ECE 398: Ringbot Motion Control Project

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December 19, 2025

1 Introduction

The purpose of this project is to recreate the existing Ringbot project that is present in the KimLab and improve it's control algorithm for turning and standing up. The current iteration of the Ringbot project is quite sophisticated and although it performs quite well, one of the main problems that is has is that it has quite a large turning radius as well as the fact that its constantly prone to falling and struggles to stand up after it has fell. Therefore to our task is to replicate the existing Ringbot project and modify the existing code in order to implement a method technique for turning with a smaller turning radius, as well as improve the control algorithm that is used to detect and counter falls. There were 6 main objectives in order to complete this project which are listed below:

1. Create Bill of Materials (BoM) for the Ringbot using the provided research paper and CAD files
2. Finish all the mechanical parts of the Ringbot body
3. Connect the digital electronics with the Raspberry Pi
4. Assemble electronics, motors, and mechanical assembly to create Ringbot
5. Test Ringbot and find sources of error
6. Improve Ringbot code

Later in this report we will talk about each step more specifically.

2 Project Timeline

We started working on the project September 17th and continued work till December 12th. The timeline events are shown below:

- **9-17:** Began creating the BOM
- **9-25:** Submitted finalized BOM
- **10-8:** Finished slicing all parts
- **10-17:** Successfully printed Ringbot legs
- **10-25:** Finished printing outer rim
- **10-27:** Began soldering connections
- **11-11:** Finished soldering peripherals
- **11-14:** Installed leg motors
- **11-21:** Completed both leg modules
- **12-10:** Created JST header board
- **12-12:** Flashed Pi and reinforced rim

3 Team Roles

Although Ram was specialized in software and Siddharth was specialized in electronics, both team members worked together in order to build the Ring bot and working on all tasking. Below is a table of how the work was split.

Table 1: Team Work Split

Siddharth	**Ram**
Sliced the CAD files according to the specifications	Worked on printing the sliced STL files on printers
Removed supports from the 3D prints and sanded off the ends	Screwed on the bearings and axel components onto the 3D prints
Soldered power converter and the IMU to the Raspberry Pi	Soldered on the U2D2 module and the JST connectors for peripherals
Soldered in Brass fittings into the outer wheel component	Flashed the Raspberry pi with the required OS image

4 Methods

4.1 BoM

The Bill of Materials for this project was developed with the help of the published IEEE research paper [1], which was based on the Ringbot Robot. From the IEEE paper, we were able to obtain broad information about the project, such as the number and types of sensors used, the output current and power characteristics of the batteries, etc. However, we quickly found out that the paper did not delve into the specific brand of equipment used or where to find them. Thus, while the paper was informative, it was only one piece of the puzzle. We were also provided with some of the STL files that were used to create the Ringbot, and thus, it allowed us to identify which parts of the Ringbot needed to be bought off the shelf and which were printed in our BOM. However, the BOM was only completed when we were given the documentation used to create the robot, which allowed us to complete the missing parts of the BOM. Once we finished the BoM, we verified it with the completed prototype in the lab and finalized our completed version.

4.2 3D Printing

For this project, there were many components that had to be 3D printed with the Bambu Lab 1S printers and the Onyx printers. As the Onyx printer was quite fragile, we focused on printing the normal PLA parts, while our mentors worked on printing the parts that needed to be printed on the Onyx printers. For our prints, we ended up with over 20 individual total parts. The most challenging part about the printing was coordinating the print times since the printer was not always available to print, and there were prints that took almost 24 hours to complete. In order to print with the highest quality, we sliced the STL files using the well-tested slicing specifications that were specifically given to us by our mentors, as well as manually going back and removing extraneous supports in the slicing. Throughout the printing process, some prints would fail due to incorrect orientation or a lack of supports. We also had to reprint some components due to incorrect color plastic. After printing, we took out all supports, overhangs, and further sanded down various locations to remove excess plastic so that the screws and bearing could fit.

4.3 Soldering

The primary source of soldering for the Ringbot was all the connections onto the Raspberry Pi. The soldering tasks mainly consisted of connecting the U2D2 communication module for the Dynamixel motors, the D24V22F5 voltage regulator, and the BN0055 STEMA QT 9-axis IMU all onto the Raspberry Pi Zero 2 W, and were performed with a typical soldering iron, solder paste, and some solder. The soldering itself proved to be quite challenging since it involved making the connections directly onto the copper vias of the Raspberry Pi instead of indirectly through jumper wires, and it resulted in us repeatedly resoldering parts when the connections failed or when too much solder on the board created unintentional short circuits. We performed the soldering under the guidance of the circuit schematics that were provided for the ringbot, and after all the soldering was completed, we checked each of our connections for opens or shorts using a multimeter and then secured each joint with a hot glue coating to ensure robustness.

4.4 Driving Module Assembly

The driving modules for the Ringbot primarily consisted of a large 3D printed frame for housing the XC330-T181-T Dynamixel motor, 3D printed 2.61:1 gears, the electronic parts and ball bearings. To develop this, we began with printing the frame on the Onyx printers. This part was performed by our mentors since the printers were quite fragile. Once we got the printed part, our first task was to remove the supports that were on the part. Since the part was printed using carbon fiber reinforced filament (CFRF), getting the supports out proved to be a challenge, especially since several holes for which screws had to be inserted had supports in them. We even had to sand off some of the excess supports and in other parts, cut them out directly from the 3D print. After much effort, we were able to finally remove all the supports, after which we began to screw in all the bearings that were housed in the frame. Since we had yet to receive the XC330-T181-T driving module motor or the 3D printed gear at that point, we left these modules in their current state.

4.5 Leg Module Assembly

Similar to the driving modules, the Leg Modules were also primarily meant to house the XM 430-W210-T motors and the battery packs. However, unlike the driving modules, the frame for the leg modules was printed by us on the Bambu Labs 1s printers using PLA. Once the part had been printed, we proceeded with sanding down the excess plastic and removing any overhang. Since there weren't as many screws in this frame as in the driving module, we didn't spend nearly as much time sanding and removing supports. Next, we then fitted and screwed on the XM 430-W210-T motors and made sure to wrap the wires through the appropriate holes. Since we didn't have the full electronics completed by this time, we decided to leave these wires unconnected. Now the final step for these modules would be to fit them onto the driving modules and make all the proper electrical connections.

4.6 Ring Assembly

This ring assembly used the Onyx rims and the regular PLA wheel components. The carbon fibre rings were inserted through the Onyx rims and secured using brass inserts to reinforce the wheel assembly. We needed to use a Dremel and a filing tool set to cut down the carbon fibre to length and insert it into the Onyx rings. The brass inserts needed to be placed into the tiny holes of the rim. We utilized a soldering iron to heat set them into place which ensured a reliable fit within the rim material. The final step of this process is to attach the outer wheel onto the Onyx rim to complete the full wheel assembly.

4.7 Raspberry Pi Setup

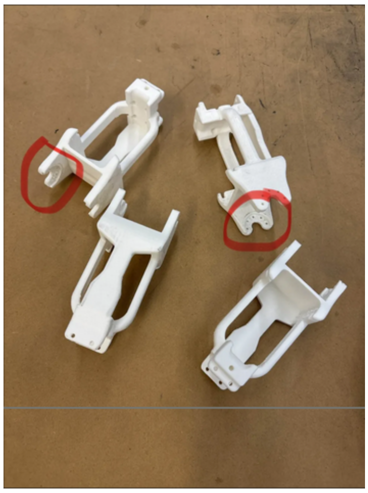
After soldering the D24V22F5 voltage regulator to the Raspberry Pi, we had to be careful with not directly connecting the Pi to power. This had to be done, so that the current wouldn't go in a reverse flow and drive the voltage regulator. Instead we connected a battery connector onto the voltage regulator to power the full setup. After successfully, powering the Pi we could now flash the Pi with our own OS. There was already a ready OS, so we used BalenaEtcher a tool which safely and easily allows to flash an OS onto storage devices. Once we flashed the SD card, we successfully booted up the Pi. After booting up the Pi, we SSHed into it and put own hotspots onto the wpasupplicant file, so that we could login to the Pi without having to be at the lab.

5 Results

The project is still a work in progress, however, we were able to complete $\geq 80\%$ of the mechanical assembly and required integration. Pictures of progress as shown below.

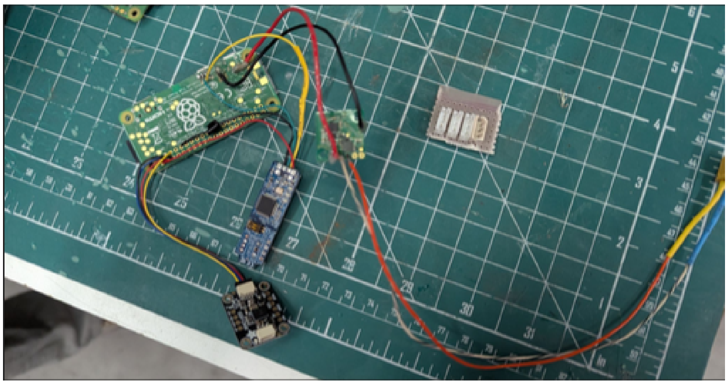
(a) Drive/Leg Modules Components

(b) Outer Wheel Prints

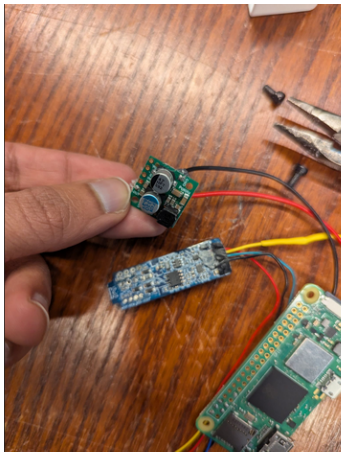


(c) Bad Prints

Figure 1: 3D Printed PLA Components

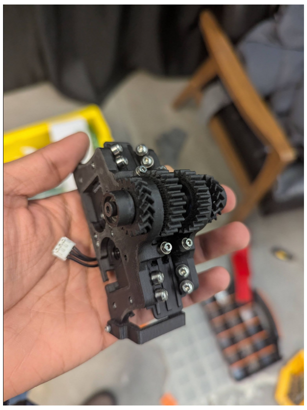


(a) Completed Raspberry Pi Soldering

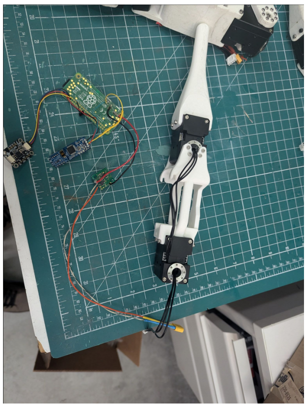


(b) Closeup of Voltage Regulator

Figure 2: Raspberry Pi Soldering



(a) Drive Module Assembly



(b) Leg Module Assembly

(c) Ring Assembly

Figure 3: Completed Assemblies

6 Discussion

Through this project, we experienced the full stack of robotics development from prototyping, hardware integration, and software development. Throughout the entire project, we had many failures and learned the process of debugging and solving hardware problems through critical thinking and using various tools, like a multimeter. Due to outdated or a lack of documentation, we had to cross-check with spec sheets when soldering and when doing the fabrication of the components. As mentioned previously, due to inaccurate orientation of components when 3D printing or not adding supports in the slicer, some components were not printed cleanly, so we had to reprint them with correct settings. Due to the length of print times and needing to wait for electronic components to ship to the lab, there were periods of time when we could not work on the project. It would have been helpful to have a simulation so we could atleast attempt to work on the control code.

7 Future Work

We still need to complete the final objectives, which are assembling the last parts of the Ringbot and trying to improve the motion control code. Another objective, which would be helpful while waiting for hardware prints or components to arrive is setting up a simulation of the Ringbot, in order to have a sandbox to change code and test it without going through the physical processes.

References

[1] Gim, K. G., & Kim, J. (2024). *Ringbot: Monocycle robot with legs. IEEE Transactions on Robotics*, *40*, 1890–1905. https://doi.org/10.1109/TRO.2024.3362326

8 Top Picks

Ram's Picks

- Aidan Andrews, Embodied Intelligence in Humanoid Robots
  - Good data collection and showed fine tuning being done for teleportation
  - Nice presentation and takeaways regarding data quality
- Leo Lin, Zeroth Bot 3d Printed humanoid project
  - Nice work given time constraints
  - I also learned about PPO RL policies through this
- Alan Lu, HARMONEX
  - Impressive and professional looking developed elbow exoskeleton
  - Exceeded his initial requirements of only needing 10 lbs

Sid's Picks

- Leo Lin - Zeroth Bot: I liked this project because I, too, had originally also worked on the Zeroth Bot as part of the Sig Robotics club; however, when I worked on it, I was unable to get the robot to function at all due to being unfamiliar with the electronics. But through this project, I was finally able to see the robot function properly.
- Sanjit Sriram, Swarup Majumder, Tony Liu - PAPRAS Reconfiguration: I liked this project since the modular aspect of the robots has always fascinated me, but I have always feared the software side of trying to implement this. I liked the fact that these students were able to easily pick up the ROS 2 software and implement it into Dynamixel motors, and it has given me the confidence to explore it.
- Jessica Xu, Emily Tam - The HOMIE: What stood out to me for this project was that they were able to get a lot of progress done on the teleoperation exoskeleton and even verify its functionality in simulation. I also liked their ability to develop solutions on the

fly, such as when they 3D printed their own parts for the exoskeleton when it wasn't on the repo.