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Project Ponderosa - Bridging Robot Simulation with Design

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Abstract

The application of robotics in industry continues to be an increasing area of growth. This requires an increased awareness in fidelity of design to better understand the relationships within the system. To achieve a higher degree of complexity in design, the use of simulation enables engineering students the ability to develop solutions for the system requirements. However, this can become problematic to adequately provide a realistic environment for teaching the design of robotics systems. In recent years, with the coordination between Cal Poly Pomona and Boys Republic, we have developed Project Ponderosa. Project Ponderosa provides Cal Poly Pomona engineering students the opportunity to design various robotics, and automation systems that will be operated and maintained by Boys Republic students for Christmas Wreath Production at their facility. This project constitutes the college student's senior capstone project providing them with real-world experiences to prepare them for work in industry.

To develop successful engineering solutions, the use of simulation tools is a fundamental element in industry during design and development while providing understanding to key specific aspects of a design and trade-offs within the design space. The engineering development of complex robotics and automation systems require software, electrical, and mechanical systems to interoperate collectively. To achieve a successful design, simulation becomes a vital phase within these domains to ensure each element operates as intended and that all elements integrate correctly at a system level. However, during senior projects, students often minimize the simulation effort to complete their senior projects within schedule. Instead, if the students would incorporate better use of simulation, they would achieve a higher degree of successes.

During the 2020 academic year, the students began their senior project design effort for Project Ponderosa focusing on delivering a physical solution. However, as COVID-19 altered student activities, the students adapted the engineering develop cycle incorporating a larger use of simulation tools to able to showcase their work at the end of the academic year. The students from Cal Poly Pomona were able to develop and validate a full simulation of a robotic system that integrated computer vision, mechanical design, and user interface development for their work on Project Ponderosa. They learned that using simulation provided them a deeper understanding of design and validation of their work.

Project Ponderosa is a continuing joint effort between Cal Poly Pomona and Boys Republic to develop a robot system that aids in the manufacturing of Christmas Wreaths by Boys Republic. In prior years, work was performed on the Boys Republic High School campus by Cal Poly

Pomona students as they developed and built various robot and automation systems. However, when COVID-19 occurred, the Cal Poly Pomona team transitioned their engineering effort to construct a design and validation of a robotic system using simulation-based methods. This also provided them an opportunity to share with Boys Republic the ongoing design and allowed the customer to gain insight during the design and development phases. As a result of the COVID-19 shutdowns, the students were able to gain a deeper understanding and benefit of simulation specifically applied to robot designs.

Introduction

As discussed in previous papers[1], robotics and automation systems are now a standard method of manufacturing across many industries. The design of these systems requires careful consideration and thought for the integration of design topics including engineering disciplines of mechanical design, electrical design, software engineering, and controls engineering[2,3]. These disciplines can be further decomposed into machine elements, fluid dynamics, analog and digital electronics, computer vision, and real-time software.

The development of robotic based systems are complex designs requiring elements of each discipline to interoperate collectively. Within these disciplines, engineers utilize multiple simulation tools as a fundamental element to aid in the engineering design and development tasks. These simulation tools provide the design engineer insight to specific aspects of a design while providing better understanding of trade-offs within the design space. To achieve a successful design, simulation becomes a vital phase within these domains to ensure each element operates as intended and that all elements integrate correctly at a system level. During the 2020 academic year, COVID-19 altered how students were able develop and showcase their work from previous years and familiar approaches. However, it provided students the opportunity to fully realize and embrace simulation tools. The students from Cal Poly Pomona were able to develop and validate a robotic system via simulation that integrated computer vision, mechanical design, and user interface development for their work on *Project Ponderosa.*

Project Ponderosa is a continuing joint effort between Cal Poly Pomona and Boys Republic High School to develop a robot system that aids in the manufacturing of Christmas Wreaths by Boys Republic. In prior years, work was performed on the Boys Republic High School campus by Cal Poly Pomona students as they developed and built various robot and automation systems. However, when COVID-19 occurred, the Cal Poly Pomona team transitioned their engineering effort to construct a design and validation of a robotic system using simulation tools as they continued their effort thereby gaining valuable experience for industry. This also provided them an opportunity to share with Boys Republic the ongoing design while allowing the customer to gain insight of the design during development phases. Upon completion of their efforts, the Cal Poly Pomona engineering students were able to demonstrate to Boys Republic the next generation robot system design using a robot system simulation tool that included the mechatronics, electronics, computer vision, fluid dynamics and user control interfaces for the system. As a result of the COVID-19 shutdowns, the students were able to gain a deeper understanding and benefit of simulation methods specifically applied to robot designs.

Due to the nature of cost and lack of opportunity, many senior engineering students working on their capstone project are unable to fully realize the breadth in the design and deployment of robotic and automation designs. Often it is impractical for engineering students to create a real-world equivalent problem to address full breadth that implementing a robotic system for automation requires. To address this challenge, a relationship between Boys Republic and Cal Poly Pomona was established which benefit both Cal Poly Pomona engineering students while providing a solution for Boys Republic in the assembly of Christmas wreaths.

The Department of Electromechanical Engineering Technology at Cal Poly Pomona focuses on teaching engineering students the relationship of the various robotics-based engineering disciplines while blending the necessary theory with application. As students develop and complete their senior project, the expected educational outcomes include the ability to understand the requirements of a given design, decompose the design using the design processes with preliminary and detailed design stages and then perform both integration and testing of the design. Throughout this process they used simulation tools to verify their approach. Project Ponderosa is a project where Cal Poly Pomona engineering students worked with the staff from Boys Republic to design a robotic system that helps in the manufacturing of Christmas wreaths that Boys' Republic use as a source to generate revenue through the sales of the Christmas wreaths.

Background

Boys Republic is a private, nonprofit, nonsectarian school and treatment community for troubled youth. Since its founding in 1907, it has guided more than 32,000 at-risk teenage boys and girls toward productive, fulfilling lives. On its central school and farm in Chino Hills, California, and in residential and day treatment centers in other communities, Boys Republic and its companion program, Girls Republic, help youth find within themselves the resources and skills to begin meaningful lives on their own. The rehabilitation process involves the development of academic, vocational, and social skills.

The goal of this community is to give troubled adolescents an opportunity to learn valuable life-skills to become productive and self-directed members of society. They do this by providing the young boys with hands-on real-life craftsman experience. Upon completion of the robotic system by Cal Poly Pomona engineering students, the boys from Boys Republic will learn how to operate and maintain the automation system while providing they boys additional vocational skills to help prevent recidivism, and instead help them continue to become productive members in society[4].

The staff and students from Boys Republic are responsible for the manufacturing and assembly of Christmas wreaths which are used to generate revenue for their facility. There are multiple operations that are required in making the wreath, however most of the process is done by hand. This manual labor includes the cutting and application of pinecones and seed pods, adding small fruits such as apples, adding colorant to the Noble fir foliage and finally the final application of adding a clear lacquer sealant. Prior to automating the process, the lacquer and green colorant application to the wreaths was performed manually someone by someone located in a small painting booth. During the manual operation, the production of the wreaths is only as fast as that one person can apply lacquer and green colorant[1]. The design from the previous year improved the lacquer application efficiency and safety, however, now the limiting factor of the manufacturing process is the application of the green colorant.

The Della Robbia wreath program was introduced originally by Boys Republic founder Margaret B. Fowler to serve as a work experience vehicle for students at the non-profit school. The wreaths were patterned after a centuries-old ceramic design created by the Della Robbia family of Florence, Italy. In 1923, the first year of the Boys Republic Della Robbia campaign, only a few dozen wreaths were produced. They were sold on the streets of Pasadena. The program grew to meet increasing demand. Today, Boys Republic's students produce and ship more than 40,000 wreaths, each year, to destinations throughout the United States and around the world[6].

Figure 1. (Left) Boys' Republic Christmas Wreath. (Right) Final assembly and production of the wreaths. Notice along the backwall the hook line assembly line that travels throughout the various assembly areas.

This year the team developed a design of a robot that would apply colorant to the wreath production while also providing some additional design features from last year's team. The detailed project objective was to build a robot arm to paint the wreaths with a water-based colorant while controlling the application flow rate. This requires developing designs utilizing machine elements, mechatronics, fluid dynamic principles, computer vision and multi-loop control systems. The system was required to apply the colorant to two different size wreaths measuring either 22 or 28 inches in diameter. The assembly hook line carrying the wreaths to be painted operated at 720 wreaths per hour for the smaller wreath, and 480 wreaths per hour for the larger wreath.

This paper addresses the continued and additional tasks that the Cal Poly Pomona students have undertaken in partnership with Boys Republic towards helping in the manufacturing of the Christmas wreaths. In this effort, the Cal Poly Pomona engineering students' initial objective was using the prior year's design efforts to then understand requirements for the application of the green colorant. This was done through several meetings with the Boys Republic staff and observing the actual manual application of the lacquer. After the Cal Poly Pomona students understood the requirements, they established a preliminary design and schedule and presented it to Boys Republic for review and approval. Upon a successful preliminary design review, the students then undertook the detailed design efforts and the test and integration phases of the engineering project. After completion of the project, the engineering students were able to understand how to develop engineering requirements for a real customer and ultimately implement the design for a robot system that can be used for a real-world project.

To provide insight into the design, this year the students embraced simulation into the overall project profile including the initial design efforts. The simulations were to provide the students a better understanding of the new design while gaining insight into the prior year's design while also being able to articulate the design activities to Vocational High School[1]. This activity proved to become pivotal to the project's success due to the eventual unfortunate events caused by COVID-19. Despite the shut-down of in-person contact, the team was able to continue its development and implement a simulated design validating their efforts.

Project Elements

The intent of the project was to continue the design of a robotic system from the prior year by implementing a second robot system. The new robot would also provide some improvement from the initial design. The robot from last year was tasked to apply a sealing lacquer coat to the wreaths that move along a hook-line. The overall project was decomposed into four fundamental tasks. Each of these tasks included an assessment of the previous year's efforts as a baseline from which to begin. The assessment included analyzing the mechanical design for the mechanism and structure of the robot arm, a fluids team responsible for controlling the application of the green colorant onto the wreath, a controls team that implements the controls algorithms, and a computer vision team that used computer vision techniques to track the wreaths as they move along the assembly line. This year the team also decided to include an additional feature to fluid flow rate control for the paint as well as adding the capability for the previous design. Throughout the project, each sub-team was required to work in unison with the other sub-teams.

The initial work of the team progressed well through the fall semester including a basic simulation to support the physical designs. However, as the critical phase of build approached, on March 13th, 2020 COVID-19 forced a shutdown of the school preventing students from meeting in person or with their customer. Despite the shutdown, the team was able to complete the design by relying solely upon the simulations. At the end of the semester, they were able to demonstrate the overall design using simulation within each respective area as well as demonstrating the design improvements between the previous year and current year. The simulation tools used included ANSYS[7], MathWorks Simulink[8] and SimScape[9], and Coppelia-Sim[10], and simulated image processing. ANSYS provided a significant insight into the mechanical design simulating various loads and stresses, Simulink and SimScape from MathWorks provided insight into the fluid system design and overall controls design. Coppelia-Sim is a full featured robotics simulation package that provided simulation for the motion of the robot joints, frictional characteristics, kinematic simulation as well as fluid-based robot end-effectors. The team also made use of simulated data they constructed to represent actual images that would be develop and validate computer vision component.

Mechanical Structure Design

To design the new robot, the students started with the prior year's mechanical design as a baseline as shown in Figure 2. The general approach is a gantry-based design that performs translation motion via prismatic based joints along the X-Axis and Y-Axis, and rotary motion for the end effector. The mechanical team also created a support framework for the entire system. The team selected T-slotted aluminum extrusions due its strength and rigidity yet also being lightweight and easily adapted to various designs. Using the aluminum extrusion frames also allowed the system to be easily reinforced with brackets and braces at the installation location.

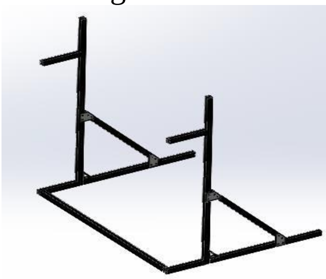


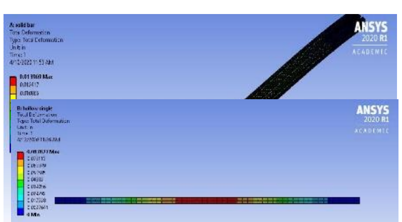
Figure 2 Baseline Frame Structure

The gantry approach was selected instead of a more familiar 5 or 6 degree-of-freedom based design due to the simplicity of the kinematics. This provides a straightforward method to describe the motions of the robot that are necessary to apply the colorant to the wreaths. To do this, inverse kinematics of a gantry can be easily solved due to the axis independence[6]. The specific implementation of the design includes three industrial stepper motors which are used to achieve the desired motions along the X-Axis, the Y-Axis and to rotate the end-effector spray mechanism assembly. Each motor has an encoder attached to it to provide the controls team the ability to accurately control the motor's position and velocities.

Figure 3 Improved Frame Structure

Each motor uses its own electronic driver and feedback control system to correct for any inaccuracies while maintaining the necessary movements to apply the green colorant. The motion along the X-Axis horizontal I-Beam is achieved by a trolly that also provides support for the end effector. The trolley is further supported by bearings along the I-Beam to ensure smooth travel. The Y-Axis motion is achieved using two motors that are coupled to two pulleys on each end that act as counterweights. Finally, using the counterweights further reduces the loads placed upon the motors and linear slides.

Upon initial evaluation of the baseline design, the team noticed there was a small amount of flexing and instability that occurred while the baseline lacquer robot was in operation. It was observed that an updated design was required to remove these deficiencies as shown in Figures 3 and 5. After analysis from the simulation, the team added an additional cross piece at the top while also adding additional bracing on the lower section. In addition, it was determined to revisit the trolley design and improve the design to reduce frictional losses that were evident as the trolley traveled along the I-Beam.



Figures 4a and 4b Top Beam Crossbar Analysis

To fully understand and rectify the issues, the team modeled and simulated the design using the software tool ANSYS. The team also analyzed with simulation to determine if the X-axis rail should be a solid frame or hollow frame. After the analysis, it was determined that the maximum amount of deformation of the hollow T-slotted framing was negligible when the maximum expected weight was applied. The values used in ANSYS was a

100 lb. load with 2 supports on each end of the 6ft beam. The maximum deformation for the hollow beam was 0.088 in and 0.014 in for the solid beam as shown in Figures 4a and 4b.

When developing the new trolley design, a Teflon with sliding block approach was used. This was chosen after simulation and analysis of frictional losses were evaluated. Having a low frictional coefficient, it can handle a compressive force exceeding an expected load of 120 lbs while ensuring smooth travel.

Figure 5a and 5b Completed Mechanical Assembly

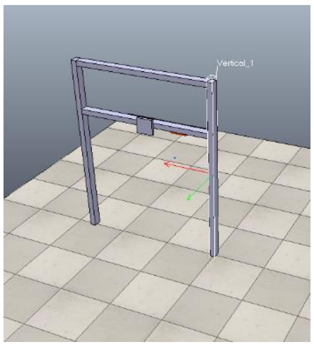


Figure 6 Frame Simulation with Trolly using Coppelia-Sim

The trolley and rack assembly were then constructed and simulated using Coppelia-Sim as shown in Figure 6 which provides a fully featured simulation environment that allows designers to simulate and observe the various movements, and forces[10]. A simplified structure that retained the resulting stiffness was modeled as well as the various candidate trolley designs. As the trolley moved left and right, the forces were measured providing confirmation that the Teflon approach was the best candidate.

The Fluid System Design

The fluid team also made use of the work from the team from the prior year, however they made extensive use of simulation and modeling by means of Matlab's SimScape[9] as well as Coppelia-Sim[10]. This also allowed the students the ability to ensure proper fluid flow by controlling the rate of colorant using a flow sensor and controllable pump. The objective to this fluid systems team was to develop the delivery system for the green colorant applied to the wreath. This includes both accurately and efficiently spraying the colorant onto the wreaths in a consistent manner while also taking to account the movement along the X-Axis while the arm is rotating.

The end effector uses a high-volume low pressure (HVLP) nozzle that operates at 30 psi. The end-effector is designed to have three arms that hold the three nozzles that can rotate at 120 degrees while spraying. This project was designed to use the previous year's nozzles, however they the solenoids to larger ones to accommodate the pressures better. The design uses a three-arm approach to provide consistent coating to the wreath. Shown in Figure 7 is the model of the nozzle assembly.

To limit the amount of overspray and emissions of the paint during operation, the HVLP end effector operates between 40-70 psi. At pressures above 70 psi, atomization of the liquid creates significant amounts of overspray, however at pressures below 40 psi, there is not enough pressure to ensure correct atomization of the lacquer for consistent coverage[12]. The final nozzle design integrates multiple nozzles at various angles to ensure that the wreath receives adequate coverage. To ensure the pressure is maintained, the team added the flow-rate controls to the task of the controls team.

Due to variability in wreath sizes, the overall design of the end effector includes three extensions (arms) each with three nozzles for a total of nine nozzles for the end-effector. Since the wreaths are circular in shape, the end effector rotates 120^{o} for a complete application. This method was selected versus using a single three-nozzle assembly to allow for quicker application of the lacquer as the wreath moves along the assembly line. In addition, this approach also alleviates the amount of stress on the tubing for the colorant that would occur if there was a 360^{o} rotation.

Figures 7a and 7b Front End Effector Sprayer Assembly. Left Front View, (Right) Rear View

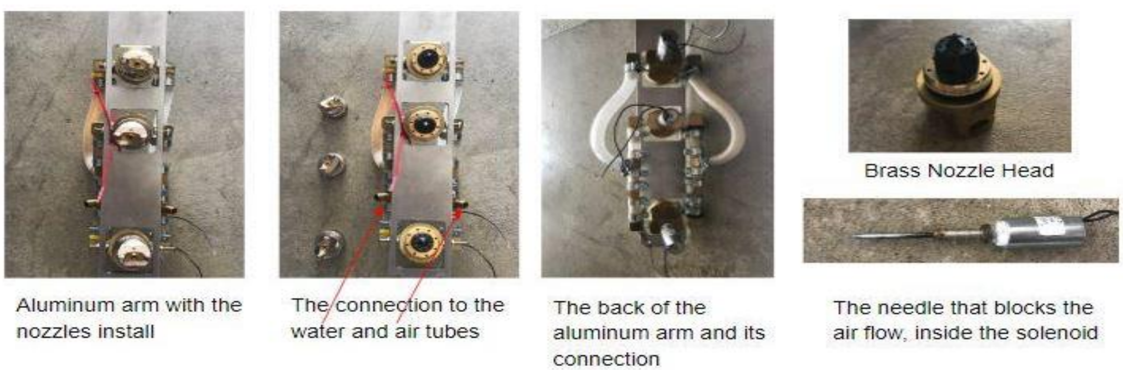


Figure 8 Nozzles and End Effector

This year, the fluids team developed a very thorough fluid simulation to provide sufficient analysis for the paint coverage and allow simulation of a flow rate control[11]. The team used MathWork's SimScape[9] and Simulink[8] to model the nozzle parameters and to support the control loop, while integrating the spray patterns and rotation of the end effector using Coppelia-Sim[10].

To model the fluid system in the robot, there are many important variables and materials the students had to consider. These variables include the tank volume for storing the fluid, the pipe and fitting effects on the fluid flow, the pump specifications and operation, the nozzle assemblies, and the pressure of the fluid through the system. It was important to ensure that the piping system does not impede the flow before the fluid leaves the spray nozzles and that the pump is powerful enough to deliver the fluid at a workable flow rate thereby ensuring the fluid is sprayed evenly. Using a pump that could be controlled, the team needed to ensure the pump is set to an optimal flow rate and pressure that allow the nozzles to receive the correct amount of fluid. The team selected the fluid flow-rate sensor and take level sensor both of which were included into the simulations.

To simulate the design, a model was created that matches the physical system using MathWorks Simulink and Simscape. Shown in Figure 9 is the simulation diagram. Each block on this diagram is adjustable. Within in the simulation, the various nozzle parameters and fluid settings were implemented to be isothermal. The pressure of the liquid is also assumed atmospheric pressure in the tank and after the nozzles. In the simulation of the paint nozzles, various parameters that map to the physical design can be set as shown in Figure 10. The modeling of the overall fluid design was later incorporated into the model of the system to develop the control behaviors to control the flow rate for the colorant.

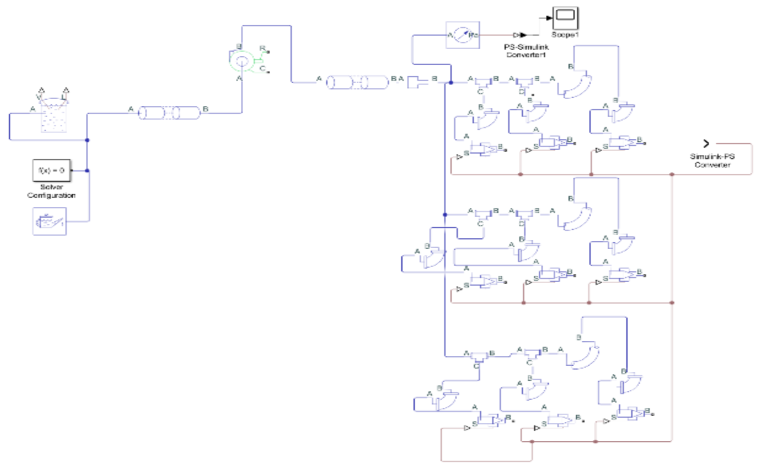


Figure 9 MathWorks SimScape Nozzle Simulation

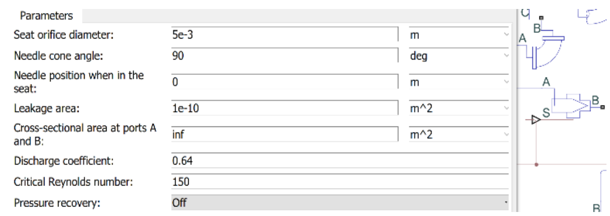
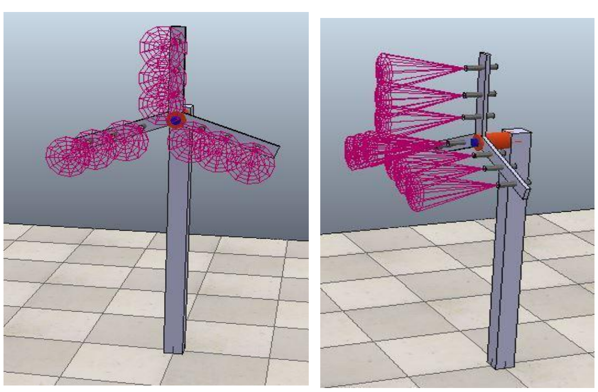


Figure 10 SimScape Nozzle Parameter Sheet



Figures 11a and 11b Coppelia-Sim Nozzle Simulation

In addition to the use of Simulink and SimScape, the team also made use of the robot simulation environment Coppelia-Sim. By coupling model of the end effector behavior flow rates to the overall arm design, the students were able to ensure there was sufficient coverage for the rotation amount and rate. The team was able to simulate and validate the design of the end effector and while testing the kinematics ensuring consistent coverage. The team was able simulate the joint rotation velocity, acceleration and jerk motions while ensuring rotation rate was fully controlled. Shown in Figure 11 is the model capturing the end effector assembly with the nozzles.

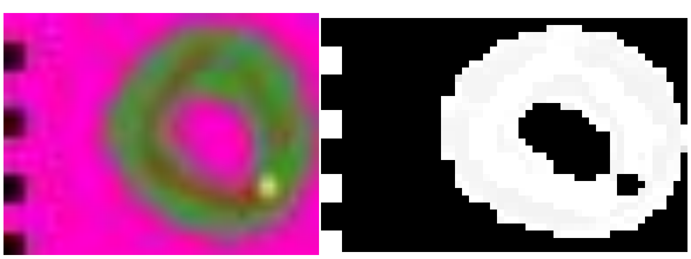
Computer Vision

The control of the robot was decomposed into two primary sensor groups. One group of students focused on capturing data using computer vision, while a second group relied upon feedback from the motors to control the various aspects of the robot.

The goal of the computer vision team was to (1) detect each wreath passing by the spray location on the assembly line, (2) alert the robot to when the wreath would arrive at the work area, (3) notify the robot when to initiate painting, and (4) verify that the colorant was sufficiently applied. The objective for the computer vision was to track the wreath and determine the velocity of the wreath as it passes in front of the end effector. The computer vision team selected the use of the OpenCV computer vision library to implement most of the computer vision fuctions[13]. Initially, the design of the computer vision algorithm detected the wreath's shape features and color as it enters the field of view of the camera, however this approach was not always reliable due to the variations in the foliage and color.

To overcome the inconsistent detections, the team developed a set of algorithms that detected absence of a constant background. The concept starts by using background with a very distinguishable color that is the opposite of green wreath on the color wheel. This color is magenta. This was simulated by constructing test image movie sequences of a wreath as it would move. By using the video sequences, the team was able to inject noise from the camera as well as variability into various wreaths that would be present on the physical assembly line. This allowed them to extend algorithms from the previous year as well as extend for new detection approaches.

The original software was required to identify the different shades of green and set them to be true if it a pixel of color is green or set to false if a color is not green. Initially the team used RGB (Red-Green-Blue) values for green, however, they realized that other colors including white, gray, or yellow also include a component of a green value. Therefore, the team modified the design and decided to use the OpenCV computer vision library to apply a mask to the images to look at HSV (Hue-Saturation-Value) values, specifically the hue and saturation of green and the range of all the shades of green that would most likely be seen throughout the process of painting the wreaths on the assembly line[8]. The team created a simulation of the wreaths with the magenta background and validated this approach was enough to detect the wreaths as they moved through the field of view.



Figures 12a and 12b (Left) Wreath with Magenta Background. (Right) Mask Applied to Image

To detect when a wreath entered the camera's field of view, the team utilized the mask to find the edge of the wreath. The software then compared the image of the wreath passing in front of the magenta background as shown in Figures 12a and 12b. The mask would be applied, and the vision algorithm was able to discriminate the wreath from the background[13]. To detect when a wreath was in the frame of the camera, the software used the magenta background with the mask, and the image columns were processed. To perform wreath detection, the team implemented an edge detection algorithm and waited until a solid column of magenta pixel values, followed by a column of pixels that were not completely magenta pixel values were detected. As earlier stated, since the magenta and green are drastically different color values, the software would detect the succeeding column to be the edge of the wreath. It should also be noted that although the wreath has a hole in the middle, this method still successfully detected the wreathy since there were still non-magenta pixel values processed.

By simulating the various possible conditions, the team was able to develop a new algorithm for finding pixel to distance and marker detection. These new algorithms can compute the distances between the wreath to the camera to allocate the quantity of colorant optimally.

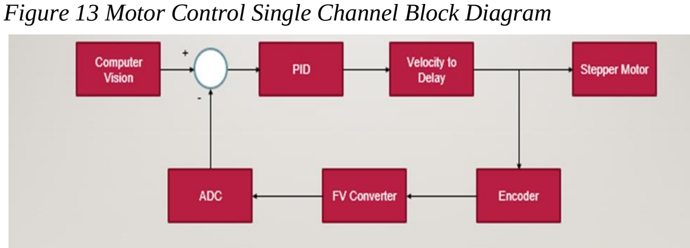
Once successful detection and image processing of a wreath was achieved, the software had to determine the position and velocity for each wreath. The change in position was found by the difference of position in every frame. The camera capture and image processing were performed at 20 frames per second allowing the difference in position to simply be the difference in position per frame rate. The image processing code processing rate was able to execute within the 20 frames per second to ensure successful wreath tracking.

Controls System Design

This year the controls team developed algorithms to implement motor control, fluid flow, wreath tracking and a user interface. The motor control was achieve using encoder feedback while using a flow rate sensor the system was able to control flow of green colorant as well as if the nozzle became clogged. Lastly, the team installed a programable logic controller (PLC) with Human Machine Interface (HMI) into the system, to provide user has a better understanding of the system while operating. Each of these elements was fully simulated using MathWorks to simulate the motions of the motors and flow control of the fluid. To perform controls processing of the robot system, the controls team selected the Jetson TX2 embedded processing board from Nvidia. The computer vision software was also implemented with this hardware as well. The key software packages were the Nvidia Nsight Eclipse Edition IDE on OpenCV for the image-processing libraries[14].

The overall control block diagram for the motor control is shown in Figure 13. The team decided to include an improved motor motion controller than the previous years. This year, they decided that the need for a motion profile to accommodate a heavy load moving quickly would help the customer achieve better painting. To achieve this, the students developed the S-Motion profile shown in Figure 14.

Figure 13 Motor Control Single Channel Block Diagram



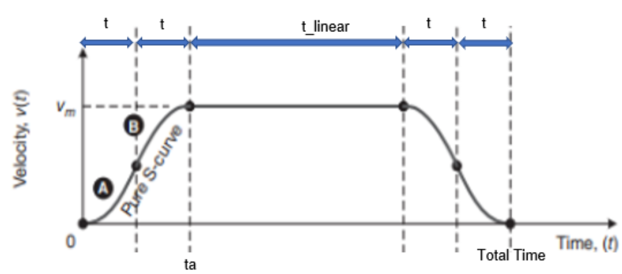


Figure 14 S-Curve Motor Motion Profile

Program Management and Multidisciplinary Environment

The overall team was composed of four sub-teams. Overall, the entire team was managed by the project manager though there was support from an assistant project manager to help keep the teams in coordination as shown in Figure 15. The project manager was responsible for ensuring the project, that the sub tasks were kept on schedule while providing a direct interface to both the customer and supervising faculty advisor. The program manager delegated the responsibility of parts procurement to the procurement lead. The procurement lead was responsible to work directly with Boys Republic staff and the individual teams to order parts or purchase work ordersthat were machined. In addition, a detailed bill of materials (BOM) was maintained by the procurement lead per the drawings in CAD to fully document the design and parts selection. Furthermore, the students that performed the roles of program management and procurementwere also equally responsible for their own tasks within the technical element of the designs within their specific sub-teams.

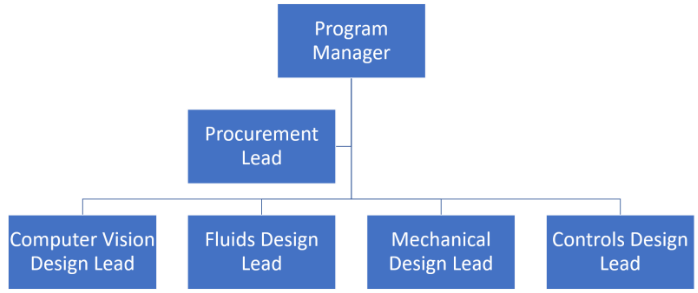


Figure 15 Team Structure

Throughout the work of the project, sub-teams would meet two to three times a week for one to two hours each meeting. During this time, each sub-team would discuss the progress for the week and assign the duties to individuals. In addition to the program management and procurement roles, each sub-teamhad a sub-team lead. Each week team members of each sub team would provide updates using status reports. Each sub team then provided the status to the project manager who would then provide them to the faculty advisor prior to the overall team's weekly meeting with the faculty advisor for the project.

Prior to COVID-19, the team would update one another communicating the various needs from each other. For example, the mechanical team would provide the controls team with various design data. Once COVID-19 occurred, the team's shifted their updates to also include how the various simulations need to interconnect with one another. For example, the fluids team would provide various models of the fluid system to the controls team to allow them to further simulate the controller design. They also shifted their method of team meetings. The meetings followed a virtual format that would is commonly used within industry today.

The structure of the teams was based on a team structure they will encounter after graduation in industry. This also allows various students the opportunity to understand both technical design as well as learn leadership roles within an engineering project. This enabled students to understand how to work together in both small and large teams and how to understand each other team's requirements. Two of the teams, fluids and machine design were predominantly mechanical engineering focused, while the other two teams, computer vision and controls were predominately electrical and software engineering focused. This multidisciplinary structure of integrated product teams provided the students the opportunity to learn how to interact with one another as they will eventually in industry.

The composition of the four teams consisted of three team members. Of the overall team structure there were three female engineering students and nine male engineering students. Moreover, both the project manager and procurement responsibilities were performed by female engineering students.

Assessment of Learning Outcomes

This project has been found to be very effective in providing opportunities for the students to understand the engineering environment they will likely confront when working in the real-world. When COVID-19 started, the students were required to quickly adapt their approach to incorporate significant amounts of simulation efforts into the design process. The project provided the engineering students the ability to design and simulate a multi-disciplinary robotic system with a real customer with a real need and real requirements. The project has also taught them how to manage and balance the technical design with a schedule and allocated costs through the provided funding from Boys Republic.

Throughout the project, the students interacted with the staff and resources with Boys Republic as well as one another. In doing this, they were able to develop and understand the critical nature of both oral and written communication skills. This was sometimes evident during the overall weekly team meetings when clarifications between teams were done. In addition, the teams were required to present their work to the customer. Throughout the work, the design was documented electronically and delivered to the customer, Boys Republic, which allow them customer the ability to ensure they would be able to maintain the design in the future.

The project provided the students the opportunity to learn design of complex robotic systems in real world environments. While capstone senior projects emphasize the hands-on design experience, most senior capstone projects do not always make full use simulation as a tool during development. In contrast, as COVID-19 occurred, the students were forced to learn and develop a greater amount of simulation to understand and develop these complex designs. This allowed them to also expand learning further about understanding and communicating with their customer though the use of various simulations throughout the project.

The project also provided students the opportunity to apply simulation tools in various applications to validate their design. When the students began the project, they worked with the customer to define and develop the system's requirements. With the simulation tools, they were ablet to receive feedback from their customer and the faculty advisor throughout the project. The allowed them to further adapt their design to the customer's requirements.

The criteria for success of the project were defined by meeting the operational requirements from the customer within cost and schedule. Despite not being able to deliver a physical system due to COVID-19, the students were able to demonstrate they met the operational requirements using the simulation tools within the allocated time frame and submitted budget.

Conclusion

In conclusion, the Project Ponderosa, through a relationship between Boys Republic and Cal Poly Pomona Engineering Department of Electromechanical Engineering Technology has provided Cal Poly Pomona engineering students the opportunity to realize a robotic automation design using simulation using real-world processes and methods. These experiences will prepare the students for their future in the engineering industry. The results of the engineering efforts further provide the boys at Boys Republic the opportunity to further develop vocational skills and become contributing members to society. The engineering students have gained valuable technical skills in engineering disciplines of mechanical, electrical, and software engineering design in part using simulation. Beyond the technical skills, the Cal Poly Pomona students have also been able to develop better oral and written communication and leadership skills while working within a multidisciplinary environment. Finally, the project has given the students the opportunity to learn how to develop new skills not necessarily taught in the classroom. These skills are essential for engineers to develop as life- long learners as technology continues to evolve.

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