Designing an Optimized Robotic Ankle for a Bipedal Robot

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***Abstract*— This project aims to redesign a proper ankle for a bipedal robot built by Caltech's AMBER Lab. Moving on from stick feet, this new design will have a motorized ankle allowing for rolling and pitching motion. The design will also include a passive toe joint that would allow the robot to have a more efficient walking gait. This form of ankle design will allow for greater balance and efficiency and will also allow the robot to travel rougher terrain than the smooth and soft lab floor. The primary goal of our work this summer is to create a fully fleshed out 3D model in an application such as SOLIDWORKS that includes all of our motorization, attachments, and main body of the ankle. At the end of the summer, a 3D printed model will be created to better demonstrate the mechanism of the ankle. The proper creation of this design will allow further progress to be made on the robot and further ankle design iterations to be made.**

I. INTRODUCTION

A. Background Information

The current issue at hand is that a bipedal robot being worked on inside the lab is using ineffective pointed shaped feet. The problem arose from the initial design having this intentional design choice made to accelerate the initial research project. A simpler contact model was ideal for studying bipedal locomotion at first. Solving and changing the feet would make the overall robot much more effective and efficient. It would allow the robot to stand completely still without falling over. The rest of the lab is currently working on other robots or optimizing controls/sensor systems. My work will be key in allowing progress on the robot to continue, mainly optimization and testing in its other areas, as well as the manufacturing of new feet to begin. AMBER Lab currently is working on Prosthetic Control & Design and Cyber-Physical & Automotive Systems as well as Bipedal Robotics. In particular, they are working on Nonlinear Control Theory and Experimental Bipedal Robotics.

B. Approach

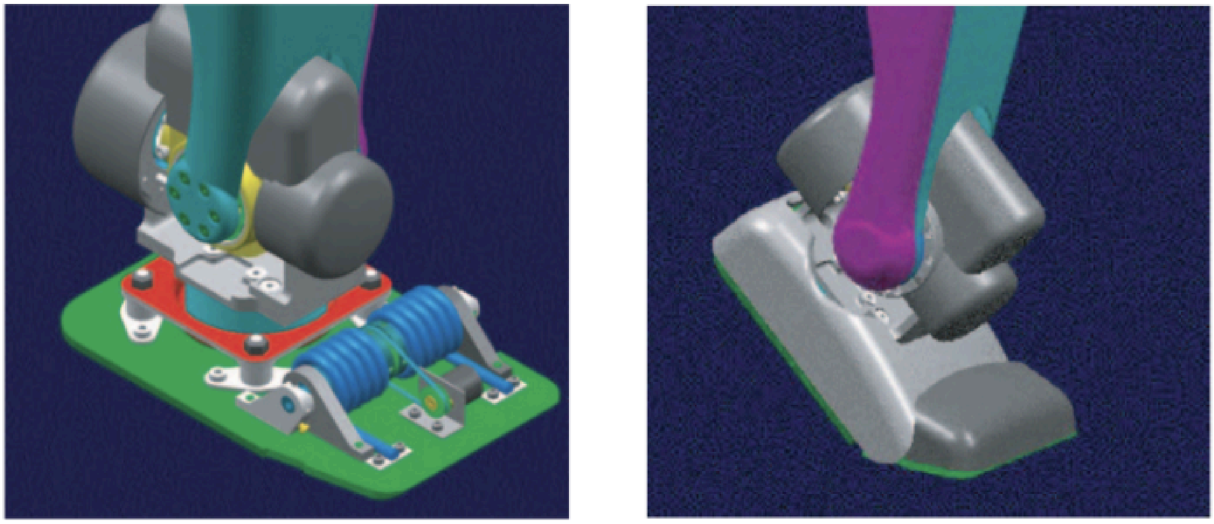
My main objective is to create an optimal design of bipedal robotic feet that properly balance and handle movement. I will conduct research and examine materials before presenting a final model of my work via SolidWorks. I expect to have a 3D model of the new feet complete with all pieces, materials, and inner workings. The current design has pointed feet with kinematic data used to determine whether or not the foot is in contact with the ground. The robot has to step in place in order not to fall over. The result of a successful design will have the robot still maintaining these sensors, but with a design for fully working ankle joints and a robot that will balance better. This includes a damping mechanism (i.e. using soft material), lightweight legs, and ankle actuation. Some criteria for success include easily manufacturable feet designs, ankle joints that work properly, and a robot that no longer falls over easily. The robot should be able to walk decently not only on the firm, flat lab floor, but on other surfaces like gravel and grass. Multiple AMBER Lab papers (including one I linked previously) have cited research using the bipedal locomotion of the robot with pointed feet. The changing of the feet may change the gait cycle, make the robot more efficient, or even change the ZMP (zero-moment point) of the legs throughout the walking cycle. My changes to this robot will likely have impacts on future research the lab wishes to conduct.

II. RESEARCH

I did a lot of research and read several articles/papers to get a better understanding of the challenge facing me and other designs done in bipedal robotics concerning ankle actuation. I created a note document to take down important information and takeaways from what I've learned. I also created a day by day lab notebook to keep track of milestones and daily progress.

I read a paper on passive toe joints and determined an ideal secondary goal would be to have passive torsion springs located at where toe joints would be in order to passively improve walking gait efficiency.[1]

Here is a picture of the design tested in the paper:



(a) Toe spring mechanism (b) Maximum toe bending

Fig. 1 Passive toe join in action

I then shifted my focus to the ankle actuation design. I found a design that properly illustrated the pitch and roll degrees of freedom that were desired in the ankle joint.[2] This design utilizes a bevel gear system, using an inner and outer frame. This inside and outside frame concept would be central to my design idea.

III. Design

A. Early Drawings

I began with some early ideas and many sketches on the double cylinder idea.

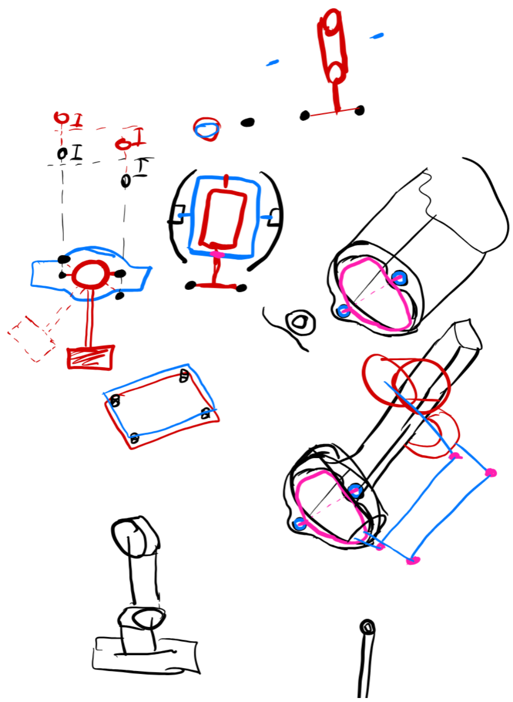


Fig. 2 Early Sketches

This idea turned into a concentric cylinder design, and I expanded on my sketches to gain one cohesive idea.

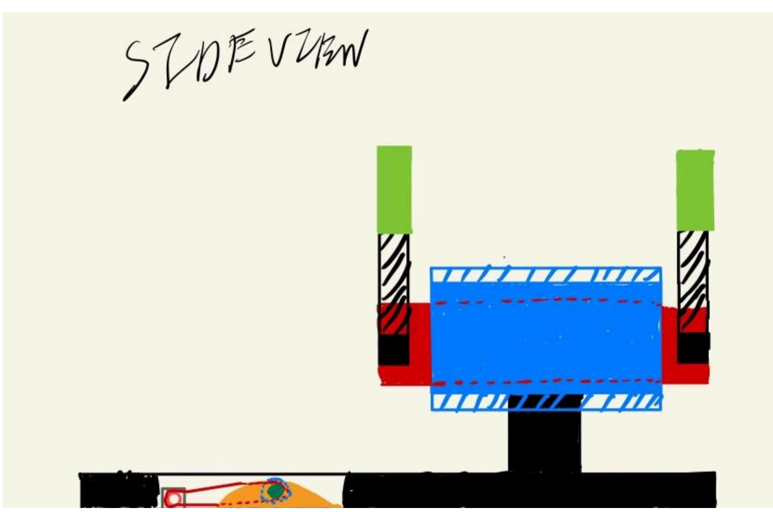


Fig. 3 Side view of my main sketch idea.

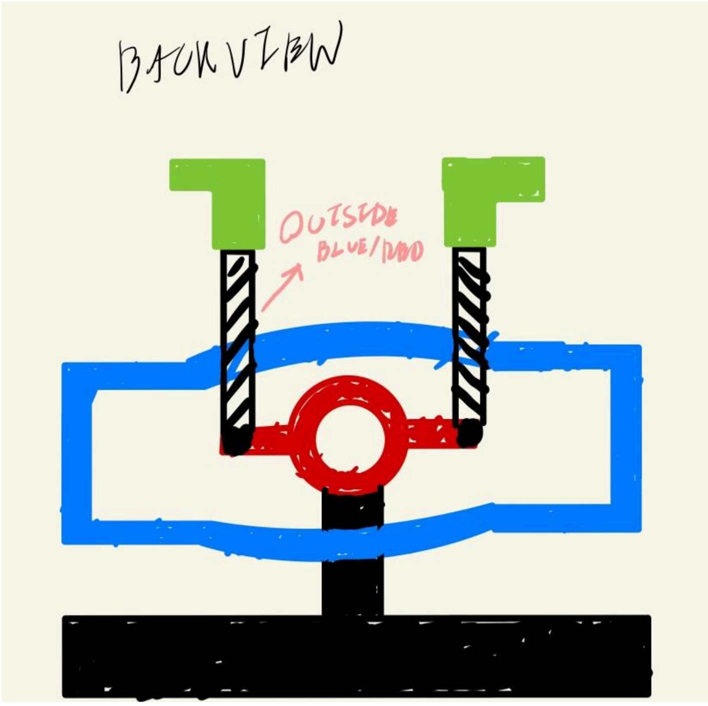


Fig. 4 Back view of my main sketch idea.

In this design, the inner red cylinder would direct the rolling movement, and the outer blue cylinder would direct pitch movement. The green segments represent a linear actuator, and the slashed black rectangle represents some form of connection (wire or 3D printed material) to help the actuators move.

B. Early Modeling

The sketches I did led to an early CAD design showing off the main idea of the ankle joint I had.

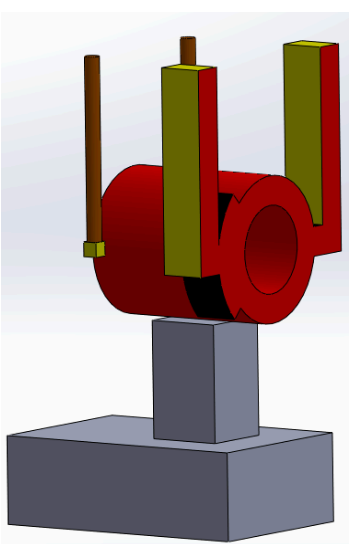


Fig. 5 CAD showing off main ankle ideas.

However, there was no way this would be the final design. After getting a better understanding of the double cylinder design, I pivoted to a better model. My mentor helped out a lot by sharing a rough model of a double cylinder design, and I was able to take that and rework it into a way I desired. I then improved with the next iteration.

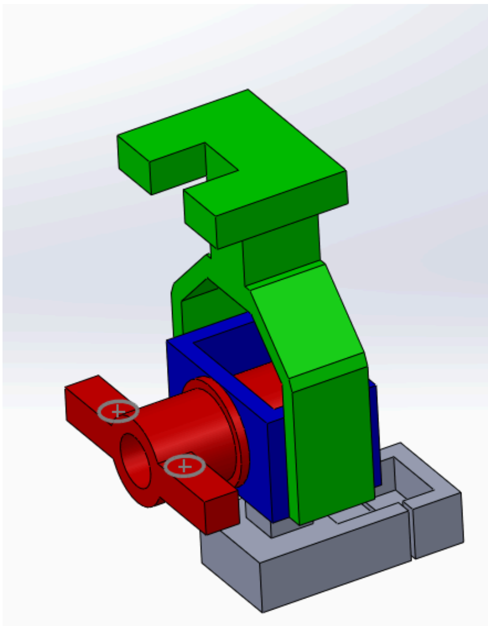


Fig. 6 Improved and colored design.

There are a few things to note about this model. First, the foot itself has a cutout and gap for some torsion springs to be placed in order to create a passive toe joint. Secondly, this design favors linear actuation instead of rotational motors as previously mentioned. This shift in thinking came from more research I did on robotic actuation. A linearly controlled system makes more sense to me and also is something I find more interesting to explore, so I hope to stay on this path in the future. I have included a picture of the ankle assembly with where the actuators and springs would be below.

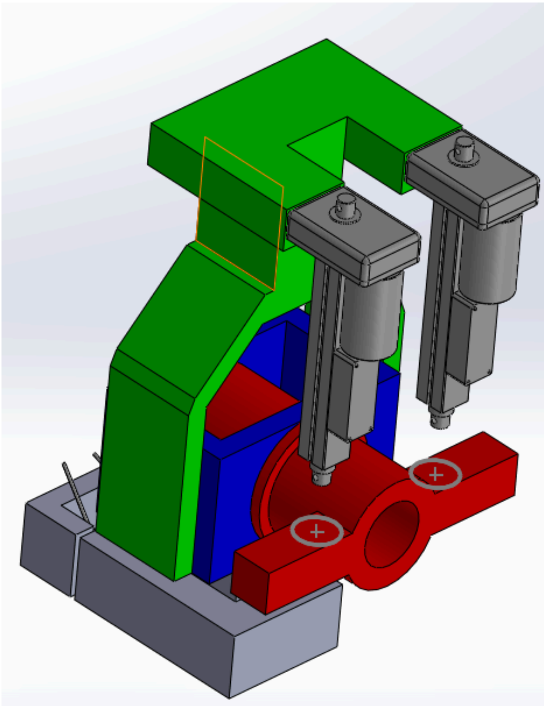


Fig. 7 Colored Assembly

One of the biggest challenges I had to face was the lack of understanding and conceptualization I had for the double cylinder design. I had a very hard time grasping the way the design works well enough for me to create a model of it while understanding how the pieces interface and work together. It took a while for me to fully get it, and eventually what helped a lot was a rough model my mentor shared with me that I was able to work off of. I have placed an image of this model below.

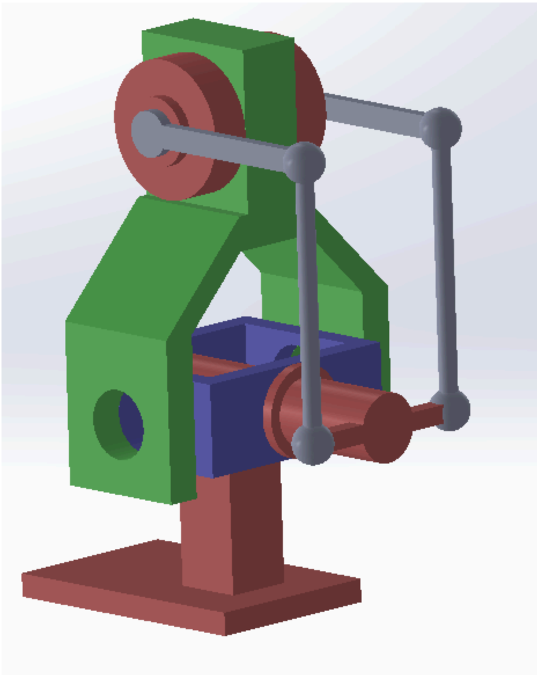


Fig. 8 Mentor suggested model

Another concern is if the actuators used would be fast enough to adjust the ankle during its gait. The actuators used in the assembly have a maximum speed of 1 inch per second, whereas rotationals motors could achieve a linear velocity of several times this with a potentially higher degree of accuracy. I would have to examine the motorization of the current model better and determine if more speed is needed.

C. Finalizing the model

One thing I didn't like about my design so far was the big, blocky foot. The main goal was to still have flat feet, and although the toe joint was on top of it, it didn't need to have walls around it.

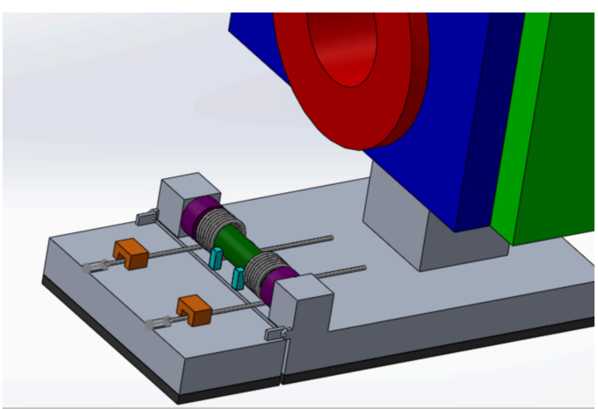


Fig. 9 Flat foot design

Note the two small hinge pieces: the sides should bend with the toe joint and keep it attached to the robot despite the toe itself being a separate piece. The orange tunnel pieces will ensure that the spring legs will stay attached to the toe, and the cyan prisms will keep the springs axially constrained in conjunction with the hollow purple cylinders. I also added a thin layer of rubber to the bottom of the foot for traction. However, there were a couple issues with the design. First, the hinge joints were not big enough to assuredly handle whatever force would be applied to them. Secondly, the design was way too big and heavy. According to Solidworks, it weighed about 40 kilograms and was about 30 centimeters tall. I didn't really consider overall dimensions of the design initially like I should have, and only focused on the relative ones. The design mostly consists of aluminum 2024-T3 solid bodies, which can be incredibly heavy. The only pieces not made of metal are the orange, cyan, dark green, and purple pieces which are ABS PC. As I started to shrink and hollow out the design, I came across another issue. While the spring legs were now too long, they could be cut. However, the linear actuators were now way too long. Even the smallest actuators I could find wouldn't give a reasonable range of motion due to their stroke length being limited by their maximum size. So, I opted for rotary motors.

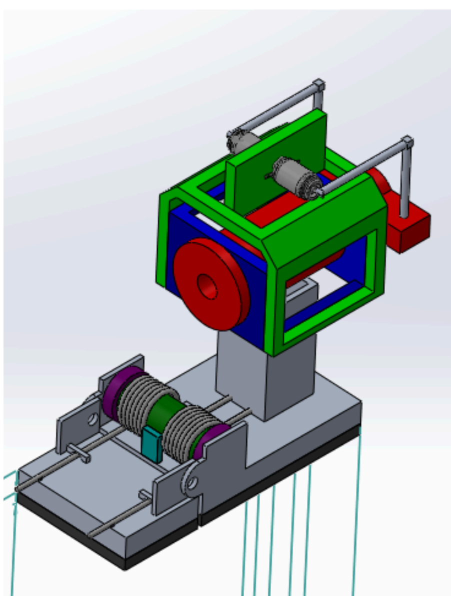


Fig. 10 Smaller rotary design.

I was able to hollow out much of the frame and shrink down the overall size of the design. The design is now 17 centimeters tall, 15 centimeters long, and 7 centimeters wide. It also now weighs a little more than a kilogram, a marked improvement. The rotary motors will utilize the rigid legs of a support joint to turn the inner red cylinder (a "rolling" ankle motion), or both will move in the same direction to pitch the ankle up or down. Both of these motions can now be done with a higher speed and accuracy than with the linear actuators. However, I still felt like the toe joint could be better connected. Along with a couple of other minor modifications, I am now at the final design shape of the foot.

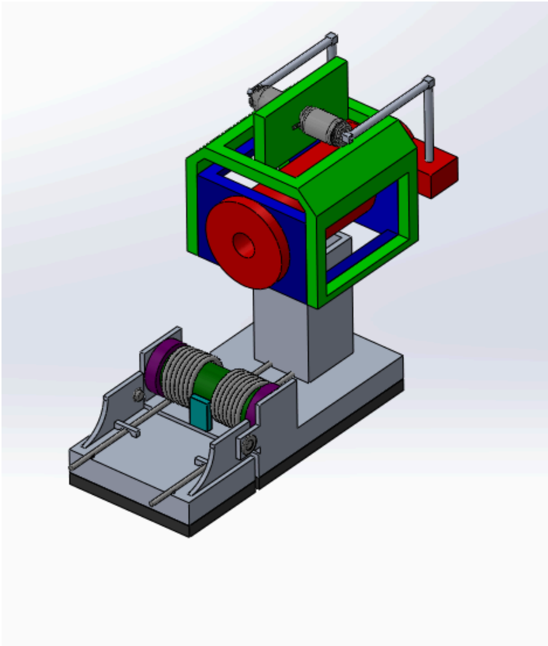


Fig. 11 Current design

Note the smoother and more firmly attached toe joint. I have also started including attachment pieces such as bearings and dowel pins for the toe joint. The next step is to include things like bolts and brackets wherever they may be needed in the assembly. There are a few other adjustments that could be made when thinking about the machining process for each of these parts. For example, the ankle to ankle joint mechanism attachment could use some improvement.

IV. CONCLUSIONS

When it came to the later stages of the project, I needed to think about how I would be able to machine every aspect of the design. This was a very interesting intersection of machining classes I had taken and the robotics field I had a little experience with. I have never done a lot of machining with a robot, so to go through this process and think a lot about that was really informative for me. I hope to finish up this design sometime during the year and start working on bigger projects. For my career and learning goals of getting into prosthetic and exoskeleton design, this has been such a great experience and I feel more prepared than ever to take on this next year of heavy robotics classes.

ACKNOWLEDGEMENTS

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REFERENCES

1. Kajita, Shuuji, Kenji Kaneko, Mitsuharu Morisawa, Shinichiro Nakaoka, and Hirohisa Hirukawa. "ZMP-based Biped Running Enhanced by Toe Springs." 2007.
2. Ashkvari, Mahyar, Aghil Yousefi-Koma, Hossein Keshavarz, and Masoud Shariat-Panahi. "Design Improvement of a 2-DOF Ankle Joint Actuation Mechanism for a Humanoid Robot." 2016.