Development of a Bio-inspired Robotics Course

Dr. Hamid Vejdani, Lawrence Technological University

Hamid Vejdani, PhD is an Assistant Professor in the A. Leon Linton Department of Mechanical Engineering at Lawrence Technological University. His research interests include dynamical modeling, control and robotics.

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Abstract

In this paper, the development of a new senior level course and its outcome results are presented. This course was offered during spring 2018 at Lawrence Technological University (LTU) for senior level undergraduate and graduate students. The course entitled " Bio-inspired robotics" and was offered as a tech-elective course for our undergraduate students in mechanical engineering department and robotics engineering. The course focused on legged locomotion in nature and its development to robotics engineering. The theme of the course was project-based and we had two groups of six students. For each team, the project was to design, build and control a bio-inspired legged robot (a legged robot that is inspired from nature). One group chose hexapod cockroach inspired robot (also known as Rhex) and another group chose Kangaroo-inspired robot. The class activities and the homework assignments were centered towards the recent papers and researchers related to the design and control of these robots through the whole semester. MATLAB simulation and development of control algorithms were introduced in the class through researching the related papers. At the end of the semester, we had two full legged robots with each group preparing a paper to explain the process for the design. Through the success of the Kangaroo-inspired robot, the robot was presented in a related conference (Dynamic Walking 2018) and motivated the students to conduct more research in this field.

Introduction

At Lawrence Technological University, like many STEM education institutes, the senior year undergraduate students are supposed to take some technical elective courses (4 courses at LTU) based on their interests and the availability of the courses that are offered during their senior year. These courses are offered such that graduate students can also take them and therefore provide a broad mixture of undergrad and graduate students from different concentrations within the department and sometimes among various majors in college of engineering. One of the great advantage of these courses is the potential diversity among the students which can offer much wider level of insights and discussions in the class which if guided appropriately can lead to collaborative learning environment and have the potential to incorporate the concepts of industry 4.0 [1] in curriculum. These technical elective courses also provide opportunity for students during the senior year to have a better understanding for their potential future graduate study. These opportunities were taken into account in the design process of the course and defining the learning objectives.

The focus of this paper is to report the design and the learning outcomes from a newly developed course called "Bio-inspired robotics" as one of the technical electives courses presented at LTU. The motivation for the development of this course was to present to students few advantages of referring to nature for designing robotics mechanisms. Since the mechanisms in animals for locomotion have been optimized over years, getting inspiration from nature provides valuable insights toward optimal engineering designs. Therefore, due to the nature of the subject, the emphasis on this course was on classroom discussions and students participation in solving the problems. The course was designed and centered toward the final project and intended to embed project-based learning (PBL) to active learning. To accomplish the final project, and due to the diversity of the students' knowledge in the class, the students were supposed to assist one another to finish the final project and therefore they were engaged in collaborative learning [2].

The course assessment was based on 40% homework, 30% final report and 30% robot hardware and demonstration. Part of the project grade (within the final report section) was based on peer evaluation that the students filled twice during the semester once toward the 10th week and the second one at the end of the semester before the due date of turning in the project.

The focus of the class was on discussing the state of the art papers on the related topics that were given to the students as homework assignments to summarize and sometimes to reproduce the results in simulation using MATLAB. These papers were given to the students the week before the discussion panel and the students were responsible to lead the discussions in the class. The papers were chosen such that the fundamentals of the key concepts needed for the projects were introduced and discussed in the class to achieve effective learning as pointed out by Litzinger et al. [3] that the effective learning are those that support the development of deep understanding around the key concepts and general principles. As part of the class activities students were engaged into in-class projects that were aligned with the homework assignments and the final project. The purpose of these homework assignments and the in-class activities were due to the students need to simulate the robot in MATLAB for their final projects.

To work on the final project, the students were asked to work predominantly outside of the class and they were supposed to present their work at the end of the semester in their group. Due to the number of the students in the class (12 students total), we had two groups each with 6 students. The combination in each group was based on the students interest but also such that different majors were put together to increase the diversity within each group as follows: Group A: 2 robotics students, 2 mechanical engineering students and 2 masters students in mechatronic systems and control. Group B: 2 robotics students, 1 Bio-medical engineering student, 1 master student in automotive engineering and 2 masters students in mechatronic systems and control.

The students who took the course had taken various courses in the past that were not necessarily needed for their final project and more importantly there were skills that were new for some students. For example, robotics students had completed all their control and programming courses and were familiar with the control strategies and robotics implementation needed for the project. For this reason their existence in each group was the key to be sure all the teams have enough knowledge to finish their projects. The bio-medical engineering and automotive engineering students were not familiar with MATLAB programming, control strategies and implementation and they had very limited knowledge of hardware implementation. However, their insights during

the design and group discussions were valuable to the group as was acknowledged by their peers in the peer evaluation. The mechatronic systems engineering students had good knowledge about control but their knowledge on hardware implementation varied among them with some very familiar with the subject and some with limited knowledge on the matter. Their distribution along with robotics students could help the team to accomplish the MATLAB simulations more efficiently.

Learning objectives of the class

The following learning objectives were targeted during the course development. After finishing the course the students should be able to:

- Define the meaning of bio-inspired engineering and bio-inspired robotics and can explain the difference between bio-inspiration and bio-mimicry
- Explain the procedure and the process to analyze a complicated biological systems in the context of dynamical systems and engineering
- Explain the difference between the concepts of template and anchor and the use of each one
- Apply the current reduced order models for animal locomotion to explain the measured data from their own walking and running
- Analyze and interpret the results from their robot experiments and explain the obtained results
- Evaluate a state of the art paper related to the project they accomplish during the semester

Teaching approach

Students were supposed to work on the project together outside of the class time. To make sure they had enough quality time that all can get together outside of the class, they had to declare in the beginning of the semester that they had at least 4 hours in each week that all of them can get together and work on the project. The class sessions were dedicated to the concepts, literature review from the well-known papers in the field, explaining and working on key simulations and mainly discussions.

To excite the students in the beginning of the semester and to give them good understanding about the benefits we can get by getting inspired from nature, the first week was spent on the state of the robots in natural environment and the superior performance of animals in these unstructured environments. The results showed that watching few documentary movies available on-line motivates the students and inspired them with lots of ideas for engineering mechanisms through the semester.

Student support strategy

Each team or any individual on the teams could set meeting time with the instructor as they needed. In addition, there were monthly informal progress report from each team during the class time. In that report, the whole team stood in front of the class and presented their progress as well as answering the questions. Other students were asked to treat the presentation like a conference presentation with challenging questions and discuss unpredicted scenarios that might happen and share their opinion and possible suggestions for the team. During the last week of the semester in which the students were the most involved in wrapping up the project, there were multiple informal updates asked by the instructor as they were working on their robot.

Desired outcomes

The desired outcomes for this class were:

- The literature review in the final report is comprehensive with respect to their specific project
- The simulations in MATLAB work and the results are plausible for the targeted benchmarks
- The team can get desired responses from simulation in MATLAB
- The team can get the robot accomplish few strides of running or hopping
- The inherent differences between the simulation results and the experimental results can be explained in the result section of the final report
- Regarding the future work in the final report, the team can point out few feasible steps that can improve the results

Assessment

The assessment of the course was based on the learning objectives with considering the desired outcomes. The homework assignments and the discussions in the class once completed by the students fulfill the first three learning objectives described above. Therefore, the majority of the homework assignments were only needed the submissions from the students. The fourth learning objective is due to the simulations that the students were supposed to accomplish in their project and also the concepts of those simulations were given in the in-class activities. The assessment of the fourth learning objective was accomplished by the simulation results in the final project.

Results

The robots illustrated in figures 1 and 2 were designed and built by the groups as part of their final projects. For the robot presented in figure 1, the students created the whole CAD model first and

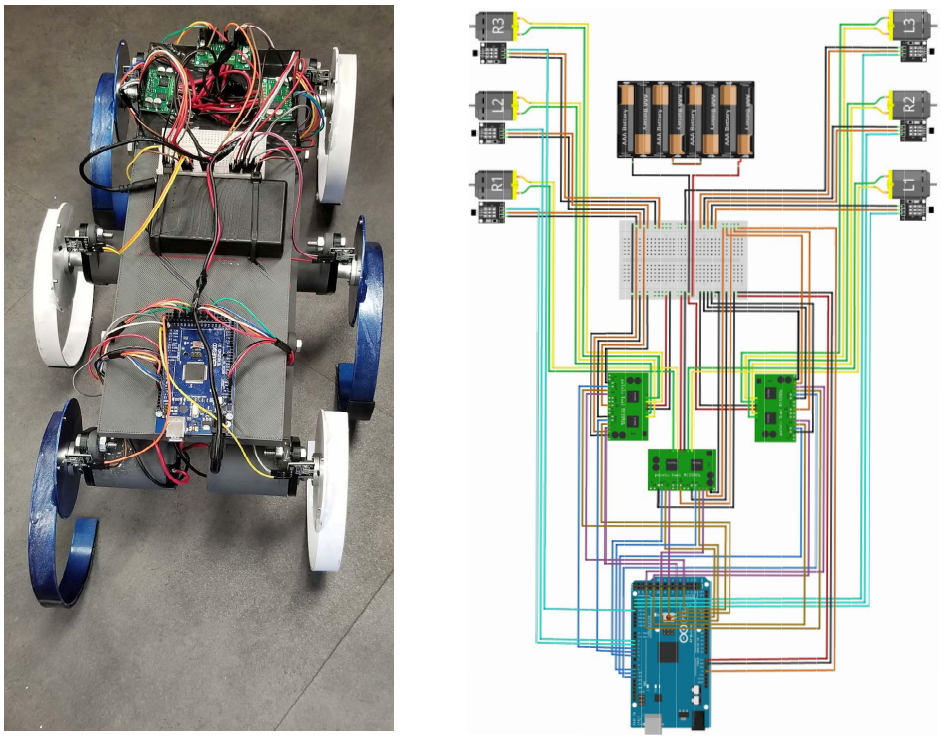

Figure 1: Final mechanical design and electronic schematics for Cockroach inspired running robot also known as Rhex in robotics community. There are six DC electric motors that each drive each leg. The legs are formed as a circular elastic material to provide elasticity to replicated the role of the tendons in the leg. The body of the robot was 3D printed on campus.

the schematics of the electronics. The automotive masters student in this group provided good insights and discussions during the design process. For the Kangaroo project illustrated in figure 2, the bio-medical engineering student had a key role in sharing and explaining the anatomy of the Kangaroo and the way that they can use the dynamics of the various components in their robot. The Kangaroo team went through two iterations for the leg and tail of the robot.

Conclusion

In this paper a newly developed course, entitled ”Bio-inspired robotics”, was presented. This course was part of the technical elective options for senior undergraduate and graduate students. For the mechanical, bio-medical and automotive engineering students (4 students or 30% of the class) this course was a serious expose to robotics and mechatronic systems. Moreover, they learned how to program and implement controllers through collaboration with their other group members. There were 2 students in the class that were not familiar with MATLAB simulation in the beginning of the semester, after the class these students not only acquired descent knowledge about MATLAB programming, but also learned how to implement their coding in micro-controllers (Arduino).

Since the course is presented at the senior year for undergraduate students, reviewing the concepts

Figure 2: Final design and inspiration for the Kangaroo robot. Since the idea the students were investigating was the effect of the tail on stability of the torso, the robot was designed as a planar monopod hopping robot and the leg is in the form of a four-bar linkage 3D printed on campus.

of dynamics and involving the students in discussions provide new insights about the fundamental concepts. Applying those principles on the experiment data from their own walking and running movement was very exciting and intriguing to the students.

The bio-medical engineering student expressed his satisfaction from the experience and the resulted project and for the next round of the class there are 5 bio-medical engineering students that are signed up for the class.

One mechanical engineering student got so interested on the subject that decided to pursue his graduate studies on the course topic. In addition to that, another masters student in mechatronics systems and control is seriously considering his PhD thesis to be on the topic of bio-inspired robotics which shows the course might have helped them to find their passion.

References

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