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Work in Progress: Using a 5-DOF Robotic Arm Project for the Enhancement of Engineering Recruitment and Education

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WIP: Using a 5-DOF Robotic Arm Project for the Enhancement of Engineering Recruitment and Education

Introduction

Biola university is a Christian university that has been focusing more on biblical and liberal arts education than engineering and technology. It currently offers a 3+2 Engineering Physics program in partnership with the University of Southern California (USC). Students spend their first three years at Biola university taking Bible, general education, math, science, and some engineering courses, then transfer to USC or other accredited engineering programs and spend the following two years to complete their Bachelor of Science degree in their desired engineering disciplines. Upon graduation, they also receive a dual degree in Engineering Physics from Biola university.

In Fall 2023, we will launch two 4-year Bachelor of Science degrees, in Engineering and Robotics respectively. These new BS degree programs have been accredited by WSCUC, and will be seeking ABET accreditation upon the graduation of our inaugural classes. Students in the Engineering major will take foundational electrical and mechanical engineering coursework in their freshmen and sophomore years, and later customize their learning path by choosing elective courses in their interested engineering fields. While having more emphasis in Artificial Intelligence and advanced robot programming and control techniques, the Robotics major will also prepare students with the knowledge in mechanical modeling of robots, sensing and actuation, and embedded system design. Therefore, we developed the engineering and robotics curricula with several cross-listed courses including Mechatronics, Embedded Systems, Computer Aided Engineering Design, and Engineering Economics, in addition to the common freshmen-year intro to programming and intro to engineering lab as well as some common math and physics courses. Both majors require students to complete a two-semester-long teamwork-based capstone design project. We anticipate that engineering students and robotics students will collaborate on some capstone design projects although the capstone courses will be offered separately.

This unique background sets the stage of the 5-DOF robotic arm project presented in this paper. The first prototype was developed by a team of three rising Engineering Physics sophomores, mentored by an engineering faculty member, during their 2022 Summer Engineering Internship experience. Currently another team of students are continuing the development and transferring the Arduino-based system to the ROS 2 platform in their Directed Research course with the same faculty member. Upon the completion of the migration to ROS 2, components of this robotic arm system will then be integrated into the course projects of multiple courses in the BS-Engineering and BS-Robotics curricula. Another direction of this project is to use this robotic arm in recruitment activities. In the following sections, more details will be provided on the development, plans, and preliminary outcomes of this work-in-progress project.

Robotic Arm Developed as a Summer Engineering Internship Project

Thanks to the generous donations, we were able to offer an internal hands-on experience called Summer Engineering Internship (SEI) to students in the Engineering Physics and Applied Physics majors over the past few years. This program engages students with 128 hours of hands-on engineering internship-like experience, mentored by two engineering faculty members. The program aims to provide undergraduate students, with little engineering experience, an enriching and relevant experience for their future careers in engineering. Students did most of their project work in our fabrication lab equipped with a laser cutter, a CNC machine, several UltiMaker 3D printers, and some power tools. They also had access to our circuits lab equipped with soldering stations, fume hoods, and circuit measurement and testing instruments. The faculty mentors gave a few short tutorials on how to use the equipment and topics related to the projects. Most of the time was dedicated to hands-on project-based learning. Students also presented their iterative designs every other week to the entire SEI group, and showcased their projects to the public with posters and demonstrations at the school-hosted exposition of summer programs.

The development of a 5 Degrees-of-Freedom (DOF) robotic arm is one of the several SEI projects in the summer of 2022. All three students on the team just completed their freshmen year back then. Prior to SEI, they gained some basic skills in Arduino programming and CAD design using Fusion 360 from their Intro to Engineering class, and very limited circuits knowledge from the General Physics II course. Throughout the eight-week SEI program, each of the three students took on different tasks at different stages of the project, while also collaborated in testing and debugging.

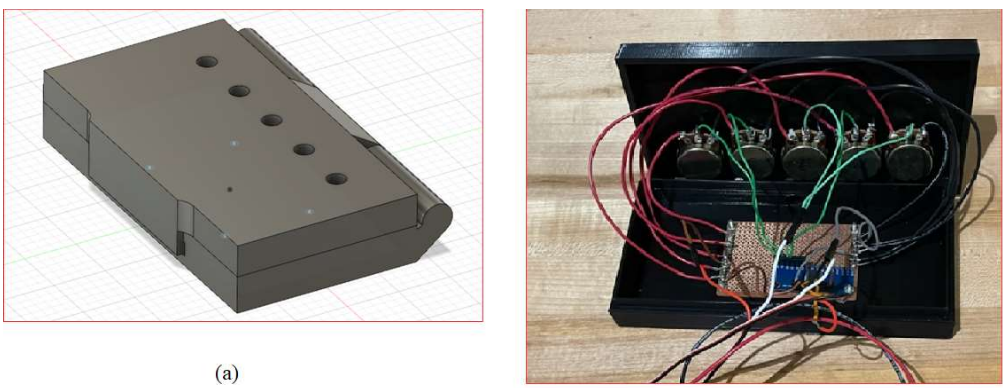
An initial design was started by a previous Engineering Physics student, whose project was cut short due to the COVID-19 pandemic and ended with only a 3D printed model lacking electronics or software. The SEI team developed a complete embedded system that enables users to control the motion of the four joints - base, shoulder, elbow, and wrist, as well as the gripper of the robotic arm by simply turning the corresponding knobs on a custom-designed control box. They modified the 3D CAD model of the base, shown in Figure 1, to enclose all the electronics and allow multiple ports and connectors to be conveniently accessed for battery charging, software update, and diagnosis.

(a) (b)

Figure 1. Base of the Robotic Arm (a) 3D CAD Model; (b) Base with Hardware

Three MG996 servo motors were used for the base, shoulder, and elbow joints while two SG50 micro-servos were used for the wrist and gripper. The PCA8695 PWM servo control board was adopted to drive the motors and communicate with the Arduino Uno via I2C protocol. Students learned some important mechatronics concepts such as PWM signal, motor selection and control, and I2C communication. They also improved the design of the linkages and redesigned the wrist to fit the gripper.

To make the project a reasonable challenge for the SEI students, we chose the teleoperation mode, instead of autonomous operation by the robotic arm which would require advanced robotics theory and programming skills. The teleoperation was implemented using potentiometer inputs. The students designed a 3D CAD model for the control box and soldered the potentiometer pins to the auxiliary circuitry on a perf board. Due to the limited analog I/O pins on the Arduino Uno with two of them reserved for the I2C protocol, a multiplexer board became necessary to feed all five potentiometer readings to the Arduino. Students learned engineering concepts such as digital address, multiplexing, using potentiometers for adjustable inputs, and also practiced soldering.



(a) (b)

Figure 2. Control Box (a) 3D CAD Model; (b) Control Box with Hardware

After several iterations of CAD design and 3D printing, and many hours of programming and debugging, the team successfully completed the design and assembly of the robotic arm. Figure 3 shows the finished system. The unit cost of the entire system is only about $88. For the exposition, they created an enjoyable task to engage the audience: by turning the potentiometers with knob covers, the end user can control the robotic arm to pick up 3D-printed blocks with letters and place them in a tray with the proper order spelling the name of the university. The robotic arm drew a lot of attention at the poster event. In the following semesters, these three SEI students demonstrated higher proficiency in courses involving computer programming and circuits.

Figure 3. Teleoperated 5-DOF Robotic Arm

Establishing a Robotics Research Platform

The author, who serves as the director of engineering program and also mentored the SEI robotic arm project, has experience at her previous institution advising undergraduate projects in ROS-based mobile robots. ROS, or Robot Operating System [1], is a set of software libraries and tools widely used by robot developers and researchers. Advanced control techniques and algorithms involving computer vision and AI can be applied to robotic systems by integrating corresponding ROS packages, rather than writing source code from scratch. Based on the author's past experience, engineering students often felt reluctant to develop their robotic systems on the ROS platform due to the unfamiliarity with Linux operating system and Python programming. Currently a mobile robotics course is offered as a technical elective course for the Computer Science major at Biola University. It seems that the computer science students feel comfortable using ROS as their learning and development platform.

As an attempt to establish a ROS 2-based research platform using the same 5-DOF robotic arm built by the SEI team, the author is currently working with three other undergraduate students on transforming the Arduino-based design to ROS 2 through a Directed Research course. The three students are in Engineering Physics and Applied Physics majors and in sophomore, junior, and senior standing respectively. One student is focusing on the conversion of the 3D CAD designs of the robotic arm from Fusion 360 to the Unified Robot Description Format (URDF) – the most popular format for specifying the geometry and configuration of robots in ROS 2. After the conversion, he will use a free-space motion-planning tool for ROS 2 called Moveit! to perform the kinematics computation and motion planning. Another student is focusing on the interface between ROS 2 and Arduino using the micro-ROS library. The originally used Arduino Uno board has been replaced with an Arduino Zero for this purpose. The third team member has been providing ROS 2 support and working on the integration of the above-mentioned modules.

The main goal of the direct research course is to transform the robotic arm from a simple Arduino-based embedded system to the ROS 2 platform so that advanced robotics research involving computer vision and AI can be performed on this robotic arm. On the other hand, we will purchase commercial ROS 2-compatible robotic arms to support the courses and capstone design in the BS-Robotics program. Therefore, migrating the built-in-house robotic arm to ROS 2 is not simply for saving equipment cost. It will be helpful to know what are the necessary components of ROS 2 that should be introduced to engineering students through cross-listed courses like Mechatronics, in order to fill in the gap and remove the obstacles for engineering students working along side robotics students in future projects. This directed research does not only train the students in development on the ROS 2 platform, but also provides the instructor insights on curriculum development.

Integration Plan of the Robotic Arm into Engineering and Robotics Curricula

Courses in the BS-Engineering and BS-Robotics curricula that can possibly incorporate learning activities using the 5-DOF Robotic Arm are listed in Table 1. Among those courses, Intro to Engineering Lab, Embedded Systems, Mechatronics, and Computer Aided Engineering Design are required by both majors, while Circuits and Instrumentation I and Robot Modeling and Dynamics are required by one major but can be taken as a technical elective by another major.

Course Title	B.S. Engineering	B.S. Robotics	Topics involving the robotic arm
Intro to Engineering Lab	required	required	basic CAD design, basic Arduino programming
Circuits and Instrumentation I	required	elective	circuits, soldering
Circuits and Instrumentation II /Embedded Systems	required	required	software/hardware interfacing, multiplexing, I2C
Mechatronics	required	required	motor control, power management, ROS/URDF basics
Computer Aided Engineering Design	required	required	SolidWorks, PCB design
Robot Modeling and Dynamics	elective	required	URDF, robotic arm kinematics and dynamics, ROS packages

Table 1. Possible Integration of the Robotic Arm in the Engineering and Robotics Courses

Introduction to Engineering Lab is a 1-credit course with a 3-hour lab session per week, to be offered in the freshmen year in Spring 2024. Students will be introduced to engineering design process and obtain some basic engineering skills through hands-on teamwork-based projects. The robotic arm will be a good platform for students to learn 3D CAD design. Instead of repeating what has been done by the SEI team already, students can come up with their own

CAD design for the wrist to allow a different type of end-effector to be attached. They can also modify the Arduino program to control the new end-effector. They can test their design with a specific task performed by the robotic arm, which will make the learning experience more interesting.

In Circuits and Instrumentation I, students can design auxiliary circuitry to improve the robotic arm. For example, a circuit to measure the battery voltage and flash a red LED when the battery needs charging. Another circuit could be a low-pass filter to reduce the interference and noise from the potentiometers. Students can also practice soldering when adding their circuits to the robotic arm.

In Embedded Systems, the robotic arm is a good platform to teach students the I/O interfacing and important concepts such as multiplexing and I2C communication.

Mechatronics is a junior year course required for both engineering and robotics majors. Currently we have purchased the Arduino Engineering Kit (AEK) Rev. 2 for the main course project. The AEK provides an interface between MATLAB/Simulink and Arduino, so that users can take sensor measurements and control motors from MATLAB and apply the functionalities in MATLAB such as image processing on their Arduino-based system. However, the mobile rover built with the AEK does not cover the mechatronics concepts related to linkages and motion transmission mechanisms. The ongoing directed research may lead to course content introducing basics of ROS 2, URDF, and Moveit! using the robotic arm. Power management of a mechatronics system and the control of multiple motors using the PCA8695 board can be taught using the robotic arm as well.

SolidWorks and Printed Circuit Board (PCB) design to be taught in the Computer Aided Engineering Design course are useful practical skills for engineering students. Course projects related to robotics need to be included as this course is also required for the robotics major. The teleoperation control box for the robotic arm currently soldered on the perf board can be readily converted to a PCB. The circuits designed in the Circuits and Instrumentation I course for battery monitoring and potentiometer noise filtering, as mentioned earlier, can also be converted to PCB. The existing 3D CAD design for the robotic arm can be transferred to SolidWorks and help students to learn advanced features and improve the design.

In the Robot Modeling and Dynamics course, ROS 2, URDF, and Moveit! will be introduced to robotics students for the kinematic and dynamic modeling and motion planning of robotic manipulators. The ongoing directed research project can allow students to explore development activities behind the scene, in addition to the modeling of a commercial robotic arm.

Assessment of Student Learning Outcomes

The student learning outcomes of our BS-Engineering and BS-Robotics programs include the first seven outcomes close to the ABET Student Outcomes [2] 1-7 and an additional Outcome 8 addressing the Christian faith integration in science and technology. We have developed our curriculum maps that reflect how these student learning outcomes are introduced, developed, and mastered in different courses, as well as assessment plans for the data collection and analysis to assess each student outcome.

The learning activities involving the 5-DOF robotic arm in our Engineering and Robotics curricula will mainly contribute to Student Outcomes (SO) 1, 2, 6, 7 as listed below:
SO #1 Identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
SO #2 Apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
SO #6 Develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
SO #7 Acquire and apply new knowledge as needed, using appropriate learning strategies.

The above student outcomes will be introduced in Introduction to Engineering Lab in the freshmen year, and further developed in the sophomore and junior year courses. We plan to assess some performance indicators of SO #1 and SO #7 in Mechatronics and Computer Aided Engineering Design respectively. For example, one of the performance indicators under SO #1, mathematic modeling (involving linear algebra and differential equation) can be assessed using a Mechatronics exam problem on the study of linkage and motion mechanisms involving the robotic arm. In Computer Aided Engineering Design, we can assess students' learning strategies to acquire and apply new knowledge, under SO #7, using an assignment of converting the robotic arm 3D CAD from Fusion 360 taught in Intro to Engineering Lab, to SolidWorks, a new software taught in this course. SO #2 and SO #6, although will be developed through the learning activities involving the robotic arm, will be assessed in the capstone design courses.

Robotic Arm for Recruitment

Engineering educators have explored many different strategies for the recruitment of prospective students into engineering programs [3][4][5][6]. Recruitment of students into our new engineering and robotics programs will be a challenge because Biola University is well known for its biblical and liberal arts education rather than engineering education, and there are several state universities in the greater LA area with competitive engineering programs.

The 5-DOF Robotic Arm project has been used in the recruitment of prospective engineering and robotics students. We demonstrated it at the university's Preview Days opening to prospective students and families, presented its poster and video during individual prospective student visits, and will include it in future presentations at high schools. Prospective students expressed strong interest in the robotic arm.

Utilizing a student-built robotic arm in the recruitment of prospective students can be highly beneficial for several reasons:

1. Showcasing the technical skills and creativity of current students, highlighting the quality of education and unique learning opportunities like the SEI provided by our university.
2. Engaging prospective students with the interactive teleoperation task. This can help to capture their attention and interest in our engineering and robotics programs.
3. Creating opportunities for engineering students to get involved in the growth of the program. Knowing that their designs and course projects related to the robotic arm will help the recruitment of future engineering students will motivate them to put in sincere effort in the projects.

Conclusions

A work-in-progress project aimed at enhancement of engineering education and recruitment utilizing a robotic arm is presented in this paper. Students participated in the Summer Engineering Internship program successfully built a teleoperated 5-DOF robotic arm. Currently students are transforming the system to the ROS 2 platform commonly used by robot developers and researchers. Plans of integrating different components of this robotic arm in the curricula of the BS-Engineering and BS-Robotics programs were discussed. We also use it as an instrument to engage prospective engineering students during their visits.

The continuing research will be based on two hypotheses: 1. The use of this robotic arm in several engineering and robotics courses will make the student learning experience more interesting and relevant. 2. The use of this robotics arm in recruitment activities will increase the likelihood of prospective students choosing Biola University and also improve current student involvement. We will use anonymous surveys and course evaluations to evaluate the effectiveness of the course integration, and will collect feedback from the incoming freshmen class to assess the impact of the robotic arm in recruitment.

The full implementation of the proposed initiatives will take place in the new several years. We hope to report our progress to the engineering education community and share our experiences and lessons at the next few ASEE annual conferences. We also plan to disseminate the projects/modules of these initiatives by uploading our source code, CAD design files, and documentation to GitHub for other institutions to access.

References

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