

Coding and Application of Cameras on a Spherical Robot & Musculoskeletal Effects of Vacuums and Hammers on the Human Arm: Experiences of a Secondary Student in Engineering Research

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Abstract

This paper discusses the results and experiences of two high school students in the NSF-funded Research Experience for Teachers (RET) Summer Scholars Program at Central Michigan University. The students participated in two veins of research through the twelve weeks of the program. Initially, the students were tasked with helping a professor interconnect computers and cameras to capture video on an omnidirectional spherical robot. Then, during the six-week RET program, the students were assigned with RET teachers to test the musculoskeletal effects of hammering on the human body, and the effects of one other everyday task of the group's choice. From learning Python to vacuuming, the students have learned a vast amount of information during this time. This program not only can have impacts on commercial or robotic fields in the future, but also greatly increase a student's interest and ability in engineering. The RET Summer Scholars Program gives an incredible advantage to students willing to pursue a career in engineering, and can benefit many more by giving them knowledge of engineering procedures and processes.

Introduction

What is the Research Experience for Teachers Summer Scholars Program? Funded by the National Science Foundation, this 12-week program paired local middle and high school students with teachers from the Central Michigan University (CMU) Research Experience for Teachers (RET) program, and CMU faculty mentors to teach them about STEM fields, by immersing them in Engineering research.

This paper discusses the results and experiences of two high school students in the program. During the twelve weeks, the students participated in two veins of research: video capture using spherical robots, and biomechanics of household vacuuming. The students' weekly schedule is shown in Figure 1. The students would work 20 hours a week to help finish a project with their professors, write an essay for submission, and attend a conference to share their project and experience in the program.

A spherical robot has incredible potential, provided it functions properly: security, rescue, and surveillance to name a few. Many modern spherical robots use internal pendulums to alter a sphere's center of mass, and make it move forward. However, this leaves the robot at a disadvantage, as it can only move in one direction before taking the time to turn. A solution to

this problem is by using multiple pendulums, creating an omnidirectional robot capable of higher mobility and reliability. While these are major improvements to the basic single-pendulum robot, it is very difficult to attach cameras to it and take smooth, continuous video. Multiple cameras that communicate with a central computer that is capable of taking specific sections of video and communicating those sections to an operator’s computer could easily eliminate this problem in design.

While physics is used to push a robot, it is also used to push a vacuum, or swing a hammer. A repetitive action such as hammering or vacuuming can have long-term effects on the human arm. We do not know how much pressure is exerted on the joints and muscles of a human arm when performing these tasks, or how to perform these tasks safely, with less risk of musculoskeletal disorders. By using motion capture technology, it is possible to map out specific points on an arm, and measure the pressure caused by these common household tasks to avoid risks.

| Week | Goal |
|------|--|
| 1 | Become introduced with faculty and long-term program goals, read papers on spherical robots |
| 2 | Meet RET teachers, long-term goals, learn about Vicon, take CITI test and sign in with IRB, go to motion capture lab |
| 3 | Set up and test PiCameras, finalize IRB registration, brainstorm hypothesis, find resources on hypothesis |
| 4 | Use Vicon to process hammering data, find ways to test hypothesis, enable Wifi on Pi Zero |
| 5 | Convert Vicon data into TRC files, begin using Opensim, use video port to use cameras, use motion capture lab to start vacuuming tests |
| 6 | Continue using Vicon for hammering and vacuuming data, find websites and programs to develop understanding of python, |
| 7 | Convert Vacuum Vicon data to TRC, convert to Excel, create graphs for different points for different trials |
| 8 | Put Vacuum TRC files into Opensim, analyze data, continue converting Vicon to Excel to graphs |
| 9 | Compare Opensim final results (Locked vs. Unlocked), organize data into graphs, |
| 10 | Revert back to Pi operations, find code needed to transfer data and images from Pi zero to Pi |
| 11 | Code the Pis, transfer data and images from Pi to Pi via USB |
| 12 | Finalize code, clear up robotics lab |

Fig. 1 RET Summer Scholar’s weekly schedule

Experience

The following paragraphs outline the experience from the students’ perspective, in chronological order. The paragraphs follow the weekly schedule previously mentioned (Fig. 1).

During the RET Summer Scholars program, students were to work with multiple local teachers and professors to accomplish a goal set by the RET faculty. Two students were assigned with RET teachers to test the musculoskeletal effects of hammering on the human body, and the effects of one other everyday task of the group’s choice. However, this was only for the first six weeks of the program. The students were also tasked with helping a professor interconnect computers and cameras to capture video on a omnidirectional spherical robot. This was done in their free time and after the first six weeks in the program. The Summer Scholars students have learned many useful skills to further their engineering dreams and careers, including the processes and procedures needed to set and accomplish goals, work with programming and computers, and engage with others to get tasks done faster and more efficient. During the first week of the program, the students learned what the goals of the faculty were, and their CMU

professor they would be working with sent them research papers and posters to read in order to gain an understanding of the project. The papers included articles about spherical robot variations and how they move.

After the first week of studying and setting up the research labs, the students were introduced to the RET teachers who they would be working with to study how hammers affect the muscles and joints of the human arm. After discussing the long-term goals of the study, all of the RET participants (teachers and summer scholars) were required to take a Collaborative Institutional Training Initiative (CITI) test¹ and get permissions from their local Institutional Review Board² (IRB) in order to participate, learn, or view any human testing needed for research. In order to learn how to capture and analyze data for the study, the participants visited the CMU motion capture lab. The lab is equipped with motion capture cameras used to track small reflective markers. The students used these markers to map out points on the arm and torso and record the coordinates for research. Using a special mapping software called Vicon³, the participants learned how to assign those coordinates to the arm, and analyze each point's movement.

With the basics of the project laid out for them, the participants were given the opportunity to brainstorm their own research subject. By using motion capture technology and Vicon, they had to find an everyday task and study the resulting musculoskeletal effects on a human arm that task creates. The participants decided on everyday vacuuming: how different kinds of vacuums affect a person, and which kind is better. The participants spent the rest of the week finding ways to test their hypothesis, and building ideas off research papers they found. After researching, they decided to test two different kinds of vacuums: a flexible and maneuverable vacuum with a ball at the base, and a regular locking vacuum cleaner that does not have ball, or the same left-right roll maneuverability. They found one of the more popular vacuums on the market, the Dyson DC40 Total Clean (Fig. 2).



Fig. 2 The vacuum used for research

Since this vacuum was ball-based, the participants had the option to either buy a locked vacuum, or find a way to make the Dyson unable to turn at the base. That decision aside, the participants also had to finalize their IRB registration in order to conduct human testing. While waiting for their IRB approval, the students began to work on the spherical robot, and were occupied with the setup and usage of their new PiCameras⁴. These cameras were specifically designed to be small and accurate enough to work with Raspberry Pi's⁵ and Pi Zeroes: credit card-sized computers that were used by the students to code the cameras, and enable them to communicate

properly with each other. After much coding trial and error, the students were able to take and save pictures using the new cameras.

The next week, after debate and research, the participants decided to look into ways to lock their vacuum. Some of their best options were to tape the head of the vacuum in place, or rapid prototype (also known as 3D printing) small pieces to fit into the head, rendering it impossible to turn from side to side. The participants decided to use both methods, locking the vacuum in place, and using tape to ensure the pieces do not move during testing. Another challenge the group faced was the physics. How were they going to get accurate data if they did not know the specifics of the vacuum? Major obstacles were the center of mass, weight, and dimensions of the vacuum. These specifics could be turned into data compatible with Opensim software, a program that can accurately calculate forces imposed by motion. By using Opensim, the group could get accurate results of how the vacuum affects the arm. Finding weight, mass, and dimensions were fairly easy, but the center of mass proved to be challenging. The group solved that problem by hanging the separate parts of the vacuum from different areas on a string (Fig. 3). The center of mass would pass through the point of the vacuum directly below the string. By hanging the vacuum from different areas, they could line up the points they knew it could be, in order to find out where the center of mass was.



Fig. 3 Hanging vacuum to determine center of mass

While the group had accurate dimensions of the vacuum, they did not have finalized IRB-approved test protocol or test subjects. The participants then changed their focus back to hammering, and continued to map and analyze the data from earlier tests for the rest of the week. The students could now begin working on the robot's Pi Zeroes again, and with help from their faculty member, set up the Wi-Fi connection needed to communicate from Pi to Pi Zero. With this completed, the Pi Zero would have the capability of sending images it had captured directly to the Pi.

The next week, the students began working on the Pi Zeroes first. They discovered that the cameras were incapable of taking high definition photos and saving them quickly. Their professor solved this problem by coding the camera to take a picture and send it via stream instead of saving. This cut down the send time significantly. Despite this, the camera still did not take the photos fast enough. By coding the camera to use its video capture port instead of the photo capture port, the camera could take high definition photos quickly, and stream them. The students now had functioning cameras. With the cameras completed, the participants shifted over to the hammering project, and began to convert their previous Vicon data into TRC files. These files turned the data into long streams of coordinates, which could be read and displayed easily with Microsoft Excel. By saving the data in Excel format, the participants could import it into Opensim, enabling them to calculate the forces exerted by the hammer onto the arm (Fig. 4).

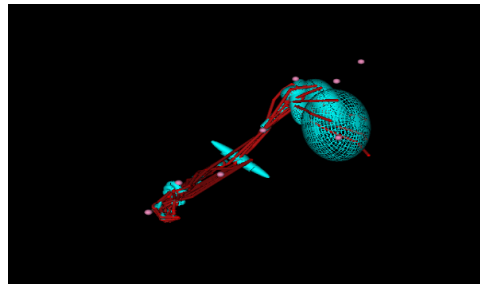


Fig. 4 A human arm displayed in Opensim software

With most of the hammering data converted and analyzed, the participants began to brainstorm their vacuum testing protocol. This protocol would have to include enough trials to accurately get enough information for analyzing, and be IRB approved. By using guides to mimic walls and tables, the tests would include vacuuming shredded paper inside and around a rectangle, both left and right, with the vacuum locked and unlocked. The participants constructed guides with wood to mimic walls, and PVC pipe to act as a table. The test subject would vacuum small shredded pieces of white paper in an area under and around the pipe while restricted by the walls (Fig.5). The walls forced the subject to rotate their wrists, an action needed to get accurate data. After all of the protocol was completed, the participants had gained their IRB approval to begin human testing.

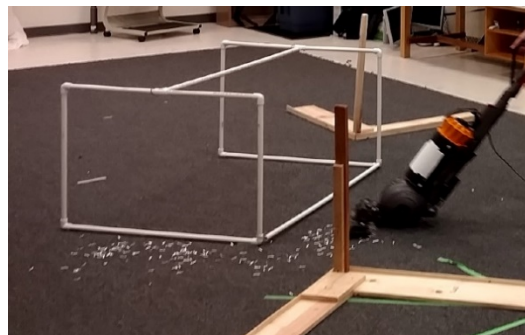


Fig. 5 Pipe and wood guides to act as barriers for test subject

Now that the protocol and guides were complete and approved, the group could begin testing. The group placed special reflective markers onto different parts of the vacuum, their arms, and their torsos. After setting up the guides and shredded paper, each member of the group performed the tests twice, with both the vacuum locked and unlocked. With the new Vicon data,

the participants could begin converting and analyzing their tests in order to reach the final answer to their hypothesis.

While most of the participants spent the rest of the week analyzing and converting the vacuum data, the students were instructed to educate themselves on basic Python⁶, the coding language used to set up and operate the PiCameras. The students settled on one website, called Code School⁷. This site offered many programs for coding, and had three courses of basic Python available for free. The students spent half the week studying and practicing their new coding knowledge, even creating a game of “Rock, Paper, Scissors” on one of the Pi Zeroes. With a basic understanding of Python, the students would be able to follow along with their professor or even help in the process of coding the PiCameras. The students reverted to analyzing data once their courses were completed.

The RET participants continued to process the vacuuming data into Vicon until there was no more data to process. The next step was for them to analyze this data with Opensim, and create easily readable graphs of the data to understand it better. After converting the files into TRC format, the participants used Microsoft Excel to create multiple graphs of the arm for each test. They created two graphs to visualize how different parts of the arm moved, one for the unlocked vacuum, and one for the locked. For example, they created graph for the elevated moment of the shoulder on the unlocked vacuum trial (Fig. 6).

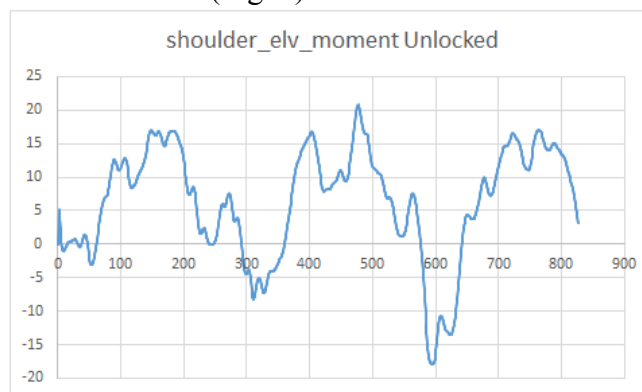


Fig. 6 A graph made to visualize specific shoulder movement.

With all of the vacuum data graphed and in TRC format, the group began processing the files into Opensim. Using Opensim, the group could run the data through two different programs: kinematics and reverse dynamics. With the output from these programs, the group could determine both the exact movement of the arm and the forces the vacuum exerted onto the various joints and muscles. This data was necessary to determine their hypothesis.

The following week, the participants finished running the data through kinematics and reverse dynamics. The group then took this data, and created charts that compared the locked and unlocked results (Fig. 7).

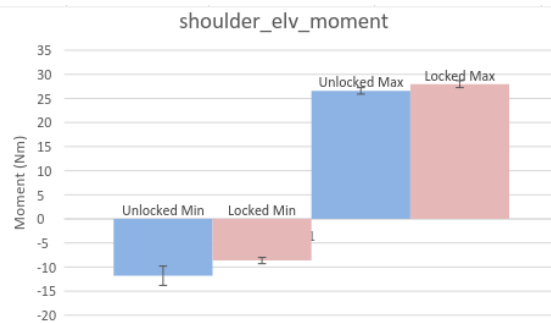


Fig. 7 Final comparison graph

Finally, the group studied the differences between each chart, and concluded that vacuuming can pose a risk for musculoskeletal disorders, and that locked vacuums with no rotation of the head can strain the wrist and arm joints more than a ball vacuum, leading to even higher risks. The participants had successfully brainstormed, tested, and concluded a hypothesis that could be used to create a better version of an essential household appliance. The hammering data the participants had collected was also finished, but the hypothesis was not determined. Because this was their eighth week, the RET teachers were finished with the program, and more data was still being collected, as there were more subjects to test. However, the students were still present, and could continue finishing their camera applications.

Without the RET teachers, the students were left with their original professor and project to attend to. With the cameras enabled and in perfect working order, the only steps left were to locate the code necessary to send images through the Pi and Pi Zero, and program them (Fig. 8). The students focused on locating the code first. The students spent most of the week researching and copying possible source codes that could interconnect the computers via sockets⁸. Sockets are ports that the computers use to communicate to other devices via USB or internet, such as keyboards and mice. However, a socket is not capable of connecting two computers. The professor solved this problem by turning the Pi Zero into an Ethernet gadget⁹, which is used to connect computers to the internet. With the Pi Zero no longer a functioning computer, it had the ability to communicate to the Pi through sockets and still have the ability to capture photos.



Fig. 8 PiZero and Picamera

The next week involved a lot more watching and learning for the students. Only their professor edited the source code, as they had only basic knowledge of Python. The two separate code strings they found each had to be edited on both computers, ran, checked, and edited again. After

a few days, they managed to send small text messages from one computer to the other very quickly. However, images would prove to be much harder. The sockets were not created to send large image files. The code was revised, and the rough product that emerged could convert image files it received into binary, the most basic computer language. This allowed the Pi Zero to send minimal amounts of information very quickly. Upon receiving the binary, the Pi would convert it back to an image file, and put it into a buffer, a temporary placeholder that can hold files and dump them without saving, which saves time. Finally, the students and professor had achieved their goal of interconnecting computers and sending images between them. However, due to lack of time, the students were not able to fully complete the project. The cameras were currently unable to detect when to take pictures, and there were not enough cameras to cover the entire spherical robot. Despite the incompleteness of the full project, the students and professor had achieved a great amount of work that may have in the future a huge impact on robotics.

The twelfth and final week of the RET summer scholars program was spent cleaning up. The professor and students smoothed out some rougher edges of the code, and cleaned up the lab in which they worked.

Conclusion

In conclusion, the students researched spherical robots and learned the basics of icon and Opensim. After taking the CITI test and registering with the IRB, they tested their PiCameras and brainstormed their vacuum hypothesis. They then began using the video port with the cameras, and converted Vicon hammering data into Opensim. While spending the next couple of weeks doing this, the students learned basic Python, and graphed the vacuuming data. The last weeks were spent comparing their hammer and vacuum data, and establishing communications between the Pi and Pi Zero using sockets. From learning Python to vacuuming, the students have learned a vast amount of information during this time. This program not only can have impacts on commercial or robotic fields in the future, but also greatly increase a student's interest and ability in engineering. The RET Summer Scholars Program gives an incredible advantage to students willing to pursue a career in engineering, and can benefit many more by giving them knowledge of engineering procedures and processes.

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