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Development of a Research-Based Course on Machine Learning and Robotics for Undergraduate Engineering Students at Hampton University

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Abstract

Through the synergy of NASA University Leadership Initiative (ULI) Project "Safe Aviation Autonomy with Learning-enabled Components in the Loop: from Formal Assurances to Trusted Recovery Methods" and NSF Excellent in Research (EIR) project "Integrated Sensor-Robot Networks for Real-time Environmental Monitoring and Marine Ecosystem Restoration in the Hampton River", the authors have successfully developed a research-based course on machine learning and robotics for undergraduate engineering students at Hampton University. This paper presents the goals, challenges, design process, engaging strategies, assessment /outcomes, and lessons learned for the new course. Besides, this paper also presents the integration of *IBM AI course* and *NVIDIA machine learning modules*, along with the *Couse Extension* -two weeks summer undergraduate research experiences on AI/ML and robotics in the Autonomous Systems Laboratory directed by Dr. Marco Pavone at Stanford University. The success in the development of this course is due to the collaboration with Stanford University, which opening Hampton Undergraduate students' eyes to the larger issues in the area of study; due to the support from industry such as IBM and NVDIA, which provide Hampton University free training license for the online course and resources.

Keywords

Research-based learning; Machine Learning and Robotics

I. Introduction

"Safe Aviation Autonomy with Learning-enabled Components in the Loop: from Formal Assurances to Trusted Recovery Methods" is a NASA funded University Leadership Initiative (ULI) project which is led by Stanford University. The objectives of the project includes:

- Assurances for Autonomous Systems with LECs: Develop and demonstrate tools and methods to provide assurances for those components within the autonomy stack that rely on machine learning techniques and other similar data-driven techniques.
- Run-Time Fault Detection, Isolation, and Recovery for LECs: Develop and demonstrate tools and methods to detect faulty operation for LEC-based autonomous aviation systems, and devise new fault isolation/recovery methods for these systems.

- Airspace Management with LEC-based Autonomous Systems: Develop and demonstrate tools and methods to extend the vehicle-centric assurances and FDIR capabilities devised

The first author, an associate professor in Dept. of Electrical and Computer Engineering at Hampton University, has served for this project as a co-PI supervising a team of ungraduated engineering students working on machine learning-based navigation and control for autonomous vehicles. Since there was no course on ML/AI and robotics course offered at Hampton university, through the NASA ULI program, four senior undergraduate students in the team were invited to audit course AA274a, an undergraduate level course on robot autonomy offered remotely from Stanford University to Hampton University students. The course description is as the following:

AA 274A: Principles of Robot Autonomy I (AA 174A, CS 237A, EE 160A, EE 260A)
Basic principles for endowing mobile autonomous robots with perception, planning, and decision-making capabilities. Algorithmic approaches for robot perception, localization, and simultaneous localization and mapping; control of non-linear systems, learning-based control, and robot motion planning; introduction to methodologies for reasoning under uncertainty, e.g., (partially observable) Markov decision processes. Extensive use of the Robot Operating System (ROS) for demonstrations and hands-on activities.

Prerequisites: CS 106A or equivalent, CME 100 or equivalent (for linear algebra), and CME 106 or equivalent (for probability theory).

The HU undergraduate students were very excited and shows strong interest during the learning process, even with their knowledge background, the course content is too hard for them. In July 2021, the first author was awarded the NSF EIR grant *"Integrated Sensor-Robot Networks for Real-time Environmental Monitoring and Marine Ecosystem Restoration in the Hampton River"*, for which the team of the undergraduate students were expected to conduct research on Machine Learning-based path planning, navigation and control for autonomous Underwater vehicle and unscrewed surface vehicle for water quality data collection. To provide the team with a comprehensive understanding of the fundamentals of machine learning and robotics together with the specific machine learning and robotics applications in autonomous systems, the first author has explored the Machine Learning Course and Robotics Course currently available in different Universities [1-7]. Especially, during her 8 weeks summer visiting at Stanford University, she also had a chance to explore resources to integrate into the course. Based upon all these works, she successfully adapted/developed course ***EGR 391- Intermediate Research Topic Course*** to a ***Research-based Course on Machine Learning and Robotics*** by combining teaching, research, and engagement. This course is especially designed for the team of junior undergraduate students who are participating in the NSF EIR and NASA ULI projects.

The challenges in course development are as the following:

1. How to make the course comprehensive enough to cover the fundamentals of machine learning and robotics, while also being understandable to students with varying levels of experience and knowledge.

2. How to find the right balance between teaching the fundamentals of machine learning and introducing more advanced topics? And how to make the course up to date with the latest advancements in the field, while also providing a solid foundation in the basics.
3. How to incorporate hands-on activities and projects to help students gain a better understanding of the fundamental concepts.

To dealing with the above problems, our strategies is as the following:

Firstly, by integrating IBM AI/ML online learning Course and NVIDIA self-study modules on robotics, students with different level can learn the fundamentals of machine learning and robotics at their own pace under the guidance and monitoring of the instructor-the author. Secondly, by involving the undergraduate students in the monthly research projects seminars offered at the top universities, the team can access to the advanced topics and the latest advancement in the field. Thirdly, thanks to the NASA ULI outreach program, we have the opportunity to augment the course with a two week summer REU at the leading university, where the students finish the implementation of ML-based visual navigation applications with TurtleBots [8].

To generalize, with the one semester course learning/training and the consecutive two weeks case study in the summer REU activities, the undergraduate students gain a much better understanding of the fundamental concepts and are well prepared to accomplish projects on data-driving modeling and learning based control for AUVs and UAVs for their senior capstone design. Feedback from the students together with the course survey shows that the students have increased their programming skills through the learning process and so far, all the senior students participating in the program has been offered graduate school admission with full fund support.

II. Course Description and Arrangement

This 3-credit hour course is an undergraduate course especially for the junior students who are participating in the NASA ULI and NSF EIR projects. The student research team are expected to learn the fundamentals of machine learning /robotics and how to conduct undergraduate research related to machine learning-based navigation and control of mobile robotics. Students who registered in the course are also expected to accomplish ML-based visual navigation applications.

The course content and arrangement are as the following:

1. Introduction to the NSF EIR project and NASA ULI project. (1 credit hour)
   Students are provided with a list of related group design and programming projects on ML-based path planning, navigation, and control of autonomous vehicles.

2. Introduction to Machine Learning and Robotics (4 credits)
   This part covers the fundamentals of machine learning and robotics, including the history and development of the field, the different types of machine learning and robotics, and the current applications of the technology.
   For this part, students use IBM AI/ML online course as a self-study tool to have better understanding of the fundamental and concepts taught in the lectures.

3. Machine Learning Algorithms (15 credits)
   This part includes exploring the different types of machines learning algorithms, including supervised learning, unsupervised learning, reinforcement learning, and deep learning, both theoretically and practically at the simulation level. We use the reference book "AI with python" to guide the students through the learning python programing training process.

4. Robotics Fundamentals (3 credits)
   This part includes fundamentals of robotics, covering the different types of robots, their components, and their applications.

5. IV. Machine Learning and Robotics in Practice (9 credits)
   This part includes the introduction of data collection and preprocessing; model selection and training; and model evaluation and optimization. Especially, how to program the mobile robots for various tasks will be detailed, with the NVIDIA Edge AI self-study modules used as the assistant tool.

6. Machine Learning and Robotics Applications (12 credits)
   This part will focus on the applications in autonomous vehicles. Instead of programming the physical robots, we use robot simulator to create embedded applications for a robot without depending physically on the actual machine.

7. Presentation of the final project (1 credits)
   It is noted that the final project only includes the design and simulation analysis of the developed algorithms. The physical systems design and programming is expected to be implemented during the two-week summer REU training at the NASA ULI leading universities.

8. Research Seminars and project progress
   The team attend the research seminars at the **First Friday** each month. The seminar is organized by the NASA ULI leading university and Graduate students and faculties at different universities gives talks about their recent work. After the seminar, the team discuss about their projects and generalize their research progress with a monthly report. This part does not use the credit hours of the course since it is assigned as the undergraduate student research task for the NSF EIR and NASA ULI projects.

III. Teaching Materials

Besides the handout and lecture slides posted at the Black Board, the teaching materials also includes the IBM-AI online course; NVIDIA robot edge AI learning modules; together with a list of reference books.

- IBM-AI Online Course: Based upon a HBCU-IBM connection, the author can apply free token for the students to get access to the online learning resources.
- NVIDIA Robot Edge AI self-study modules: an open source provided by the faculties who participate in the AI and robotics course development program

- Reference Books:
  Deep Learning with Python by Francois Chollet

  Robotics: Modelling, Planning and Control by Bruno Siciliano
  Artificial Intelligence: A Modern Approach by Stuart Russell and Peter Norvig
  Reinforcement Learning: An Introduction by Richard S. Sutton and Andrew G. Barto

IV. Computing and Simulation Platform

We have used Keras and Gazebo as computing and simulation platform. Keras is an open-source software library that provides a Python interface for artificial neural networks. Gazebo is an open-source software platform for which anyone can develop a plug-in with model components

V. Learning Outcomes and Assessment

The learning outcomes of the course EGR 391 are as the following:

1. Understand the meaning, purpose, scope, stages, applications, and effects of AI/ML
2. Understand the fundamental concepts of Machine Learning and Deep Learning
3. Distinguish between supervised, semi-supervised, and unsupervised learning
4. Familiar with Deep Reinforcement Learning
5. Understand the basic concepts related to robotics, edge AI, vision deep neural network.
6. Learn research, scholarly and creative methodologies and be better informed about salient and current issues
7. Learn to function within a multidisciplinary team of researchers and how research, scholarly and creative projects are managed.
8. Develop a technical report on the application of ML algorithms with simulation results

The assessment of the course EGR 391 includes the assignments and quizzes on the fundamental concepts; (30%); coding and simulation practice (20%); research documentation(10%); final project report (25%) and presentation (15%). It is noted that students were asked to do the documentation throughout the learning process, including lectures, self-study modules; coding and debugging; project meetings, seminars, etc. This work will help the students have better understanding of the concepts and ML and robotics and improve their programing skills. The final project has been assessed based upon the modeling, design and simulation of the control system and research writing, while the application to physical system to execute the main function is not required, since the students are expected to implement ML-based visual navigation applications with TurtleBots [8] during the two week summer REU at Stanford University, as shown in the following photos.

Figure 1: Introduction to TurtleBots

Figure 2: Navigation Test

VI. Feedback from the students and lesson learned

The feedback of the developed course from the students are very positive.

Feedback #1: "During that course, I attended lectures on basic robotics and artificial intelligence subtopics including but not limited to neural networks, reinforcement learning, and machine learning application. The lectures supplemented the IBM AI Course, allowing me to gain an IBM badge for my LinkedIn account. The final project allowed my classmates and me to showcase what we learned through a simple obstacle avoidance simulation. The biggest takeaway from the course was realizing its potential connection to my own interests. Nothing is without its critiques, and I believe a future goal for the class is to offer smaller coding activities throughout the course that build upon each other. Nevertheless, the overall experience was an enriching journey that allowed me to understand machine learning and its applications in robotics."

Feedback #2: "This Course helped me to understand the fundamental concepts of Artificial Intelligence (AI), Machine Learning (ML) and Robotics. During the duration of the class, we completed the IBM AI Course, an intensive course that uses many resources, like videos or/and slides, to teach the student the different complex subjects surrounding AI. Summer REU at Stanford University was a program hosted to introduce 9 undergraduate students from Hampton University and the University of New Mexico to robotics and machine learning. During this program, we participated in research guided by graduate students and career-building activities guided by an advisement counselor. We were given the opportunity to tour multiple lab facilities in the area and network. Personally, the program gave me a whole new perspective on AI/ML and robotics."

Feedback #3: "By taking the course and the continuing REU program at Stanford University, I am inspired to pursue a Ph. D. degree in Electrical and Computer Engineering in the future."

From the student feedback, the first author is considering separate the course to two 3 credits sessions, thus the students could have more training on coding.

VII. Conclusion and Future Work

Combining research, teaching and engagement, the author has developed a research-based course on machine learning and robotics for undergraduate engineering students. Feedback from the students and course survey shows that the expected goals have been achieved. However, there still exist some improvement that the author plan to accomplish in the future. The main concern is how to develop this course to an **elective course** open to engineering students at different levels in Hampton University. Also, how to make the course "translatable" to other universities, especially to other HBCU/MRI is also a challenge, since the course developed in this paper is strongly supported by NASA ULI and NSF EIR funds. Currently, the first author is also seeking funding opportunity that would support this effort.

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REFERENCE

1. Sami Khorbotly, "Machine Learning: An undergraduate Engineering Course", 2022 ASEE
2. Introduction to Deep Learning: A First Course in Machine Learning
3. Niklas Lavesson. Learning machine learning: a case study. IEEE Transactions on Education, 53(4):672–676, 2010.
4. Maja J. Mataric "Robotics Education for All Ages", Proceedings, AAAI Spring Symposium on Accessible, Hands-on AI and Robotics Education, Palo Alto, CA, Mar 22-24, 2004.
5. Sergeyev, A., Alaraje, N., "Partnership with industry to offer a professional certificate in robotics automation", ASEE Annual Conference & Exposition (ASEE 2010), AC 2010-968
6. Sergeyev, A., Alaraje, N., "Promoting robotics education: curriculum and state-of-the-art robotics laboratory development", The Technology Interface Journal, Vol. 10, #3, 2010.
7. A. Ng, Online courses at https://deeplearning.ai
8. https://learn.turtlebot.com/2015/02/03/1/