Use of a Mini Humanoid Robot Platform for Experiential Lab Activities in a Biomechatronics Course

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Abstract
The field of Biomechatronics is important for the design of devices, such as wearable robots, humanoid robots, assistive devices, or rehabilitative robots. Due to the multidisciplinary nature of the field, courses in Biomechatronics typically encompass fundamental background material in both engineering and biomedical disciplines, as well as more domain specific knowledge related to the end application areas. To reinforce this multidisciplinary knowledge, a series of team-based challenge exercises were recently incorporated into a Biomechatronics course at the Rochester Institute of Technology (RIT) using the low-cost Robotis Mini Humanoid robot and a project-based learning approach. Students were required to complete task-based challenges using both the Robotis virtual platform and the physical humanoid robots. The virtual environment allowed students to do the majority of programming outside of the laboratory, thereby minimizing the amount of time required with the actual robots. As part of the challenge exercises, students needed to both complete the challenge task and describe the associated biomechanics associated with the task. Examples of challenges included hitting targets in 3D space, designing a wearable exoskeletal device to add functionality to the robot platform, or participating in a limbo contest to demonstrate balance. Student responses to the challenges were favorable and suggest that the Mini humanoid platform can be used as a relatively low-cost, engaging means of reinforcing key multidisciplinary course concepts.

1. Introduction

Biomechatronics is a multidisciplinary field that combines multiple engineering and biological disciplines and plays an integral role of the development of electromechanical devices for therapeutic, assistive or diagnostic applications. Applications of biomechatronic devices include prosthetics, exoskeletal devices, biomimetic or bioinspired robots, rehabilitative robots, or other access technologies. The study of Biomechatronics typically includes prerequisite knowledge from a variety of disciplines, including Robotics, Biology, Mechanical Engineering, and Electrical Engineering. As the field continues to grow, courses in Biomechatronics are beginning to emerge and multiple textbooks have been written in support of the subject [1-3] since traditional courses in robotics may cover topics such as kinetics and kinematics, but do not cover topics such as muscle physiology or skeletal anatomy. Students in biological disciplines interested in Biomechatronics may have a fundamental understanding of anatomy and physiology, but may be lacking in-depth knowledge in areas such as dynamics, controls, or electronics. To allow students from multiple disciplines to fully engage in Biomechatronics courses, the course content should include both anatomical and physiological concepts as well as discipline specific knowledge from robotics and engineering. However, the primary challenge in creating such a course is the tradeoff between breadth of knowledge and depth of knowledge.

Project-based learning (PBL) has been shown to improve students understanding of subject matter, to promote independent thinking, and to aid in meaningful learning of course content [4-7]. Furthermore, PBL can aid in the synthesis of knowledge from multiple disciplines [8], making it an ideal approach for enhancing student understanding of multidisciplinary content in Biomechatronics. In addition, experiential learning approaches that utilize learning-by-doing processes have been suggested to enhance the effectiveness of robotics courses [9, 10]. According to Kolb, learning-by-doing approaches allow the learners to acquire both practical skills as well as theoretical knowledge [9, 11].

The Biomechatronics course at the Rochester Institute of Technology (RIT) is an upper and graduate level 3 credit hour, semester-long course taught in the Mechanical Engineering Department. Biomechatronics has traditionally been taught at RIT in a standard lecture format with some in-class demonstrations and out-of-class programming-based assignments. Instructor observations suggest that students commonly struggle with visualization of kinematic concepts, such as transformation matrices and Euler angles, and have a strong interest in applying the course concepts to real-world applications. To reinforce course concepts and enhance student engagement, a PBL approach coupled with learn-by-doing exercises was implemented into the course structure. Students were given six project-based challenges throughout the semester, where each of the challenges was focused around reinforcing and applying key course concepts. Students were allowed to work in groups to complete the challenges and were required to submit final reports on the findings from each challenge. All of the project-based challenges integrated a learn-by doing approach using the Robotis Mini humanoid platform (Robotis Inc., Lake Forest, CA) to further develop programming skills and reinforce course content.

2. Materials and Methods

The Robotis Mini humanoid platform is a programmable humanoid robot with 16 degrees of freedom (DOF), an embedded controller with a 32-bit ARM Cortex-M3 processor, and bluetooth connectivity [12]. Programming can be done using the Robotis R+Motion software platform provided by Robotis Inc.. R+Motion allows for 3D visualization of robot commands prior to downloading to the humanoid and can be interfaced with MATLAB (Mathworks Inc., Natick, MA) for further customization. The R+Motion software package is a free download for students, making it ideally suited for programming, debugging, and visualization of robot functions prior to class or laboratory sessions. The mini-humanoid robot also allows for easy visualization and testing of key Biomechatronics course concepts.

To reinforce course concepts using a PBL and learn-by-doing approach, six challenge-based exercises were developed. For each exercise, students were given specific robot tasks to be performed, however, the means by which the students could accomplish the tasks was open-ended. Students were allowed to work in groups of up to four students. Each challenge exercise was developed to reinforce specific course concepts and the specific course concepts that were reinforced were associated with the course learning outcomes. The challenges also allowed the students to bring in design and manufacturing concepts, including additive manufacturing. A detailed project report was required for each challenge exercise and was the primary means by which each project-based assignment was assessed.

Challenge Number	Description of Robot Task	Course Concepts Reinforced
1	Perform YMCA arm movements	Degrees of freedom, biomechanics, joint and segment angles
2	Hit targets in 3D space	Coordinate transformations, Denavit-Hartenberg parameters, kinematics
3	Achieve balanced positions	Balance, dynamic stability, support polygons
4	Design exoskeletal or prosthetic device to add robot functionality	Motors, engineering requirements, project planning
5	Build exoskeletal or prosthetic device to add robot functionality	Prosthetics, exoskeletal devices
6	Compete in limbo contest	Biomechanics, synthesis of course concepts

Table 1. List of key tasks and concepts that were reinforced for each of the challenge exercises.

Table 1 provides a description of the challenge exercises, including the robot tasks that the students needed to perform and the key concepts that each challenge exercise were intended to reinforce. The challenges progressed in level of difficulty and open-endedness. For example, Challenge #1 focused on learning the robotic platform through demonstration of YMCA dance movements while the final challenge engaged the students in a limbo contest. Other challenges included hitting targets in 3-D space, demonstrating balance, and designing, building, and testing a prosthetic or exoskeletal device for the robot that would add functionality or degrees of freedom to the existing platform.

Challenge #2 focused on hitting targets in 3-D space. Historically students in the course have struggled with visualization of kinematic concepts and coordinate transformations. Thus, as part of Challenge #2, the students were required to move the robot's upper and lower extremities from a base position to other positions in 3-D space. The students were required to map between global and local coordinate systems using a custom MATLAB interface and relate key course concepts, such as Denavit-Hartenberg parameters and coordinate transformations, to their outcomes in their project report. The challenge included learn-by-doing aspects that involved integrating R+Motion with MATLAB as well open-ended PBL aspects.

Challenges 3, 4, and 5 focused heavily on PBL. For Challenge 3, the students were required to demonstrate balance in a variety of open-ended scenarios while in Challenges 4 and 5, students were tasked with designing, fabricating, and testing a prosthetic or exoskeletal device that integrated with the robot and enhanced robot functionality or added an additional degree of freedom. The students were not allowed to modify the robot or reduce the robot's existing capabilities. As part of Challenge 4, the students were required to define customer and engineering requirements, design their device, and create test plans. For Challenge 5, the design needed to be fabricated and integrated with robot and the functionality of the device assessed using their previously developed test plans. Alternatively, the students could demonstrate the functionality of their device virtually using computer aided design (CAD) tools or other means, as appropriate.

The final challenge exercise required the students to synthesize multiple course concepts through participation in a limbo challenge and in-class competition. As described by Zuhrie et al. [10], robot competitions can be used to enhance student motivation and learning outcomes. For Challenge 5, the students were tasked to perform "limbo motions" in which the robot needed to start in a standing position 12" away from a limbo bar, "limbo" under the bar without knocking it down, and return to a standing position clear of the other side of the bar. For the purposes of the challenge and due to balance limitations with the robot, the robot could bend forward or backward to perform the limbo motions and could use hands or other body parts for balance. However, the robot could not be modified in any form. To achieve the maximum number of points on the graded portion of the assignment, the robot needed to pass under the limbo bar when it was at a height of 50% of the robot's height. For the in-class competition portion, the goal was simply to pass under the bar at as low of a height as possible. In case of ties between groups, the tie-breakers included having fewer points of contact with the ground and fewer steps in the programming algorithm. Additional faculty members were recruited to aid in judging of the competition and prizes were awarded to winning teams. For the project report, students were required to document their approach using key concepts associated with balance and stability and define what additional degrees of freedom or capabilities would be required for the humanoid to perform traditional limbo motions in which the robot is leaning backward.

Another key element of all the challenges was to promote the students to be creative and have fun with the humanoid platform. For the final challenge exercise, students were required to create a tropical t-shirt design. Students and faculty judges were asked to vote for their favorite designs during the final limbo contest and the winning designs will be printed and worn by the robots in future course offerings. As another creative exercise, as part of Challenge 3, which focused on balance, the students were asked to come up with one additional "silly pose" for the robot that demonstrated balance and that classmates in future semesters would need to replicate. In addition to putting the robot into the balanced position, the students were required to justify, based on the center of mass and support polygons, why the position was balanced. Thus, the exercise integrated fun and creativity with serious learning outcomes.

Assessment of the learning outcomes associated with each challenge assignment was done through assessment of written project reports. Rubrics were created for each assignment and included assessment of how well the students demonstrated knowledge of the concepts being reinforced as well as general documentation quality. Preliminary assessment of the effects of the PBL and learn-by-doing approach was done indirectly using course evaluations and student comments. Comparisons were made to course evaluations from previous semesters, as feasible.

3. Results

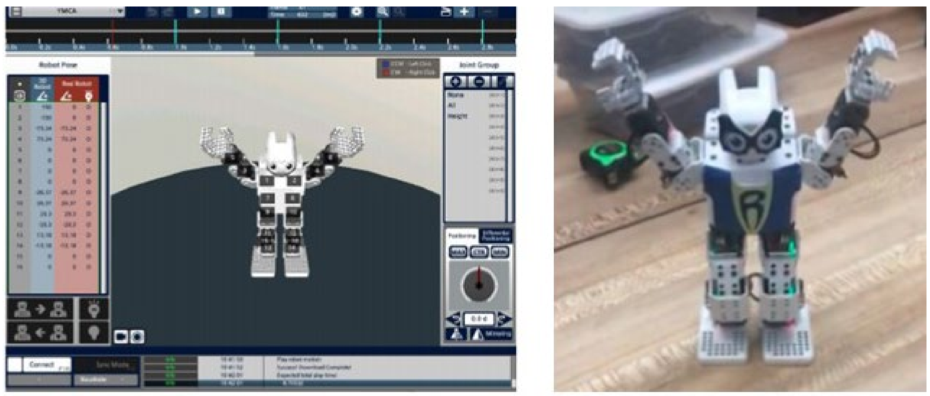

Figure 1. Demonstrations of Robotis humanoid robots performing the Y motions associated with Challenge 1 in virtual (left) and live (right) environments.

The PBL and learn-by-doing approach was piloted during the spring semester of the 2020-2021 academic year. Thirty-three students were enrolled in the dual-listed undergraduate/graduate Biomechatronics at RIT. Fourteen of the students were enrolled in the undergraduate version of the course while 19 were enrolled as graduate students. Twenty-six of the students were majoring in Mechanical Engineering, 5 were majoring in Biomedical Engineering, and 2 were majoring in non-Engineering disciplines.

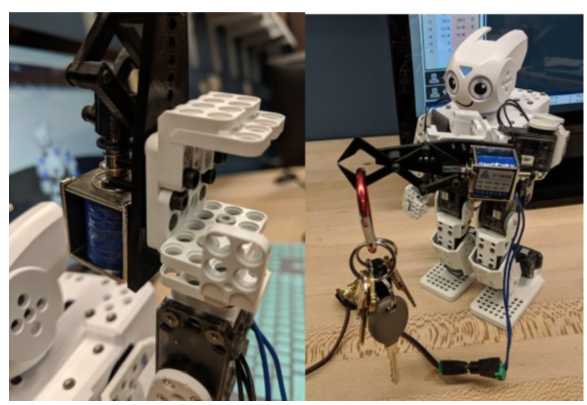

Figure 2. Prosthetic gripper added to robot to add additional degree of freedom and grasping capabilities at wrist joint.

Representative results from the different challenge exercises can be seen in Figures 1 - 3. Figure 1 shows Y motions of the YMCA challenge being performed in the R+Motion virtual environment and by the mini-humanoid. Figure 1 illustrates how motions can be visualized using the R+Motion environment prior to class or lab times. Figures 2 and 3 illustrate two of the prosthetic or exoskeletal devices developed as part of Challenges 4 and 5. In Figure 2, a grasping device was designed to allow the Robotis Mini to perform grasping motions and pick up objects, something that cannot be done with the robot in its standard configuration. Figure 3 shows a tail

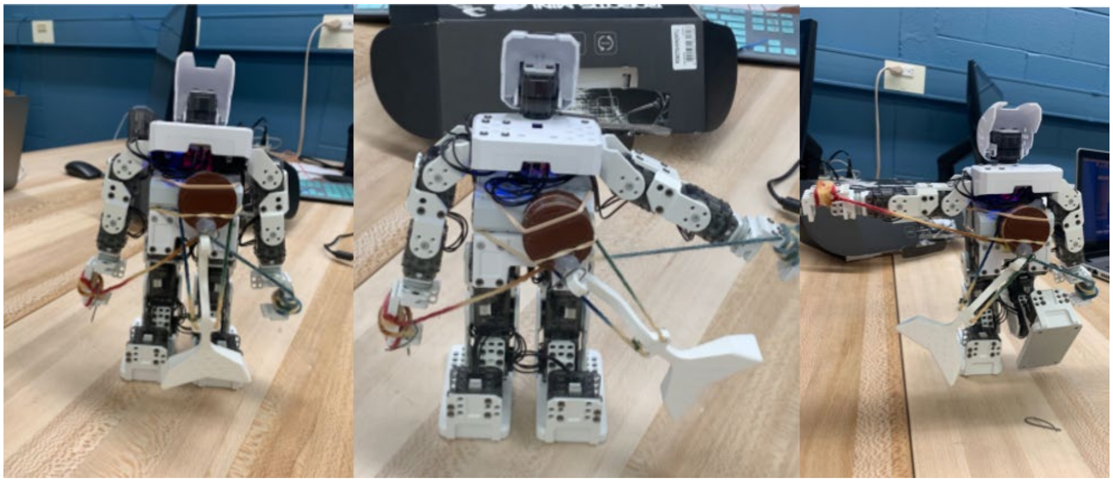

Figure 3. (Left) Backpack tail assembly used to enhance robot balance. (Center) Actuation of tail using existing robot actuators.. (Right) Demonstration of improved balance with tail assistance.

device that was 3D printed to improve the balance of the robot. Improved balance was demonstrated by having the robot perform bending motions and leaning motions while standing on one leg. The tail device successfully improved the balance of the robot and highlighted how the challenge activities promoted real-world learning and creativity.

Figure 4 shows two variations of limbo motions performed by the students during the final in-class limbo competition. As can be seen in Figure 4, the types of motions the students utilized to achieve the objectives of the challenge varied greatly. Some students chose to have the robot in a more prone position while others utilized a supine position. All students were able to successfully complete the baseline objectives of the challenge, which was to limbo under a bar that was 50% of the robot's height. Furthermore, student engagement in the competition was high with many students commenting favorably about how much they enjoyed the limbo challenge.

Indirect methods were used for assessment of student satisfaction and improvement in understanding of course content. Comparisons were made between course offerings in 2016, 2018, and 2020 since the course is only offered every other year. Overall course grades did not vary significantly between offerings and individual graded items were not compared since the learning outcomes and assessment methods varied between years. However, as shown in Table 2, course evaluations showed that the changes made to the course in 2020 improved the students' perception of how the course advanced their understanding of the content. For the pilot offering of the course in 2016, student ratings of how the course "advanced their understanding" were 4.29and 4.2 for the undergraduate and graduate sections, respectively. In 2018, the student ratings were 4.33 for both the undergraduate and graduate offerings. In 2020, the student ratings were 4.7 and 4.64 for the undergraduate and graduate offerings, respectively. The improvements in how the course advanced their understanding suggest that the integration of the robots and

Year	Undergraduate*	Graduate*
2016	4.29 (n=14)	4.2 (n=5)
2018	4.33 (n=6)	4.33 (n=6)
2020	4.7 (n = 10)	4.64 (n=11)

* Maximum rating = 5

Table 2. Comparison of student perceptions of how course "advanced their understanding" of course material.

challenges may have positively impacted student perceptions of the course. Furthermore, student comments from 2018 stated that they would have liked "more hands on labs" or the "addition of a physical project". Student comments from 2020 suggest that the labs involving the robots "furthered their understanding of the course content", "were their favorite part of the class", "applied the concepts learned in class", and improved student learning "during the open-ended assignments". The only comments that were negative related to the use of the robots discussed the number of robots available per group. Student comments suggested that one robot per group would be preferred to give the groups more time to experiment with the robots rather than three robots shared between all groups in the course.

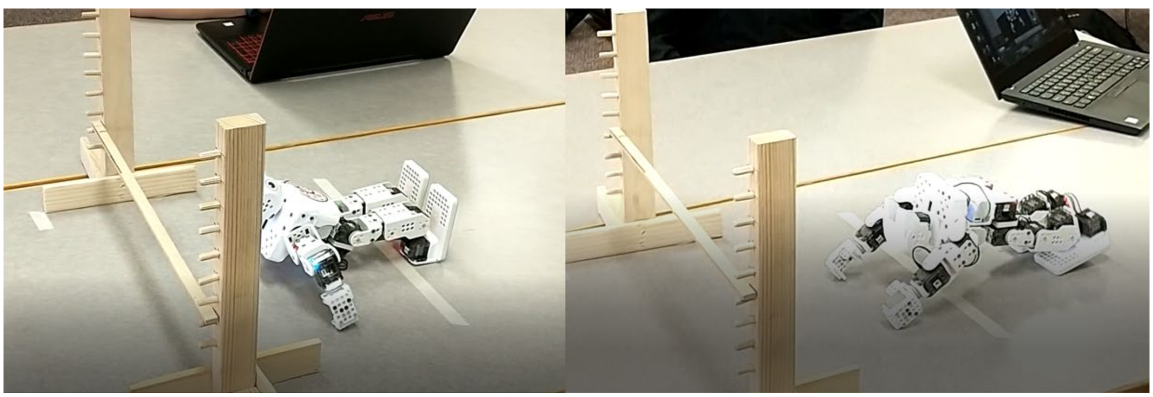

Figure 5. Robotis Mini humanoid performing "limbo movements".

4. Discussion and Conclusions

Student feedback suggests that the addition of PBL and learn-by-doing exercises improved student understanding of the course content for a multidisciplinary course in Biomechatronics. The findings are consistent with those presented by Li [6] and Chang et al. [5] that PBL can enhance student learning and overall student satisfaction, particularly for multidisciplinary courses. A more robust approach for assessment could be incorporated in future course offerings and used to understand the specific impacts of the PBL approach.

From the instructor perspective, the integration of the PBL and learn-by-doing exercises helped maximize the amount of material that could be covered during the course. Since

Biomechatronics, by nature, requires coverage of a broad range of topics, there is limited time to help reinforce course concepts within a lecture based format. The projects allowed critical course concepts to be revisited and applied in real world-scenarios. The projects could also be customized to both undergraduate and graduate student requirements, even within the same course structure. In addition, the projects were done primarily out of class, which offered additional benefits during COVID when the numbers of students in labs or classrooms were limited. Students could work with the robots in small groups in the lab on their own while maintaining appropriate COVID distancing requirements.

Humanoid platforms also work well for reinforcing Biomechatronic concepts. In particular, the Robotis Mini platform was low cost, easy to program, and offered a virtual environment that allowed for significant development to be done prior to working with the actual robot. In addition, the R+Motion environment was easily interfaced with MATLAB making it well-suited for more sophisticated programming exercises. During the initial course offering at RIT, only three robots were available, which presented some logistical challenges, particularly if robot components were broken or damaged. Ideally, there should be one robot per group to maximize the amount of time that each group can work with the robots. This finding was further supported by student comments.

Overall, results from this study suggest that PBL can be effectively integrated into courses in Biomechatronics and used to enhance student learning. Future work should focus on a more robust assessment of how the PBL approach enhanced learning of course learning outcomes and overall student satisfaction with the course structure. A more thorough assessment would provide valuable guidance to others looking to replicate the teaching approach in other multidisciplinary courses. Furthermore, refinement of the existing activities or the addition of more activities could likely further improve the course and associated learning outcomes.

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