw and hexagonal head / Deformable rubber</td></tr>
<tr><td rowspan="6">Electronic Features</td><td>Batteries</td><td colspan="2">LiPO Battery</td><td>Lead Acid</td></tr>
<tr><td>Motor Controller</td><td>RoboClaw Orin Robotics</td><td colspan="2">Motor Shield VHN5019</td></tr>
<tr><td>Motor</td><td colspan="3">Geared motor with encoder and Servomotor</td></tr>
<tr><td>Controller</td><td>Ardupilot</td><td colspan="2">Arduino Mega</td></tr>
<tr><td rowspan="2">Sensors</td><td colspan="3">Ultrasonic and Inertial Sensors</td></tr>
<tr><td>Limit Switch</td><td>GPS</td><td>GPS, LIDAR 2D</td></tr>
<tr><td rowspan="5">Programming Features</td><td>Image Proc.</td><td colspan="3">OpenCV</td></tr>
<tr><td rowspan="2">Main Control</td><td colspan="3">C++</td></tr>
<tr><td>Arduino</td><td colspan="2">AVR Studio</td></tr>
<tr><td rowspan="2">Navigation system</td><td colspan="3">Path Algorithm based on sensor and camera</td></tr>
<tr><td colspan="2"></td><td>LIDAR 2D</td></tr>
</table>

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