Investigating Ways to Develop and Control a Multi Purpose and Low Cost Agricultural Robotic Vehicle, in Scale

Dimitrios Loukatos[1], George Tzaninis[1], Konstantinos G. Arvanitis[1] and Nikolaos Armonis[2]
[1]Dept. of Natural Resources Management & Agricultural Engineering
Agricultural University of Athens, Athens, Greece
[2]Hellas Digital Research and Innovative Products Company, Athens, Greece
dlouka@aua.gr, giwrgostzaninis@gmail.com, karvan@aua.gr, n.armonis@hellasdigital.gr

Abstract

Agriculture is a sector that is rapidly changing due to the technological advances of our era, but is not always easy for the students to catch up with this fast evolving process. A good way to tackle it is to let them experiment trying to develop innovative robotic vehicles for agricultural purposes. This paper describes exactly the trials being made to design and implement an electric robotic vehicle, in scale, in a cost-effective manner, using metal, wood, recyclable materials and small motors. Students experimented with bipolar stepper motors as well as with brushed DC motors and performed a comparative study between the two types. Starting from configurations involving only one Arduino Uno board, students shifted to scenarios with more components, and even with Raspberry Pi units, in order to better understand fundamental automatic control principles and remote operation issues. The trials made to properly program the robot using both visual and textual programming environments are also reported. Most of the remote interaction scenarios have been carried out through Wi-Fi interfaces, while some of them involved LoRa interfaces to extend the effective controlling distance of the robot. For better efficiency and autonomy, a small solar panel unit has been adapted on the top of the robot and energy consumption for different configurations has been studied as well. Finally, the paper, going beyond strictly educational purposes, reports on characteristic derived robotic layouts and proposes possible "real-world" use case scenarios.

Keywords: Agricultural Vehicles, Smart Control, Energy Consumption, Educational Robotics, Project Based Learning

1. Introduction

Agriculture is, beyond any doubt, one of the most important sectors of primary industry, yet it is characterized as sensitive, unstable, complex, dynamic, and highly competitive. In the twenty-first century, according to FAO, agricultural productivity should be increased by 60% in order to ensure a safe food supply which would adequately satisfy the nutritional needs of the constantly growing world population (FAO, 2013). This goal has to be achieved despite the fact that the required resources are already stretched, as the amount of available agricultural land is declining due to increasing urbanization, soil erosion, and high salinity levels, while 70% of the world's freshwater supplies are consumed for agricultural purposes. In addition, it is required for agriculture to address the issues which arise from the global climate change, concerning the reduction of its greenhouse gas emissions, as well as the adjustment to extreme weather conditions which impact the quantity and quality of the crops (FAO, 2013). To successfully tackle these issues, the sector of agriculture has to become more productive and "climate-smart", by successfully exploiting a variety of existing and emerging technologies (Symeonaki et al, 2019). Among them, Robotics and Autonomous Systems (RAS) technologies could positively contribute to the transformation of the agri-food sector (Bechar and Vigneault, 2016; Bechar and Vigneault, 2017; Krishna, 2016; UK-RAS Network, 2018).

Robotic platforms equipped with a variety of remote and proximity sensors and making use of low cost Internet of Things technologies, advanced analytics, computational intelligence tools, machine learning techniques, advanced automatic control schemes, future telecommunications and Cloud computing technologies could provide information about soil, seeds, livestock, crops, costs, farm equipment and the use of water and fertilizer. It is expected to make more intelligent decisions about the level of resources needed and determine when and where to distribute those resources in order to minimize waste and maximize yields, in the context of Precision Agriculture.

The involvement of robotic automation in the field of Agriculture would also help to attract skilled workers and graduates to the sector. Therefore, it is very important to educate future agricultural engineers in the disciplines and technologies that are involved in modern robotics but is not always easy for students to catch up with this fast evolving process. A good way to tackle such difficulties is to let students experiment trying to design and to implement (i.e., to construct and program) similar robotic vehicles on their own, assisted by innovative systems that have recently made the scene and are becoming very popular among the student communities willing to develop similar projects, without the barriers that strictly commercial educational robotic solutions are posing (Doran and Clark, 2018).

This paper describes exactly the trials being made to develop an electric robotic vehicle, in scale, in a cost effective manner, using metal, wood, recyclable materials and small motors. The students experimented with bipolar stepper motors as well as with brushed DC motors and also performed a comparative study between the two types. Starting from configurations involving only one Arduino Uno (Arduino, 2019) board, the students shifted to scenarios with more Arduinos and even with Raspberry Pi (Raspberry, 2019) units to be familiar with fundamental automatic control functions (in terms of speed and direction stabilization) and remote operation issues. The paper also reports on the efforts made to properly program the robot using both visual and textual programming environments. Finally, the paper presents typical use case scenarios and highlights open issues and plans for the future.

2. Requirements and Design Overview

The specific goal being set for the students of the specialty of Farm Machinery, at the Agricultural University of Athens, was to design, implement and test a DIY robotic vehicle, in scale, that could host various sensors for environmental measurements or perform light farming activities, like planting seeds, spraying or carrying light crop cargos. This robotic vehicle had to be simple to manufacture, durable and cost-effective. Furthermore, it should have a moderate size and torque, more than one hour autonomy and the speed of a walking man, without being too heavy or too greedy, in terms of energy consumption. Finally, the vehicle should be able to roll on slightly anomalous or inclined terrains. The basic robotic vehicle design principles are depicted in the left part of Fig. 1.

As this robotic vehicle was intended to serve as a "vanilla" platform for testing environmental sensing equipment or to perform light duty agricultural tasks, a mechanism for commanding it, either locally or remotely, should be incorporated as well. For this reason, the low level controlling tasks had to be addressed locally by an Arduino Uno unit, installed on the robot and accompanied by simple electronic components like potentiometers and suitable motor-driving equipment. For the high level tasks, like providing remote human-robot interaction, the robot had to be equipped with a Raspberry Pi unit able to run python (or C) code and to act as a bridge between the fixed on the robot Arduino and the smart phone of the user. The latter device should provide commands via its touch screen, its accelerometer sensor or via a cloud-based voice recognition mechanism, in a way based on and extending the methods described in (Loukatos et al, 2018). In recapitulating, both visual (e.g. Ardublock and MIT App Inventor) and textual (e.g. Arduino IDE, C, python) programming environments were used to provide a satisfactory behavior for the robotic vehicle.

3. Implementation Details

The selection of the hardware components intended to minimize the size and the cost and maximize the reusability. Software design and implementation was following the same principles.

Taking the abovementioned requirements under consideration, students resulted in a layout involving two independent electric motors giving motion to the wheels of each side, through a chain drive system. This setup eliminates the need for extra mechanisms dedicated in steering tasks, provides simplicity, robustness and increased maneuverability. The basic robotic vehicle layout using two stepper motors is depicted in the right part of Fig. 1.

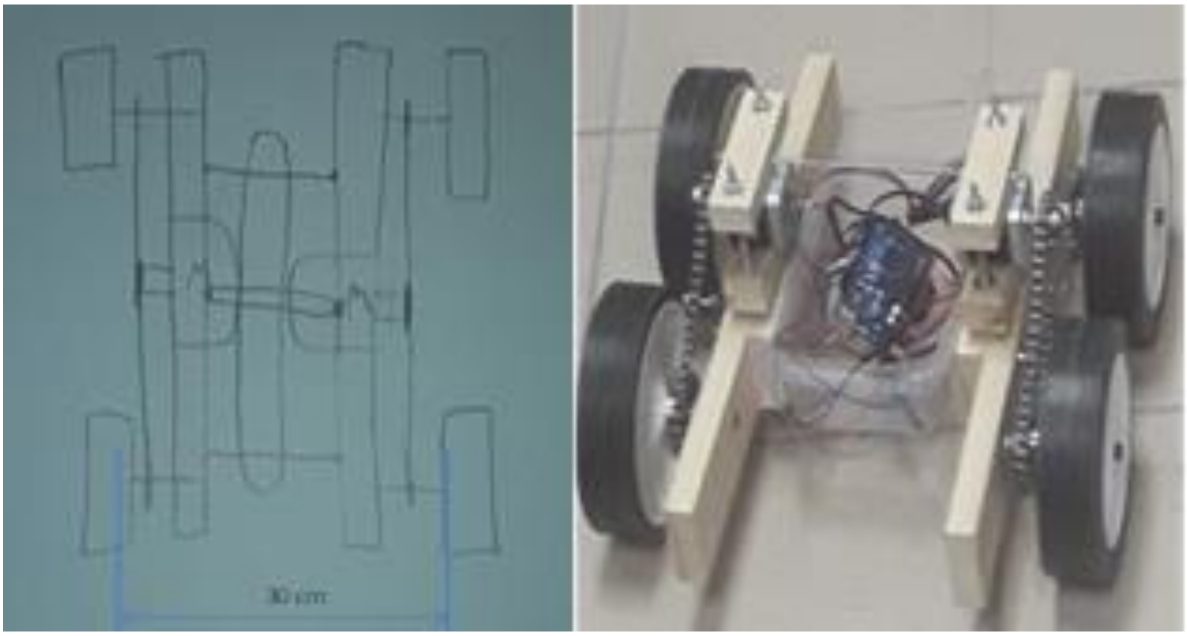

Figure 1. Initial robotic vehicle design providing one independent motor per-side and all-wheel drive (left). An early implementation using stepper motors (right)

Indeed, it is mainly a two separate parts (i.e., left and right) design, parts that are connected via threaded rods, of 3mm in diameter, thus providing suspension elasticity. The control of the motors was to be done by a microcontroller (Arduino Uno), via suitable power electronics (motor drivers mainly of L298 type). The necessary power would be provided by power banks or deep discharge batteries. Size specifications tend to a 40x40 cm layout. The motors to be used should deliver a torque of around 5kg-cm, at 100 rpm, in order to have a combined drag force of around 4kg, taking into account the revolution reducer (:3) and the given wheel diameter (approximately 7cm).

According to the Initial requirements for locally controlling and testing the robot two potentiometers were fixed on the robot, for selecting the speed and the direction of the vehicle, respectively. Further tests involved ultrasonic and IR distance sensors to intercept obstacles or human gestures nearby.

In terms of software, as students were not very familiar with textual programming, a considerable amount of tasks was done via the Ardublock visual programming tool, for Arduino related tasks, and via the MIT App Inventor environment, for smart phone related remote control tasks over Wi-Fi. The Arduino unit and the Raspberry Pi unit on the robot are communicating via suitable serial commands.

A good practice being followed was to use a separate power source (e.g., a power bank) for supplying the controlling circuit, as the motors have a quite “crude” behavior that sometimes results in sudden voltage drops on the main battery units supplying them.

4. EVALUATION AND DERIVED ENHANCEMENTS

The modular nature of the experimental robotic layout development allowed for an educationally meaningful and very detailed description of the progress steps during the testing process. More specifically, according to the initial implementation involving two stepper motors to move the robot, it was observed/verified that these over engineered motors had a very high torque without requiring a built-in revolution reducer, they allow easy and precise movement determination, but they consume too much power and produce a lot of heat. Indeed, while the robot was powered at 8V, the stepper motor system consumed 2.0A at fast speed, 2.8A at medium speed and 3.1A at low speed. Its maximum consumption was at a standstill, while any increase in motors' load did not significantly increase the power consumption. Speeds being achieved, varied from $0.25ms^{-1}$ to $0.75ms^{-1}$, that where similar to these of a walking man, as expected. The pulling force of the robot was about 2.5kg and its weight about 4kg. The cost of the whole robot was below 125€.

The powering issues lead the working team to replace the stepper motors with simple, brushed DC motors that have a much lower consumption which follows the load changes in a progressive manner. As a tradeoff, these DC motors require a feedback control system, to provide accurate operation, and thus such a mechanism was added, using photo interrupters fixed around the driving sprockets. This feedback mechanism configuration allows for a timer granularity at the order of 0.1s, which is not ideal in terms of responsiveness but, from educational aspect, allows for a clear inspection of robot's speed fluctuations during the speed correction process. For better results, a more aggressive integral speed correction schema was adopted for actual speeds lower than the target speed, while a less aggressive schema was adopted for speeds higher than the target value. Furthermore, the robotic vehicle was enhanced by incorporating a direction stabilization mechanism, based on data fusion of signals provided by a nine-degree of freedom IMU/compass data unit fixed on the top of the robot and connected with the Arduino via an I2C interface. For better matching the stepper motor counterpart characteristics, the two brushed DC motors had to be slightly over-voltaged (using 16V instead of 12V) so as to provide better torque and speed. Under the later setup, the system consumed, without load, at a low speed 0.14A, at average speed 0.16A, and at high speed it consumed 0.18A. In the case of operation under load at high speed, it consumed 0.32A with low load, 0.48A with medium load and 0.80A with high load. The vehicle's electronic system (microcontroller and motor driver circuits) consumed about 50-60 mA to operate, a comparatively small quantity that should be added to the abovementioned calculations. Most of the remote interaction scenarios have been carried out through Wi-Fi (Wi-Fi, 2019) interfaces, while some of them involved LoRa (LoRa, 2019) interfaces, to extend the effective controlling distance. In order to host the LoRa shield a second Arduino Uno unit was fixed on the robotic vehicle, instead of the Raspberry Pi unit. The adoption of the LoRa protocol for controlling the robotic vehicle demanded a custom Arduino based remote control unit, using a second LoRa shield at the user's end. The top left part of Fig. 2 provides a detailed view of the discussed enhancements involving brushed DC motors, photo interrupters, IMU/compass sensors and LoRa radio.

More ambitious enhancements involved motors of higher torque (i.e., more than the double), larger batteries and required the replacement of the initial motor driver (L298 chip) with an improved circuit, based on MOSFET type transistors and thus being able to handle higher currents with lower voltage drops. This layout allowed for greater wheels (of about 25cm in diameter) to be fixed on the chassis. Added to that, a small solar panel unit has been adapted on the top of the robot. This 15W solar panel was able to deliver at about 0.8A at 18V under good sunlight conditions, amount that could assist and charge the batteries. The top right part of Fig. 2 depicts the abovementioned robot's enhancements in size as well as the solar panel assisting the vehicle. The case depicted in the bottom part of Fig. 2 refers to a vehicle variant intended to pass over the young plants, mainly for inspecting and spraying them with fertilizers or for killing the weeds. Strong motors, big wheels and two solar panels are present in this layout. The controlling logic remains the same.

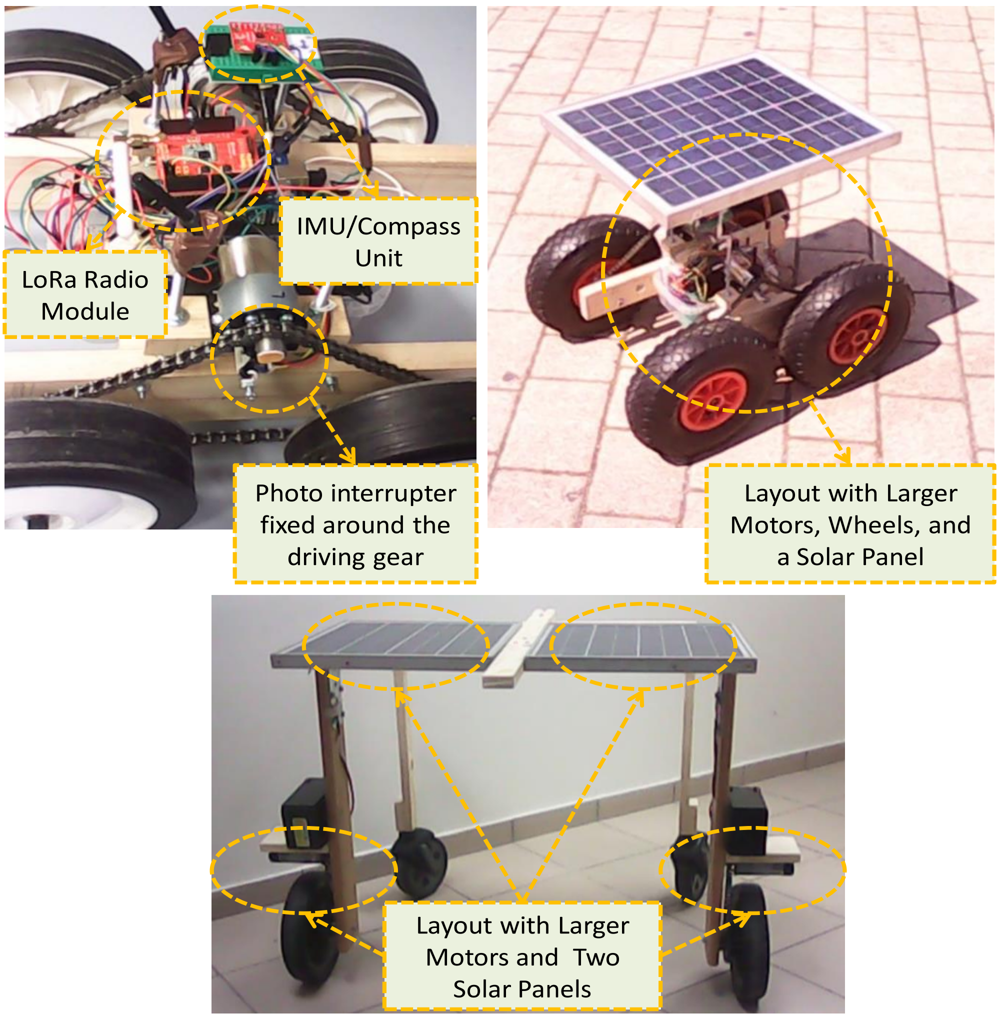

Figure 2. Enhancements involving feedback mechanism for DC motors, IMU/Compass unit and LoRa shields for Arduino (top left). Further enhancements involving solar panel assistance and bigger motors and wheels (top right and bottom)

5. Conclusions and Future Work

This paper highlighted the trials being made to design and implement electric robotic vehicles, in scale, in a cost effective manner, using metal, wood, recyclable materials and small motors, in order to aim students to catch up with the rapid technological advances in the agricultural era. Experimental configurations involved different motor types and controlling units. Brushed DC motors along with Arduino based controlling units form a cheap but educationally fruitful schema. By using a simple photo interrupter based speed feedback mechanism as well as IMU/compass modules it is possible to understand the fundamentals of automatic and remote control and proceed with code improvements that lead a more adaptive behavior. Both visual and textual programming environments were used to properly program the robot. In terms of remote operation, tests with LoRa interfaces provided an effective solution for increasing the controlling distance of the robot while keeping the power consumption at a low level. Energy consumption for the different configurations was studied, as well as solutions involved assistance by small solar panels.

The overall configuration, although initially targeted at educational goals, can easily be adapted to provide “real-world” solutions. For this reason, characteristic derived robotic layouts and the corresponding indicative use scenarios were also presented. Plans for the near feature involve further experimentation with the derived robotic vehicles, in larger and more robust electro-mechanical layouts. Furthermore, as LoRa interfaces drastically extend the effective controlling distance, more sophisticated methods for monitoring the robotic vehicle will be investigated, including fusion with GPS data or incorporation of machine vision techniques.

6. Acknowledgements

We would like to thank the personnel of the Farm Machinery Laboratory and the students of the Dept. of Natural Resources Management & Agricultural Engineering of the Agricultural University of Athens, Greece, for their assistance in tools and labor, during the construction stages of the robotic vehicles. We would also like to thank the CEO and staff of Hellas Digital company for their great assistance in replying to our numerous questions and in offering high-end electronic equipment.

References

Arduino Uno (2019). Arduino Uno board description on the official Arduino site. Retrieved in April 2019 from the site: https://store.arduino.cc/arduino-uno-rev3

Bechar, A. and Vigneault, C. (2016) 'Agricultural robots for field operations: Concepts and components', Biosystems Engineering, 149, pp. 94–111. doi: 10.1016/j.biosystemseng. 2016.06.014

Bechar, A. and Vigneault, C. (2017) 'Agricultural robots for field operations. Part 2: Operations and systems', Biosystems Engineering, 153, pp. 110–128. doi: 10.1016/j.biosystemseng.2016. 11.004

Doran, M. V, and Clark, G. W. (2018) 'Enhancing Robotic Experiences throughout the Computing Curriculum', SIGCSE'18, February 21-24, Baltimore, MD, USA (pp. 368–371).

FAO (2013) 'Climate-smart agriculture sourcebook', Food and Agriculture Organization of the United Nations. Retrieved in April 2019 from the site: http://www.fao.org/3/i3325e/i3325e.pdf. Accessed in April 2019.

Krishna, K.R., (2016), 'Push button Agriculture: Robotics, drones, satellite-guided soil and crop management', Apple Academic Press, Oakville, Ontario, Canada.ISBN-13: 978-1-77188-305-4 (eBook - PDF).

LoRa (2019). LoRa protocol description on Wikipedia. Retrieved in April 2019 from: https://en. wikipedia.org/wiki/LoRa

Loukatos, D., Kahn K. and Alimisis D., (2018) 'Flexible Techniques for Fast Developing and Remotely Controlling DIY Robots, with AI flavor', Proceedings of the 'Educational Robotics 2018 (EDUROBOTICS)', Rome, Italy, published by Springer, ISBN 978-3-030-18141-3

Raspberry (2019). Raspberry Pi 3 Model B board description on the official Raspberry site. Retrieved in April of 2019 from the site: https://www.raspberrypi.org/products/raspberry-pi-3-model-b/

Symeonaki, E.G., Arvanitis, K.G. and Piromalis, D.D. (2019), 'Cloud computing for IoT applications in climate-smart agriculture: A review on the trends and challenges towards sustainability'. In Theodoridis, A., Ragkos, A. and Salampasis, M. (Eds.), Innovative Approaches and Applications for Sustainable Rural Development, HAICTA 2017, Springer, Cham, Earth System Sciences Series, Vol. 29, Chapter 9, pp. 147-167, 2019. DOI: 10.1007/978-3-030-02312-6_9.

UK-RAS Network: Robotics & Autonomous Systems (2018), 'Agricultural robotics: The future of agricultural robots", UK-RAS White Papers, ISSN: 2398-4414. Online at: https://arxiv.org/ ftp/arxiv/papers/1806/1806.06762.pdf.

Wi-Fi (2019). The IEEE 802.11 Standard. Retrieved in April 2019 from the site: http://www.ieee802.org/11/