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Garwin Family Foundation Summer Program 2021

Final Reflection on the 2021 MIT Beaver Works Summer Institute

This summer, I had the opportunity to attend the MIT Beaver Works Summer Institute (BWSI) with the support of the Garwin Family Foundation. BWSI is a four-week engineering summer program jointly hosted by MIT and Lincoln Labs. In 2021, BWSI had 13 different virtual courses with a total of 330 students, as well as two satellite sites in Huntsville Alabama and Kwajalein Atoll. I was in the virtual Autonomous Air Vehicle Racing course. Our course was made up of 2 lead instructors, 4 TAs, and 22 students from all over the US. On weekdays, we had zoom classes from 9 AM to 4 PM and office hours from 4 PM to 5 PM. We also used discord to ask questions and socialize inside and outside of class time.

In the first week of class, we covered a lot of fundamental material. We reviewed git, Linux, and python debugging. We also learned about drone hardware, autonomous drone architecture, and the Robotic Operating System (ROS). We spent a lot of time getting hands-on practice with Linux and ROS in a simulation environment. By the end of the week, we were able to manually drive the drone around the simulation. However, the simulation environment was generally very unstable, so our instructors announced that they would possibly change the course structure. We later found out that BWSI was going to send us real mini drones to work with which was very exciting!

In the second week of class, we had two main focuses: rotation/kinematics of the drone and computer vision. For rotation and kinematics of the drone, we had to use a lot of math, some of which I haven't learned before. We learned how to express orientation angles in different formats and transform them to different reference frames. As a class, we also derived a few formulas governing quadcopter motion. These theoretical exercises were interesting, but also made me appreciate software packages. If we didn't have software packages, we would have to do all these calculations every time we wanted a drone to do something! For the second part of the week, we talked about computer vision, which is how computers process and extract information from images. We covered a ton of material in lecture and used what we learned to complete practical coding problems. In this short time, we covered topics like thresholding, image morphology, regression, edge detection, and color segmentation. On Friday, we used our newfound computer vision skills to write a program that could detect and trace a LED strip, even if the strip was partially obscured. Before coming to BWSI, I only had a very high-level knowledge of these concepts, but now I feel that I have a better understanding of them.

In the third week of BWSI, we learned about robotic controls, state estimation, and path planning algorithms. For me, the most important thing I learned from the third week was Proportional Integral Derivative (PID) controllers, which are used extremely commonly in robotics. We also learned how to program our drones in this week. We started by just having the

drone move and then added computer vision capabilities using the drone's front camera. We used PID controllers to control our drones to follow and fly up to Aruco markers. This was great preparation for the final challenge.

By tradition, the last week of BWSI is always taken up by a final challenge that utilizes everything we learned in the past three weeks. Our class's final challenge was really open-ended: we were supposed to come up with any project that utilizes the previous weeks' material and work in teams to make our idea happen. I wanted to program the drone to fly through some sort of obstacle course autonomously. Several of my classmates had similar ideas, and we formed a team of three. We decided to use pool noodles and tape (lots and lots of tape) to make and position hoops for the drone to fly through. Our goal was for the drone to be able to fly through any obstacle configuration autonomously.

We worked on this project from Monday to Saturday: all day, every day. We started by developing computer vision code that allowed the drone to find the hoops in a messy environment. Then, I worked on pose estimation, while my teammates wrote a control framework for navigating the hoops. We combined our programs for the drone to be able to know exactly where the hoop is at all times and react accordingly. Our code ended up using just about everything we learned in the past weeks: computer vision, Euler angles, PID controls, and a finite state machine. We spent a lot of time experimenting with and tuning the PID. This resulted in a LOT of crashes, so we ended up naming our team "The Missing Propellors". At the end of the week, the drone was able to navigate any hoop configuration so long as the hoop colors were in order. The developed system was robust enough to recover from small crashes and search for hoops that were out of camera frame.

On Sunday - the last day of the program, BWSI hosted a big final event with presentations from all the teams in all the classes. It was incredible to see all the different things other people were working on. We also presented our project on this day. At the end of the final event, we found out that our project had won the grand prize out of the seven teams in our class! This was a really exciting way to cap off the program.

Outside of our classes, BWSI also hosted an hour-long, camp-wide seminar during lunchtime on Mondays through Thursdays every week. There were talks by MIT professors, researchers, and even a few directors from large companies and the military. My favorite talk was from an MIT professor who talked about his work in building biomimetic robots. I already had an interest in biomimetics, and his presentation only convinced me further that it is something I might want to pursue in the future.

I also attended two special evening events put on by the BWSI staff. One was a Diversity, Equity, and Inclusion panel featuring MIT students. I learned a lot about what it's like to be a student at MIT. Additionally, I also went to a Women's Networking Dinner where we got to hear from several women with successful careers in STEM. It was very inspiring to hear their stories about career and family.

Aside from learning technical things, our class also got to know each other through discord. It was fun to joke around together about the different things we were learning, and we also helped each other with the coding problems. When we got to start flying the drones, everybody posted pictures of their epic crashes which was really funny!

BWSI has been an amazing experience. I have learned so much technical content and created a pretty awesome final project. It has definitely encouraged me to keep pursuing engineering. Perhaps even more importantly, I have learned lessons that have wider applications. This was the first time I truly appreciated the power of a well-communicating team: we could never have done the whole final project by ourselves individually. Also, I learned how to deal with a more demanding course load. BWSI was like (as described by our instructors) drinking from a firehose, and there was no way you could have finished every single challenge problem. I learned to balance when to cram and when to just let it go (there was definitely cramming for the final project).

I'm so grateful for our instructors who were constantly ready to answer questions, help fix code, and offer advice. They were always there to lighten the mood, bring us back on track, or patiently explain rotation matrices for the fifth time. And finally, a huge thank you to the Garwin Family Foundation for letting me have such a wonderful (dare I say, *transformational*?) experience!