Low Cost Platform for Teaching AI Self-Driving Cars Topics for Undergraduate Students in Emerging Countries

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***Abstract*— This full paper presents the validation and results of a low cost scaled car platform into a project-based course in order to teach AI self-driving cars topics for undergraduate programs in Universities. This is an elective course of the Mechatronics program at Pontificia Universidad Catolica del Peru (PUCP) whose second edition of the course was developed during January through March 2020. The main objective of this article is to present the results of the second edition of the project-based course, which details the integration of a low cost robotic platform with an embedded board used to execute computer vision and AI algorithms. Using a robotic platform allowed the students to focus on the application of the algorithms in a real scenario and learn from experience instead of using only simulation platforms.**

The proposed course aims to introduce the students in self-driving cars topics, and apply the theoretical concepts to develop an autonomous car using the robotic platform. The topics of the course are structured in five categories including Automotive Design Concepts, Localization and Navigation, Computer Vision Techniques, Artificial Intelligent Techniques and Simulation Environment; and is divided into fourteen theoretical lectures and five practical laboratories. The project-based course is aligned with four Students Outcomes from ABET accreditation entity for undergraduate programs in order to reinforce their abilities to work as a team, self-learning, hands-on experience, develop prototypes, testing in real scenarios, and learn basic scientific writing and presentation skills.

The results of the second edition of the course show that the students enrolled were able to accomplish the development of a self-driving car capable of completing a lap on a racetrack autonomously only using image processing and AI algorithms. In comparison with the first edition of the course, the inclusion of a scaled car as a base for the project avoided mechanical problems with the chassis and allowed the students to focus on the sensors integration and algorithms programming.

Keywords—Self-driving cars, Artificial Intelligence, low cost, project-based course, Abet Student Outcomes

I. Introduction

Self-driving cars combine sensors, actuators and software to control the navigation algorithms employed to drive a vehicle [1]. Companies such as Tesla, Uber, Nissan, Google, have developed prototypes of self-driving cars with the intention of decreasing the human effort for driving [2]. The benefits of self-driving cars are fewer accidents, reduced traffic, and enhanced human productivity. These automated cars are trained to execute real time decisions using artificial intelligence algorithms [3]. The development of these topics in undergraduate and postgraduate students is of high interest in several universities and e-learning courses, hence the necessity of a low-cost robotic platform capable of running autonomous driving algorithms.

Project-based courses for teaching autonomous vehicles have been developed in several programs. In [4] a course where students build an entire autonomous system is proposed by using a 1/10th scale model; the course includes topics such as Robotic Operating system (ROS), Computer Vision and Reinforcement Learning. With the same mechanical platform, MIT [5] proposed a four (04) module course for teaching Robotics to high school students using self-driving cars which includes a final race competition. Driving competitions are useful for students in order to test and compare control strategies and algorithms, some of the challenges are path following, traffic lights recognition and obstacle avoidance [6].

Scaled autonomous vehicle platforms based on commercial systems such as Raspberry Pi or Arduino have been implemented, in [7] a small Convolutional Neural Network (CNN) used to drive inside a lane a was tested on a Raspberry Pi. A similar approach was used in [8] but a Haar Cascade

Classifier was built for classifying traffic lights while a Hough Transform was used for lane detection, both algorithms were implemented using OpenCV. In [9] additional algorithms were included in a Raspberry Pi in order to detect traffic signal and control steering and path planning using A*. These studies have validated and demonstrated the tendency to develop and validate self-driving algorithms in embedded systems.

Instead of using a Raspberry Pi, FPGA based platforms were implemented and tested for scaled autonomous driving. HydraMini [10] used the Xilinx PYNQ-Z2 which has Deep Learning Processing Unit (DPU) as the main controller that allows it to run faster CNN and other AI algorithms. Many other platforms based on FPGA have been implemented and tested in competitions [11-14], most of them with the capability of driving inside the lanes, avoiding obstacles, and traffic light and signal detection. The results of these studies, we can observe that the usage of embedded systems with parallel processing are commonly used to improve the performance of self-driving algorithms.

A previous publication described the structure of a low cost self-driving cars project-based course for undergraduate students [15]. The preliminary results of the first edition of the course revealed the necessity for a robotics platform with a mechanically robust chassis with hardware components to cover the main requirements of an autonomous vehicle and with the necessary processing capacity to execute computer vision and AI algorithms. Therefore, this article aims to present the scaled car platform used and the improvement of the project-based course. The structure of the proposed course is aligned with an International accreditation entity such as ABET specifically is focused on the development of four of the seven ABET Students Outcomes. A validation of this platform was performed with undergraduate mechatronics students of the Pontificia Universidad Católica del Perú from January to March 2020.

This work presents a low-cost scaled car platform used for teaching AI Self-Driving Cars topics for undergraduate students in emerging countries and the preliminary results of the project-based course implementation. In section I the description and importance of the topics, similar platforms and self-driving cars courses are presented and discussed. Section II describes the hardware characteristics of the robotics platform and Section III presents the embedded system and algorithms used for programming the platform. Section IV describes the course methodology, details the course structure including the topic distribution and evaluation metrics aligned with the Abet Student Outcomes. Section V demonstrates the results of the application of this platform combined with the project- based course in undergraduate mechatronic students on a regular semester. In section VI the conclusions and future work of the development and application of the robotics platform are discussed.

II. Robotic platform

As stated in [15], a robotic platform with a robust chassis should be provided to the students from the first day in order to standardize their tasks as well as reduce problems that arose from hardware selection, vehicle design and implementation. For this reason, a commercial 1:14 scale FPV crawler was selected due to its size as well as having high traction wheels and a suspension system. This provides the vehicle with the capacity to carry additional electronic components and sensors required for the autonomous system.

The commercial vehicle includes DC motors for traction and steering each with its corresponding integrated driver circuit, a camera to transmit a live video feed as seen by the vehicle, and an integrated communication system. In order to provide a suitable platform for the students to use and test self-driving algorithms, it was necessary to modify the original electronics. First, the motor drivers were replaced with off the shelf open source models that could be easily integrated into an external electronic system for close loop control. The steering mechanism was also modified to replace the standard brushed DC motor with a steering servo to ensure a more precise steering angle control since the original mechanism would only allow for full right and left turns.

In order to allow the students to deploy self-driving algorithms on the vehicle, a sensor suite consisting of an HD camera and ultrasonic sensors were also added to enable road detection via computer vision and simple obstacle avoidance algorithms. For the computing unit, the vehicle was outfitted with a microcontroller to generate low level signals that actuate the motors while an embedded system Jetson Nano was employed to perform high level processing and self-driving algorithms. All additional components were selected to be low-cost and accessible by students from local electronics providers thus allowing the students to test different configurations and evaluate the performance of the tested algorithms. Figure 1 shows an example of the configuration of the robotics platform described in this section.

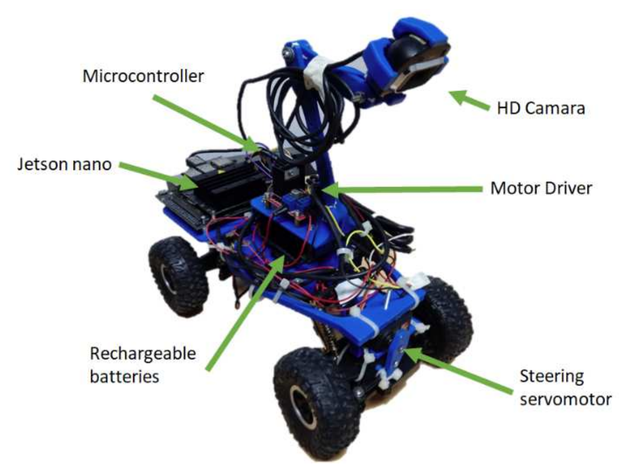


Fig. 1. Example of the robotic platform configuration

III. Embedded System and Algorithms

An NVIDIA Jetson Nano embedded system was selected in order to allow the students to develop basic control and artificial intelligence (AI) algorithms. The Jetson Nano is a low-cost platform that includes a Graphic Process Unit (GPU); this feature facilitates the training of AI algorithms due to its hardware that is capable of executing parallel processes, which is ideal for AI self-driving algorithms. In addition, the use of GPU increases the execution speed of AI algorithms as is shown in [16] and [17] where Jetson TX1 and TX2 was tested and CNN models can process at least 30 frames per second. The main features of this platform are shown in Table 1.

TABLE I. EMBEDDED SYSTEM SPECIFICATIONS

GPU	128-core Maxwell
CPU	Quad-core ARM A57 @ 1.43 GHz
Memory	4GB 64-bit LPDDR4 25.6 GB/s
Storage	microSD
Connectivity	Gigabit Ethernet
Price	~ 99 USD

In the course, the programming language applied was Python, which is widely used in the field of AI and has different libraries such as Numpy, Pandas, Scikit-learn and Tensorflow-Keras. These libraries facilitate the understanding and teaching of different algorithms such as Neural Networks and Convolutional Neural Networks (CNN). In the course, the following topics for classification and regression tasks are presented:

- **Linear and Logistic Regression:** Basic concepts that allow the basis of neural networks.
- **Neural Networks:** what are neural networks, activation functions, weight initialization and regularization techniques (dropout, batch normalization, weight regularization)
- **Convolutional Neural Networks:** how to build a basic CNN and common architectures such as ResNet and VGG.
- **Applications of CNN**: Object recognition and classification such as traffic signals and traffic lights.

Finally, the NVIDIA Deep Learning Institute offers a 8 hours free-course called "Getting Started with AI on Jetson Nano" This course is suggested to the students in order to learn the popular AI library PyTorch, which is widely used in the latest publications. In addition, the students can access the free slides and videos of the MIT course "Introduction to Deep Learning"; in this course there are explained basic Deep Learning concepts and its applications in the real world.

IV. COURSE STRUCTURE

The proposed course was aimed to introduce the students in self-driving cars topics, and apply the theoretical concepts to develop an autonomous car using the robotic platform. The structure of the course involves theoretical lectures, practical exercises and in-class programming examples. These are complemented with practical laboratories in which reduced groups of students (4 to 6 per group) use the robotic platform in order to develop a scaled car capable of driving autonomously through a two-lane racetrack. The course is structured in five (05) categories divided into fourteen (14) theoretical lectures (39 hours) and five (05) practical laboratories (10 hours) as presented in Table 2. This table indicates the relation between the lectures and the topics covered in the practice labs. The details of the course structure and development was explained in [15].

TABLE II. COURSE STRUCTURE: MODULES, LECTURES AND PRACTICAL LABORATORIES

Module	Lectures	Practical Laboratories
Automotive Design Concepts (10 hours)	Evolution of technologies in the automotive industry	Lab 1: Mechanical design and Implementation of scaled car
	Conventional cars and their Technologies	
	Autonomous cars	
Localization and Navigation (12 hours)	Mapping	Lab 2: Electronic design and instrumentation of scaled car
	Localization	
	Path Planning	
	Self-driving steering control	
Computer Vision Techniques (5 hours)	Computer vision concepts	Lab 3: Navigation algorithm implementation (w/ computer vision algorithms)
	Lane Detection	
	Object detection and tracking	
Artificial Intelligence Techniques (6 hours)	Machine learning	Lab 4: Optimization of algorithm (w/ deep learning models)
	Deep Learning for Self- driving vehicles	
Simulation environment (6 hours)	Simulator interaction	Lab 5: Testing and project presentation
	Autonomous driving simulation	

The mechatronics program at PUCP was accredited in 2016 by ABET, which is an international accreditation entity. ABET defines seven Student Outcomes and evaluates each program using these outcomes which are meant to measure the level of progress of the students in order to be prepared for their professional practice of engineering [18]. These Student Outcomes are developed and measured in different courses throughout the program. For these reasons, the course was aligned with four of the seven ABET Student Outcomes in order to develop and reinforce the following:

Outcome 2 – Apply engineering design to produce solutions: The students are challenged with problems related to autonomous driving vehicles, from which they find solutions using theoretical and practical knowledge in order to develop a functional prototype as the course project.

Outcome 3 - Communicate effectively: At the end of the course, each group must elaborate a short paper in which they describe the development and present the results from the group project.

Outcome 5 – Function effectively on a team: From the beginning of the course, the students are divided into small groups. They are expected to work in groups during the practical laboratories and during the development of the project course.

Outcome 7 – Acquire and apply new knowledge: The theoretical lesson introduces the students to concepts related to self-driving vehicles, but they are expected to complement these concepts in order to apply this knowledge during the practical lesson and the development of the project.

The evaluation metrics used for this course were specially designed in order to evaluate the comprehension of theoretical topics as well as the applications of these concepts into a practical project. Moreover, the evaluation considers the development of technical documents and communication skills. These metrics were modified from the initial version of the course presented in [15], where a detailed description of each metric was presented. Each metric was used to measure the development of the four ABET Student Outcomes previously described. A detailed description of the evaluation metrics is presented in Table 3.

TABLE III. EVALUATION METRICS FOR THE PROPOSED COURSE

Metric	**Description**	**Weight**	**ABET Student Outcomes**
Midterm Exam (ME)	Evaluation with theoretical questions of the application of technologies and algorithms in ideal self-driving cars cases	20 %	Outcome 7
Final Exam (FE)		20 %	
Practical Laboratories (PL)	Evaluation of the group performance on the topics developed in each laboratory session	20 %	Outcome 2 Outcome 5
Project implementation (PI)	Evaluation of the final project performance focus on the self-driving algorithm design	30 %	
Documentation (D)	Evaluation of the preparation and writing of the short paper	10 %	Outcome 3
Peer review evaluation (PR)	Evaluation between the members of each group in order to determine the dedication of each participant	± 15%	-

V. COURSE VALIDATION AND RESULTS

The course was available at PUCP to 4th and 5th year undergraduate engineering students from January to March 2020 (summer course). During this period, seventeen (17) students signed up in the course. The students were divided into four groups of 4-6 members.

A. Metrics results

The distribution of the grades scored by the students enrolled during this period is shown in Figure 2. At the end of the course all the students enrolled approved the course, with an average grade of 14.3 ± 1.7. The theoretical evaluations (ME and FE) presented a large gap between the students. Moreover, the FE has an improvement on the grades over the ME. The practical evaluations (PL and PI) show a significant difference between both grades, the PL grades range from 9.0 to 14.0 and the PI range from 14.0 to 18.0. The difference between both practical grades reflects an improvement at the end of the course, in which the students present their final project. On the other hand, on the documentation grade (D) the students obtained an approved grade with an average grade of 15.7 ± 1.8.

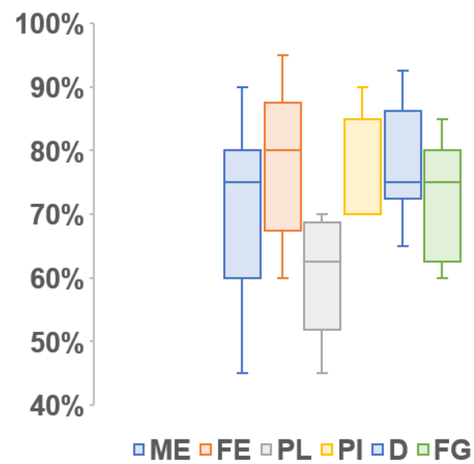


Fig. 2. Final grades of MTR37C course: Midterm Exam (ME), Final Exam (FE), Practical laboratories (PL), Project Implementation (PI), Documentation (D) and Final Grade (FG)

The development of the student outcomes described in the previous section were measured based on the grades obtained at the end of the course. This analysis is displayed in Figure 3, and presents the results of the four outcomes classified into four categories. The results on the Outcome 2, 3 and 5 demonstrated that all the students have at least a satisfactory development. On the other hand, 12% of students are still in progress on the development of the Outcome 7, and the other 88% had at least a satisfactory development.

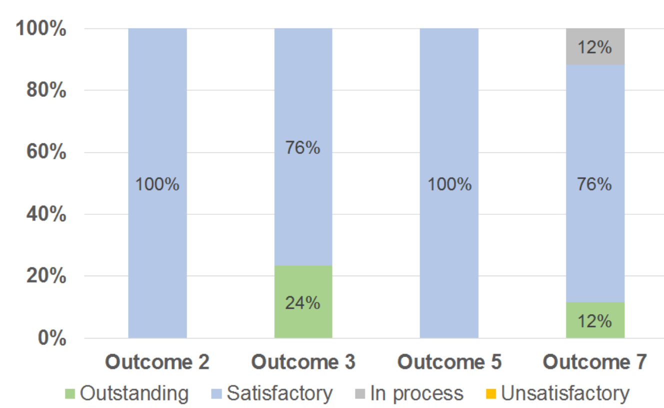
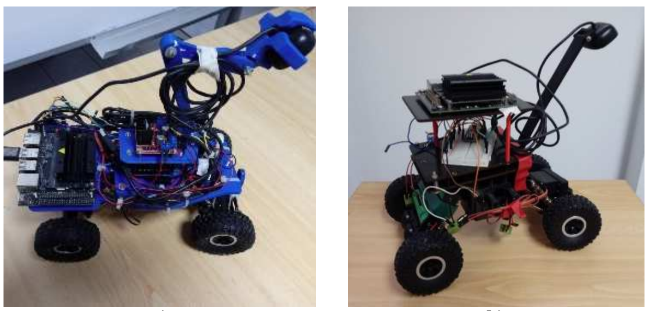


Fig. 3. Student Outcomes results from course MTR37C

B. Outcomes Results Evidences

In this section, the description of the evidence, that shows how ABET Outcomes were achieved, is presented. Regarding the Abet Outcome 2, the students that were enrolled in the course have already taken mechanical and electronic design courses, which gave them a prior engineering knowledge that was applied in the vehicle parts design. Students developed an additional structural support for a HD camera, some students used 3D printing and others Laser Cutting; in Fig. 4 the structures elaborated are shown. It is important to mention that the students considered factors such as weight, size, stability and assembly during the design process; for these reasons, PLA and acrylic were employed for the structure.



a) **b)**

Fig. 4. Car modifications for structural support.

As evidence of the Outcome 7, the students developed Lane Detection Algorithms using NVIDIA embedded system Jetson Nano. All the implemented algorithms used the detected in order to estimate the steering angle in order to control the direction of the car in a track that consisted of two 45 degree and four 90 degree curves (Fig. 5). It has two lanes with the same width and two types of lines: continuous and discontinuous. During the test, the vehicle could be placed in any position of the track at the beginning and should maintain its lane at least during a full lap.

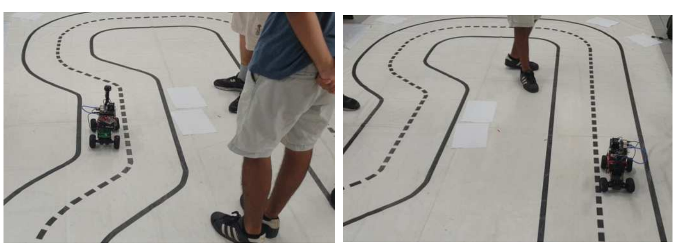
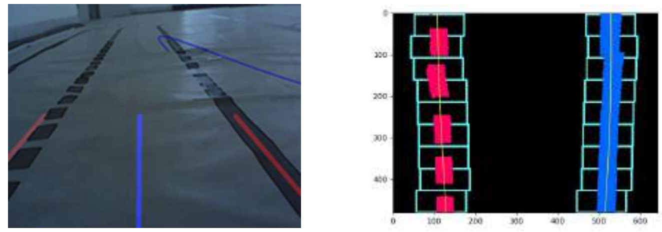


Fig. 5. Strudents testing algorithms in racing track

At the end of the competition, all the groups were able to complete at least one complete lap with their respective self-driving algorithms. The groups 1 and 2 only completed 1 lap, while groups 3 and 4 completed more than 3 laps. The first two groups implemented a lane detection algorithm based on Hough transform (see Figure 6a), while the other two groups implemented a self-coded algorithm used to analyze and determine the position of the lane lines and the type of line (see Figure 6b).



a) **b)**

Fig. 6. Lane detection using image processing algorithm

VI. Conclusions

The scaled car platform presented in this article was used alongside the proposed project-based course in undergraduate students of the Pontificia Universidad Católica del Perú. The topics covered during the theoretical and practical lessons of the course were validated by the usage of the platform for the development of a practical project in which small groups of 4-5 students had to implement a self-driving algorithm in order to complete a lap into a racing track. The results obtained were successful since all groups that were enrolled in this edition of the course accomplished this requirement. In comparison with the first edition of the course [15], the students did not have a scaled car platform to be used as a base of their design and only one group could accomplish this task.

The scaled car platform used during this edition of the course uses a commercial 1:14 scaled FPV crawler as base, but similar scaled cars can be used to replicate this course. The structure of the scaled car was modified in order to include an HD camera, a NVidia Jetson Nano and other electronic components to achieve the self-driving task. A total investment of ~ 300 USD per group was necessary to implement the robotic platform, and then the same platform can be used in other editions of the course. This platform gives the opportunity to undergraduate students to apply their knowledge of self-driving car topics into real life applications, not only limited to race tracks but also can be applied to other types of self-driving applications. The low cost implementation is beneficial to universities with low resources of institutions in emerging countries where it is not possible to apply concepts of self-driving vehicles using real size cars of other scaled car educational platforms.

The structure of the proposed course is aligned with four Abet Student Outcomes. This could be beneficial for undergraduate programs that aim to seek to accredit their academic program with an international entity. By the implementation of a course with a similar structure, the students could develop the abilities to work as a team, self-learning, hands-on experience, develop prototypes, testing in real scenarios, and learn basic scientific writing and presentation skills. Then the metrics of the course could be used to measure the achievement of the ABET Students Outcomes 2, 3, 5 and 7.

As future work, the authors will design and implement a standardized modular scaled car platform. We expect that using a modular design the students will have the opportunity to test the influence of the mechanical characteristics of the vehicle in the performance of the self-driving algorithms. Moreover, the structure of the course will include more topics related to AI algorithms in order to apply existing computational models for autonomous driving applications.

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