A Multidisciplinary Course and the Corresponding Laboratory Platform Development for Teaching the Fundamentals of Advanced Autonomous Vehicles

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Abstract

In the past few decades, autonomous features have been gradually augmented to traditional ground transportation systems. These features can range from simple cruise control, blind spot detection, and lane departure control, all the way to autopilot systems. Aiming to train the next generation of engineers in this field and to fill the skill gap among students in traditional engineering disciplines, a multi-purpose and multidisciplinary course, named “Autonomous Ground Vehicles”, along with an open-source laboratory platform was developed by the authors. The proposed laboratory platform can be used to study a wide range of topics regarding autonomous vehicles, ranging from low-level data acquisition and control to higher-level concepts such as sensor fusion and SLAM. This paper discusses the pedagogical considerations in the syllabus and experimental laboratory platform design for this unique course. The course was offered as a cross-listed elective course among Mechanical Engineering, Mechatronics and Robotics Engineering, and Computer Science majors. Therefore, the challenges faced during the course offering, especially to ensure that the course is appropriate for ME, MRE, and CS students while complex enough to cover the essential fundamentals of autonomous vehicles are also discussed. Finally, the outcomes of offering this course in terms of student feedback, the lessons learned, and the future directions will be presented and discussed in the paper.

Introduction

The term Mechatronics, originally derived by merging ‘mecha’ from mechanics and ‘tronics’ from electronics, refers nowadays to a synergistic integration of precision mechanical engineering with electronics and intelligent computer control in the design of manufacturing processes and smart products. Examples of such systems include consumer electronics, smart home appliances, building automation, medical and healthcare applications, heavy machinery, manufacturing, autonomous vehicles in ground transportation and aviation industries, and industrial and space robotics. Especially in the past few decades, the advancements in control systems, integrated electronics, embedded systems, computers, and internet have significantly contributed to the growth of Mechatronics. Mechatronics engineers design, develop, and manufacture smart and autonomous systems and processes in various application areas with the ultimate goal of improving human lives and well-beings.

To prepare the next generation of students for this growing field and to address the needs of the industry, various universities and educational institutions have introduced individual course offerings and stand-alone degree programs in the field of Mechatronics and/or Robotics. Recognizing this need, especially in the Midwest region, and in pursuit of its commitment to shape a changing world, Southern Illinois University Edwardsville (SIUE) has invested personnel and resources to create a degree program in Mechatronics and Robotics Engineering (MRE) to prepare students for this growing industry. The SIUE offers one of the most comprehensive and affordable engineering programs in the St. Louis region with eight undergraduate degrees, five master's degrees and a cooperative doctoral program. Students learn from expert faculty, perform cutting-edge research, and participate in intercollegiate design competitions. Companies in the metropolitan St. Louis area provide students challenging internships and co-op opportunities, which often turn into permanent employment. Students gain extensive hands-on experience in the School's state-of-the-art facilities, including the new Fowler Student Design Center. The new MRE program has seen a rapid growth in enrollment since its initial offering in Fall 2016 and has a current enrollment of 64 undergraduate students.

One of the necessary outcomes of any educational effort towards MRE should be interdisciplinary knowledge of mechanical, electrical, computer, software, and systems engineering so that the graduates can oversee the entire design and development process of any given Mechatronics and Robotics system. In our program, this exposure is provided through courses offered by Mechanical, Electrical, and Industrial Engineering faculty. Furthermore, the students gain extensive hands-on skills in the various labs of the School of Engineering, offered as mandatory parts of the curriculum.

Mobile robotics is an important focus area of the MRE field. Aerial and ground mobile robots are increasingly being used in agriculture, logistics, maintenance and inspection, security and defense, space explorations, and nuclear applications in which the operating conditions might be undesirable or dangerous for human operators. Furthermore, driverless cars and the field of autonomous transportation in general, are heavily based on the fundamentals of mobile robotics. Therefore, in recent years, it has become of utmost importance to familiarize the engineering students with the basics of mobile robots by offering courses involving a heavy experimental focus[1,2]. To this end, experimental robotic platforms of various complexity and cost have been developed by academic professionals[3] and the commercial sectors around the world[4]. An additional advantage of such platforms is their applicability in other MRE and Control-related courses[5]. Furthermore, the entertaining nature of robots makes them great candidates to engage the creativity of the freshman engineering students and to motivate and persuade them towards an MRE-related degree program[6,7,8]. The importance of offering a robotics course in the engineering programs, its desired features, and the challenges faced in the US academic institutions, along with a roadmap for future are summarized in[9]. Further insights from offering senior-level robotics courses are also provided by[10,11,12].

In recent years, the democratization of access through open source hardware (e.g. Arduino and Raspberry Pi) and software (C++ and Python), and the Maker Movement have significantly reduced the capital costs associated with mobile robots. Arduino microcontrollers have extensively been used as low-level data acquisition and control interfaces[13,14], whereas single-board computers such as Raspberry Pi are utilized to accomplish some of the higher-level robot functionalities including navigation, localization, and communication[15]. Arduino and Raspberry Pi boards are also used to teach the most recent technological advancements in Internet of Things (IoT)[16] and wireless Networks[17]. Robot platforms based on Lego parts have also attracted a great deal of interest among educators, due to their ease of assembly and lower costs[18,19].

Despite the abundance of commercial robotic platforms in the market, the limited educational focus of these platforms, high acquisition costs, and lack of insight that the students would get when utilizing an off-the-shelf robot make it challenging to use these products in various engineering courses. Therefore, in this paper, the development of a special-topics multidisciplinary robotics course, titled 'Autonomous Ground Vehicles', and the corresponding laboratory platform is presented. This cross-listed course was developed and offered to Mechanical Engineering (ME), Mechatronics and Robotics Engineering (MRE), and Computer Science (CS) students. Furthermore, the laboratory platform was designed to not only familiarize the students with the development process of mobile robots and their individual components, but also to facilitate the implementation of advanced and computationally-complex algorithms prevalent in the field of mobile robotics.

Experimental Laboratory Platform

Following a similar trend world-wide, various mobile robotic courses have been designed and offered at the School of Engineering of SIUE in the past decade. These courses, mainly housed in the Computer Science department, addressed system-level problems and aspects of mobile robots using inexpensive and commercially-available platforms. Similar platforms were also utilized in other departments to teach the fundamentals of Mechatronics and Robotics Engineering. With the rapid growth of the robotics industry, classrooms in K-12 institutions now frequently make use of inexpensive robotic platforms as educational tools across varying topics to develop general creative problem-solving skills among the students. Therefore, more and more students have been exposed to basic robotics using these platforms before entering the college, so to provide a deeper understanding of the field of robotics, more advanced platforms need to be utilized in higher education. This need is of higher importance at the School of Engineering of SIUE, due to the increasing enrollment in the new MRE degree program. To this end, with financial support form the Emeriti Faculty Association at SIUE, a new mobile robotic platform was designed and developed.

Based on the aforementioned objectives, the experimental robotic platform was designed such that it can

- be custom-built in-house by undergraduate students interested in research outside the classroom.

- be developed at a low cost, around $500 per platform.
- be controlled remotely.
- provide a multidisciplinary learning experience with the individual components of the robot including motors, motor drivers, encoders, various sensors, and low- and high-level controllers.
- demonstrate the practical implementation of some of the commonly-used and open-source programming languages, namely Python and C++.
- expose the students to a wide range of mobile robotics concepts from low-level basic data acquisition and control all the way to high-level functionalities such as navigation, obstacle avoidance, localization, and mapping.
- familiarize the students with the concept of omnidirectional motion.
- be utilized as laboratory platform in various course across the School of Engineering.

After the initial design and the procurement of the components, six of these robots were developed during an approximately six-months period, with a cost of about $700 per robot. The development required a collaboration among ME, and MRE undergraduate and graduate students and the faculty. The focus on the involvement of ME and MRE undergraduate and graduate student was one of the main reasons for the delay in the development of the robots. Faculty involvement towards the end of the project development was deemed necessary to speed up the completion of the robots. Despite the completion of the hardware part of the robot, the software development required more rigorous programming skills, and therefore, involvement of a Computer Science student. Figure 1 shows a photograph of the finished robotic platform. The robot uses three omnidirectional wheels positioned $120°$ apart for holonomic locomotion.

The robot includes an NVIDIA Jetson TX2 Development Board as the main processor for high-level and computationally-intense algorithms for robot motion, localization, and mapping. The Jetson board is a Linux-based processor for which Python is used as the programming language to interface it to an Arduino Mega microcontroller. The Arduino, connected via serial to the Jetson board and programmed in C++ using Arduino IDE, is used as the low-level data acquisition and control platform. To perceive its environment, a wide array of sensing technologies are included with the robot: an RGB camera onboard the Jetson board; six ultrasonic range finders; four infrared range sensors; a Lidar; and an Inertial Measurement Unit (IMU). Furthermore, three 12 V brushed DC motors with onboard quadrature encoders, capable of providing a resolution of 48 counts per revolution on the motor shaft and 2256 counts per revolution of the output shaft (due to the existence of an 47:1 gearbox), are used. Motors are driven by a 4-channel motor controller capable of encoder mixing. All the electrical components of the robot are powered by an 12 V battery (NiMh and LiPO chemistries) along with a buck DC-DC converter to step down the voltage. Further electronic circuits were included to ensure safety of various components, especially the Jetson board. The robot chassis was designed and assembled in-house, using acrylic plastic sheets and threaded metallic rods. A complete list of the robot components along with their manufacturer is summarized in Table 1. Note that the Lidars were available in-house and were not included in the original cost requirements. Furthermore, although each robot included one battery pack, three of them were equipped with LiPO batteries

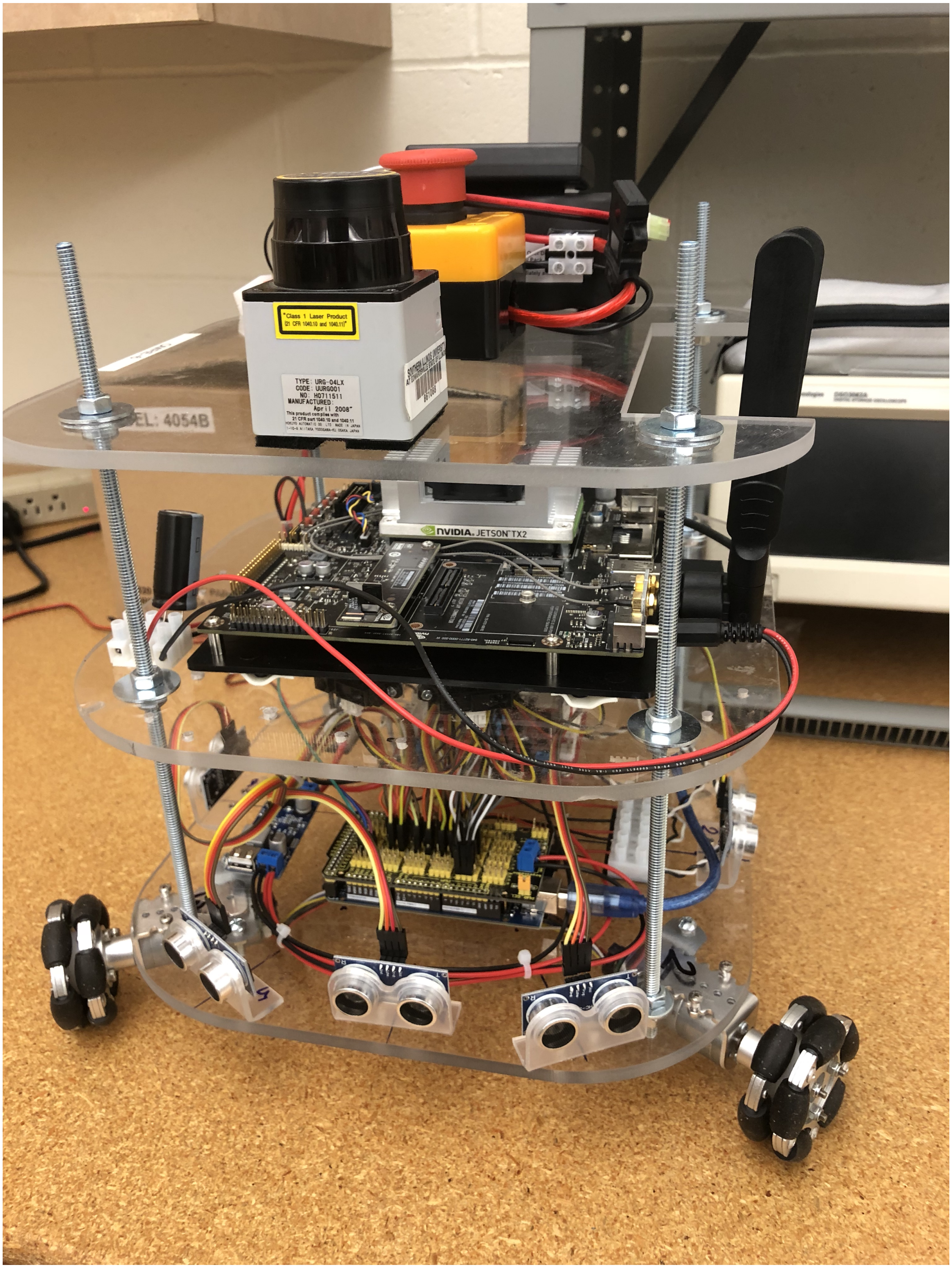

Figure 1: The developed Omnidirectional robot.

and the rest were equipped with NiMh batteries so that the students are exposed to different battery chemistries.

Course Design and Implementation

As mentioned earlier, the experimental robotic platforms were designed to accompany a multidisciplinary mobile robotics course to be offered to ME, MRE, and CS students. This course was intended to cover various aspects of mobile robotics such as individual component characterization, system integration and control, programming, localization, navigation, etc. as applicable to today's robotics technologies. Furthermore, the course was designed to be flexible despite the ratio of the students with diverse backgrounds. In other words, while the student teams might not be homogeneous in terms of students' expertise, they must still work together to define interfaces between their areas of expertise and test the robotic system as a whole. Table 2 below is a tentative outline for this course which was planned to be offered collaboratively between ME and CS faculty.

The motivation behind the course design in Table 2 was based on previous similar course offerings in the ME and CS departments. More specifically, the first column in Table 2, which was supposed to be taught by the ME faculty, was inspired by a more traditional robotics course in kinematics, dynamics, and control of robot manipulators. The planning and design stage of the course development, including the experimental robotic platforms, took around 8 months and the course was offered in Fall 2018. Due to various conflicts, the course was offered solely by the first author on this paper, an ME faculty, and therefore, the course focus had to shift towards the mechatronics aspects of mobile robots. More specifically, the following topics were covered in the lectures:

- Week 1: Introduction
- Week 2: Linear Algebra Overview
- Week 3: Linear Algebra Overview
- Week 4: Rigid Motions
- Week 5: Rigid Motions
- Week 6: Locomotion - Experimental Design Considerations
- Week 7: Mobile Robot Kinematics
- Week 8: Mobile Robot Kinematics
- Week 9: Mobile Robot Kinematics - Lab 1
- Week 10: Mobile Robot Kinematics - Lab 2
- Week 11: Perception and Odometry - Lab 3
- Week 12: Perception and Odometry - Lab 4
- Week 13: Control Design

Table 1: Individual components of the robot.

Component	**Model No.**	**Quantity**
Main Processor	NVIDIA Jetson TX2 Developer Kit	1
Low-level Microcontroller	Arduino Mega 2560	1
Lidar	Hokuyo URG-04LX Lidar	1
Ultrasonic Sensor	HC-SRO4 Ultrasonic Range Finder	6
Infrared Sensor	Sharp GP2Y0A21YK0F Infrared Sensor	4
Motor Controller	Dagu HiTech Electronic 4-channel Motor Driver Board	1
Motor	Pololu 47:1 Metal Gearmotor 25Dx52L mm HP 12 V with 48 CPR Encoder	3
Wheels	60 mm Aluminim Omni-directional Wheels	3
Inertial Measurement Unit	Pololu minIMU-9 v5	1
DC-DC converter	DROK Buck Regulator DC 9V-36V Step Down to DC 5V-5.3V Voltage Power Inverter Module	1
E-Stop	Baomain Red Sign Emergency Stop Push Button	1
Battery	FLOUREON 11.1V 3S Lipo Battery 5500mAh	1
Battery	NiMH Battery Pack: 12V 5000mAh	1

Table 2: Initial plan for the course syllabus

Week No.	Content	
Week 1	Introduction	Introduction
Week 2	Python Programming	Robot Operating System
Week 3	Sensors	Sensors
Week 4	Electric Motors	Visual Perception
Week 5	Forward Kinematics	Visual Conception
Week 6	Forward Kinematics	Sensor Fusion
Week 7	Inverse Kinematics	Sensor Fusion
Week 8	Inverse Kinematics	Localization
Week 9	Dynamic Modeling	Localization
Week 10	Dynamic Modeling	Navigation
Week 11	Control Design	Navigation
Week 12	Control Design	Mapping
Week 13	Control Design	Mapping
Week 14	Advanced Topics (Project)	
Week 15	Advanced Topics (Project)	

- Week 14: Control Design - Lab 5
- Week 15: Course Project

The labs mentioned above provided a hands-on learning experience for the students with the experimental robotic platforms. More specifically, in Lab 1, students examined various components of the robot to get familiar with their individual functionalities. They, specially, focused on the DC motors and did several experiments to learn the fundamentals of motor PWM control and speed estimation using encoder measurements. Furthermore, in this lab, the students had to study the underlying C++ code behind the low-level control of the robot, achieved using the Arduino microcontroller. Lab 2 focused on the sensing capabilities of the robot and gave the students an opportunity to learn the operation fundamentals and coding of the ultrasonic and infrared sensors. In Lab 3, the students were tasked to implement the problem of inverse velocity kinematics in Python to be able to navigate the robot in its local coordinate frame. Although Python is increasingly being used in academic research and industrial applications, it is not typically covered in undergraduate engineering curricula. This was the case with the majority of the students in this class; however, to be able to implement the high-level robot algorithms, the students had to learn about Python programming on their own as take-home assignments. The students studied an open-access book[20], which provides a great introduction to Python programming. The students' Python knowledge was then tested in two quizzes in the first half of the semester. In Lab 4, the students had to code an odometry algorithm to determine the global coordinates of the robot. Finally, Lab 5 focused on bringing the previous lab teachings together, in order for the students to design a closed-loop Go-to-Goal controller.

As discussed above, the labs were conducted in the second half of the semester. In the first half, however, the students were assigned homework problems based on the theoretical contents of the lectures. The homework assignments also gave an opportunity for the students to learn about the state-of-the-art of the robotics field. The course included an open-ended project in which the students had to get familiar with more advanced sensing capabilities of the robot, namely camera and Lidar, and to use them for robot navigation and obstacle avoidance. In addition to these activities, a midterm and a final exam were also included as a part of the course assessment.

Challenges, Outcomes, and Future Directions

As mentioned earlier, the Autonomous Ground Vehicles course was offered in Fall 2018 as a cross-listed, special topics, elective course among ME, MRE, and CS majors by the first author. The majority of the students in the class were CS students who were not previously exposed to fundamental engineering courses such as Differential Equations and Dynamics. ME students, on the other hand, while being confident in basic engineering courses, did not have the same interdisciplinary knowledge as the MRE students. Finally, both ME and MRE students lacked algorithms, data structures, object-oriented programming, and software engineering backgrounds that CS students possessed. This significant disparity among the students' backgrounds made it challenging to cover more advanced topics in the field of mobile robots and the majority of the course focused on providing the required foundation, and therefore, the course deviated from its originally-planned path.

Technical difficulties in regards to the experimental robots were some of the other challenges faced during the offering of this course. Wireless connectivity issues and serial communication limitations and delays between the lower-level Arduino and higher-level Jetson Development board could sometimes cause uncertainty and confusion among the students. Although some of these technical difficulties arose from the custom built of the robots, the omni-directional nature of the robot and open-source nature of the employed hardware and software platforms also created challenges.

Omnidirectional robots have experienced a great deal of interest in the robotics community and industry due to their holonomic motion, making them the perfect solution in robotic applications with space limitations which could benefit from lower degrees of freedom robot manipulators, provided that they are equipped with omnidirectional robots as their base. Furthermore, as demonstration projects, omnidirectional robots can be attractive to both academic and public audience due to their unique motion capabilities. The omnidirectional motion is typically achieved using omnidirectional wheels such as Mechanum or Swedish wheels, which are equipped with additional rollers across the wheel circumference. Passive rotation of the rollers can be a significant source of error when estimating the robot position based on the encoder measurements and odometry. The control design for omnidirectional robots has also shown to be difficult due to the need for accurate coordination among the individual motors and susceptibility to external disturbances. More research still needs to be conducted on these robots to improve their performance and increase their reliability.

Open-source hardware and software platforms are low-cost alternatives to commercial products commonly used in the field of robotics and are also increasingly being used in industry. Developing open-source platforms for control education will not only be a more feasible option for a wide range of educational institutions, but can also prepare the students with recent technological trends in industry. Utilizing open-source platforms can also expose the students to the development details of a real-world system and therefore, can provide a deeper learning experience. However, the entire development process using open-source platforms and its troubleshooting can be very lengthy and time consuming. Students with good hands-on skills are typically needed in order to develop such platforms; furthermore, the educators who wish to utilize such systems typically lack the expertise in all aspects of their implementation. Debugging open-source systems can also be challenging as majority of the troubleshooting is done through forum discussions which appear to be very noisy and unfocused. There is also a disconnect between the forum participants, typically computer scientists and hobbyists, and control educators. Finally, there is a lack of available resources for utilizing open-source platforms for the implementation of real-time and advanced control methodologies. More academic focus in the mechatronics and robotic communities on the use of open-source platforms in terms of providing formal education to instructors and students about the fundamentals of such platforms and providing inputs in the development of these systems can ease their integration into the mechatronics and robotics curricula.

Despite these challenges, the first time offering of this course was fairly successful, as it provided a valuable interdisciplinary experience for the students. The majority of the students (five out of six students who participated in Student Evaluation of Teaching) agreed that: The course was interesting and motivated them to learn; The activities/assignments were useful in helping them learn; Overall, the instruction in this course enhanced their learning of the course content. The soft skills obtained through the student' involvement in multidisciplinary groups with diverse and randomly-assigned members could be extremely beneficial for students future careers in which, they would need to work in such teams. Finally, below are some of the students comments in regards to this course:

"The instructor is teaching a very intensive and difficult topic and did a good job of getting the information across in the time frame provided. He expects a lot out of his students, and for this reason, I feel like I have benefited greatly by trying my best to keep up with his expectations. I feel like I have gotten more out of his class than I have from any other professor."

"The robots may still have some bugs to work out. I hope the prior experience from the labs and project this semester will be helpful for this class in the future."

"Considering that this is the first time the class is offered, I think it went very well. Perhaps there is some more potential in the labs and with the project for future classes, but I think it is off to a great start."

"More hands on works with the robots. More information about how to implement the final project would have been useful."

The lessons learned from this course offering will be utilized in the future to improve its overall quality. More specifically, focus on topics such as rigid motions and kinematics, especially wheel kinematics, could be reduced without impacting the course outcomes. Improvements on the software side of the robots are required to reduce the uncertainties faced during the lab sessions. Utilizing software platforms such as Robot Operating System (ROS) can also simplify some of the algorithm implementation issues; however, care should be given to ensure that the students still get an exposure to lower-level concepts. Furthermore, ROS is known to have a steep learning curve, so designing educational modules to simplify learning about ROS can also be helpful. Finally, it would be very beneficial if a multidisciplinary course like this is offered by multiple faculty with diverse but complementing backgrounds.

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References

[1] I. Nourbakhsh, K. Crowley, A. Bhave, E. Hamner, T. Hsiu, A. S. Perez-Bergquist, S. Richards, and K. Wilkinson, "The robotic autonomy mobile robotics course: Robot design, curriculum design and educational assessment," *Autonomous Robots*, vol. 18, no. 1, pp. 103–127, 2005.

[2] A. Soto, P. Espinace, and R. Mitnik, "A mobile robotics course for undergraduate students in computer science," in *2006 IEEE 3rd Latin American Robotics Symposium*, Oct 2006, pp. 187–192.

[3] A. Gilmore, "Design elements of a mobile robotics course based on student feedback," in *2015 ASEE Annual Conference & Exposition*, no. 10.18260/p.23798. Seattle, Washington: ASEE Conferences, June 2015, https://peer.asee.org/23798.

[4] A. Minaie and R. Sanati-Mehrizy, "An international study of robotics courses in the computer science/engineering curriculum," in *2006 Annual Conference & Exposition*. Chicago, Illinois: ASEE Conferences, June 2006, https://peer.asee.org/942.

[5] R. Alba-Flores and F. Rios-Gutierrez, "Control systems design course with a focus for applications in mobile robotics," in *2013 ASEE Annual Conference & Exposition*. Atlanta, Georgia: ASEE Conferences, June 2013, https://peer.asee.org/19352.

[6] R. L. Avanzato, "Collaborative mobile robot design in an introductory programming course for engineers," in *1998 Annual Conference*. Seattle, Washington: ASEE Conferences, June 1998, https://peer.asee.org/6966.

[7] D. Bolick, R. Drushel, and J. Gallagher, "Increasing accessibility to a first year engineering course in mobile autonomous robotics," in *2005 Annual Conference*. Portland, Oregon: ASEE Conferences, June 2005, https://peer.asee.org/14879.

[8] T. Sharpe, R. Maher, J. Peterson, J. Becker, and B. Towle, "Development and implementation of a robot based freshman engineering course," in *2005 Annual Conference*. Portland, Oregon: ASEE Conferences, June 2005, https://peer.asee.org/15301.

[9] P. Ren, J. Terpenny, D. Hong, and R. Goff, “Bridging theory and practice in a senior level robotics course for mechanical and electrical engineers,” in *2009 Annual Conference & Exposition*. Austin, Texas: ASEE Conferences, June 2009, https://peer.asee.org/4915.

[10] C. N. Thai, “Work in progress: Development of a senior level robotics course for engineering students,” in *2011 ASEE Annual Conference & Exposition*. Vancouver, BC: ASEE Conferences, June 2011, https://peer.asee.org/18408.

[11] W. W. Walter and W. E. Spath, “Experience teaching a multidisciplinary project-based robotics course building autonomous mobile robots,” in *2011 ASEE Annual Conference & Exposition*. Vancouver, BC: ASEE Conferences, June 2011, https://peer.asee.org/17955.

[12] P. Wild, K. Firth, , and B. Surgenor, “Lessons learned from a mobile robot based mechatronics course,” in *2005 Annual Conference*. Portland, Oregon: ASEE Conferences, June 2005, https://peer.asee.org/14171.

[13] G. W. Recktenwald and D. E. Hall, “Using Arduino as a platform for programming, design and measurement in a freshman engineering course,” in *2011 ASEE Annual Conference & Exposition*. Vancouver, BC: ASEE Conferences, June 2011, https://peer.asee.org/18720.

[14] W. W. Walter and T. G. Southerton, “Teaching robotics by building autonomous mobile robots using the Arduino,” in *2014 ASEE Annual Conference & Exposition*. Indianapolis, Indiana: ASEE Conferences, June 2014, https://peer.asee.org/23103.

[15] S. He and S.-J. Hsieh, “Multi-sensors for robot teaming using Raspberry Pi and VEX robotics construction kit,” in *2018 ASEE Annual Conference & Exposition*. Salt Lake City, Utah: ASEE Conferences, June 2018, https://peer.asee.org/30829.

[16] G. J. Mullett, “Teaching the internet of things (IoT) using universally available Raspberry Pi and Arduino platforms,” in *2016 ASEE Annual Conference & Exposition*, no. 10.18260/p.26053. New Orleans, Louisiana: ASEE Conferences, June 2016, https://peer.asee.org/26053.

[17] C. BouSaba, T. Kazar, and W. C. Pizio, “Wireless network security using Raspberry Pi,” in *2016 ASEE Annual Conference & Exposition*, no. 10.18260/p.27206. New Orleans, Louisiana: ASEE Conferences, June 2016, https://peer.asee.org/27206.

[18] E. Danahy, E. Wang, J. Brockman, A. Carberry, B. Shapiro, and C. B. Rogers, “Lego-based robotics in higher education: 15 years of student creativity,” *International Journal of Advanced Robotic Systems*, vol. 11, no. 2, p. 27, 2014.

[19] T. Inanc and H. Dinh, “A low-cost autonomous mobile robotics experiment: Control, vision, sonar, and handy board,” *Computer Applications in Engineering Education*, vol. 20, no. 2, pp. 203–213, 2012. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/cae.20386

[20] C. R. Severance, *Python for Everybody: Exploring Data in Python 3*. CreateSpace Independent Publishing Platform, 2016.