Background

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. Here are some papers illustrating this work: Risk-Averse Control via CVaR Barrier Functions: Application to Bipedal Robot Locomotion (caltech.edu), Distributed Quadratic Programming-Based Nonlinear Controllers for Periodic Gaits on Legged Robots (caltech.edu), galliker2022bipedal.pdf (caltech.edu).

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.

Progress

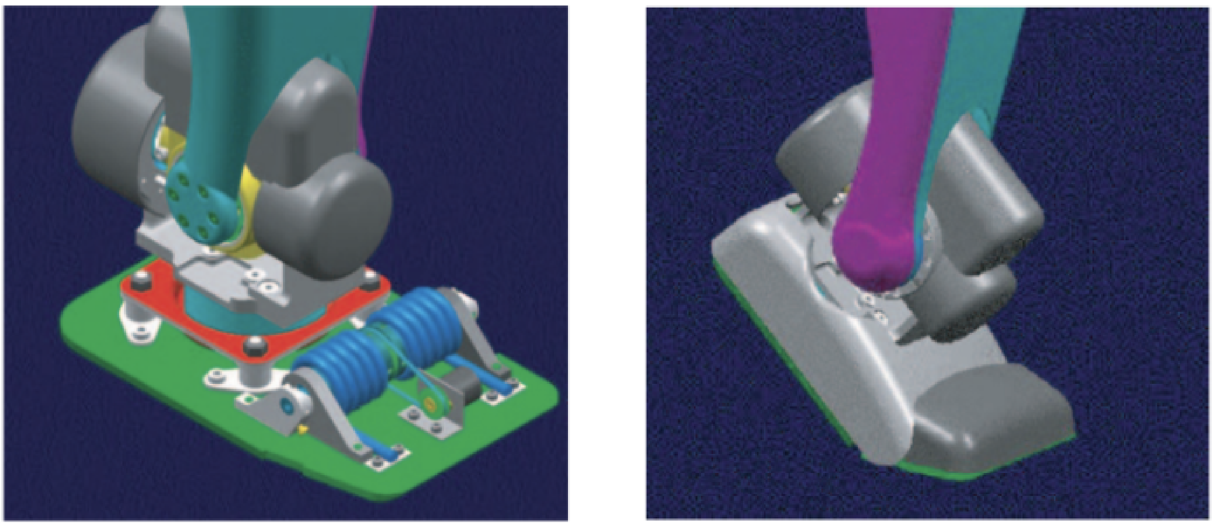
I have done a lot of research and read several articles/papers to get a better understanding of the challenge facing me and other designs done in bipedal robotics concerning ankle actuation. I created a note document to take down important information and takeaways from what I’ve learned. I also created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

Faster and Smoother Walking of Humanoid HRP-2 with Passive Toe Joints*

Ramzi Sellaouti[*1], Olivier Stasse[*2], Shuuji Kajita[*3], Kazuhito Yokoi[*1] and Abderrahmane Kheddar[*2]
[*1] JRL, AIST [*2] JRL, CNRS [*3] HRG, AIST

I read the above 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.

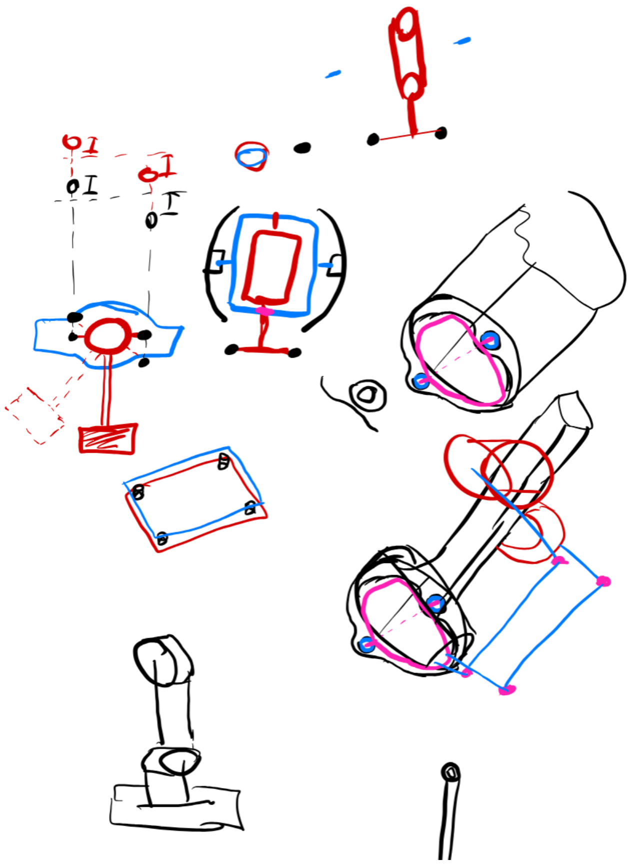
Here is a picture of the design tested in the paper:



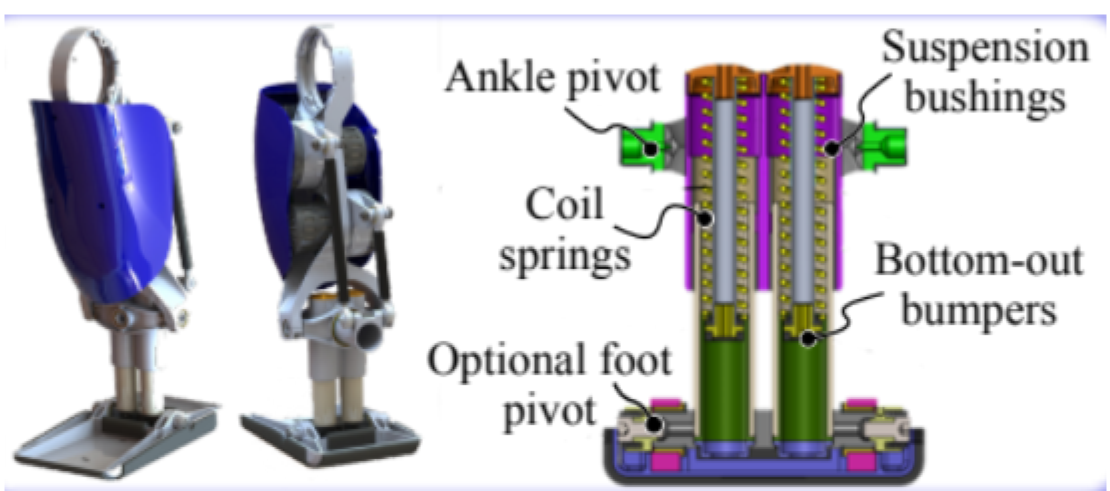
(a) Toe spring mechanism (b) Maximum toe bending

I then shifted my focus onto the ankle joint.

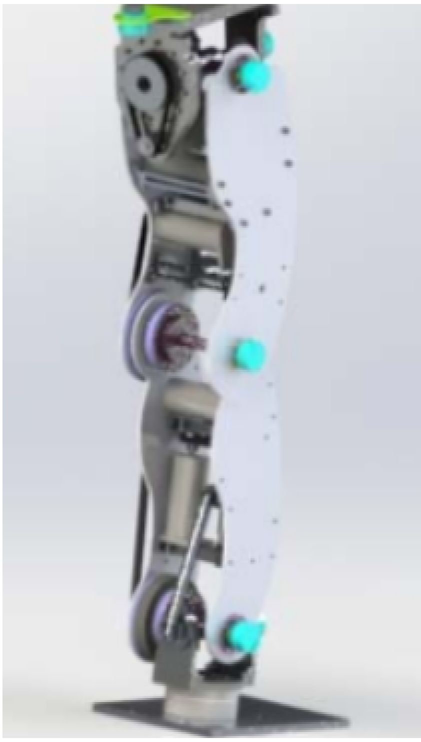
It is important to ensure that the ankle design accounts for a simple way to control both the roll *and* pitch of the robot's foot.



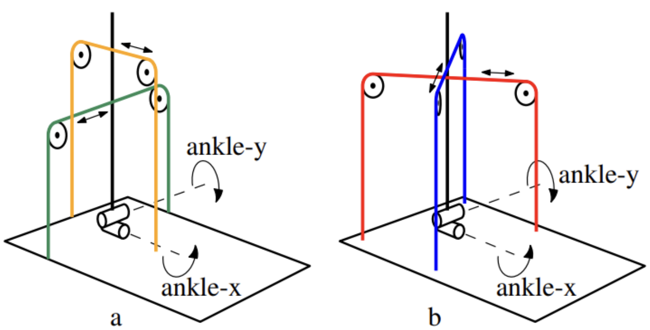
Here are some sketches for the ankle joints that my mentor and I did. There were a couple of designs I looked at. Namely, a spring-based DURUS design:



And a bevel gear based SURENA design:

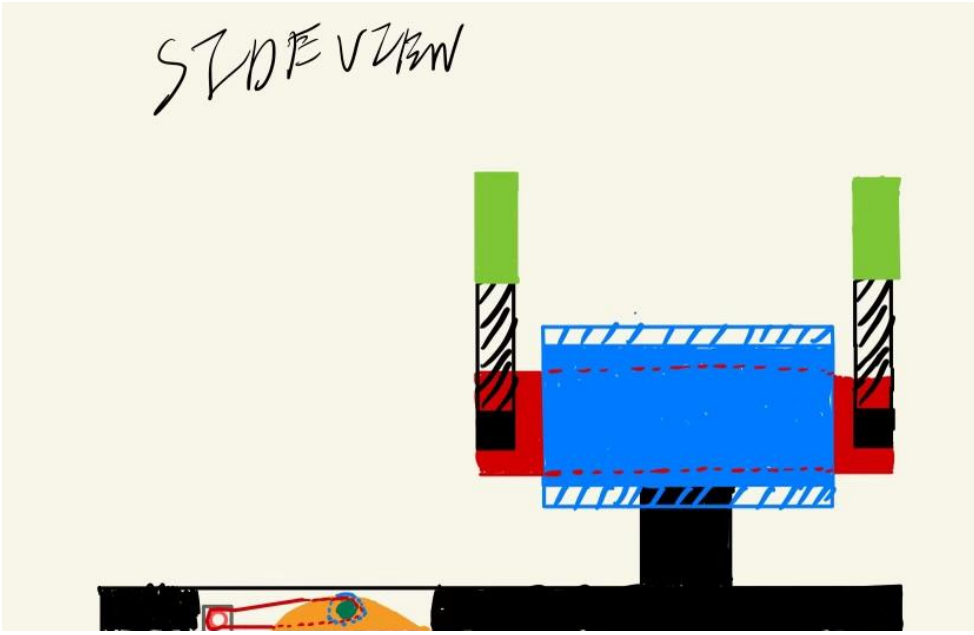


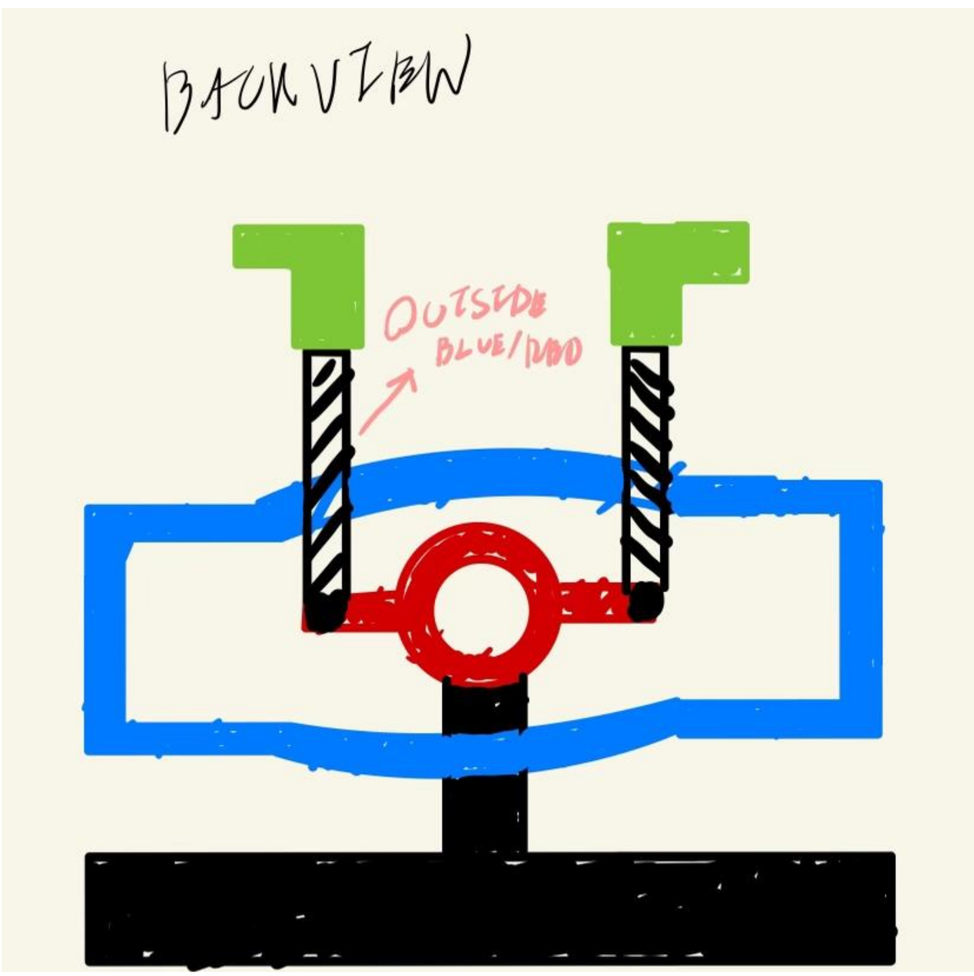
However, a third paper provided a more intriguing design:



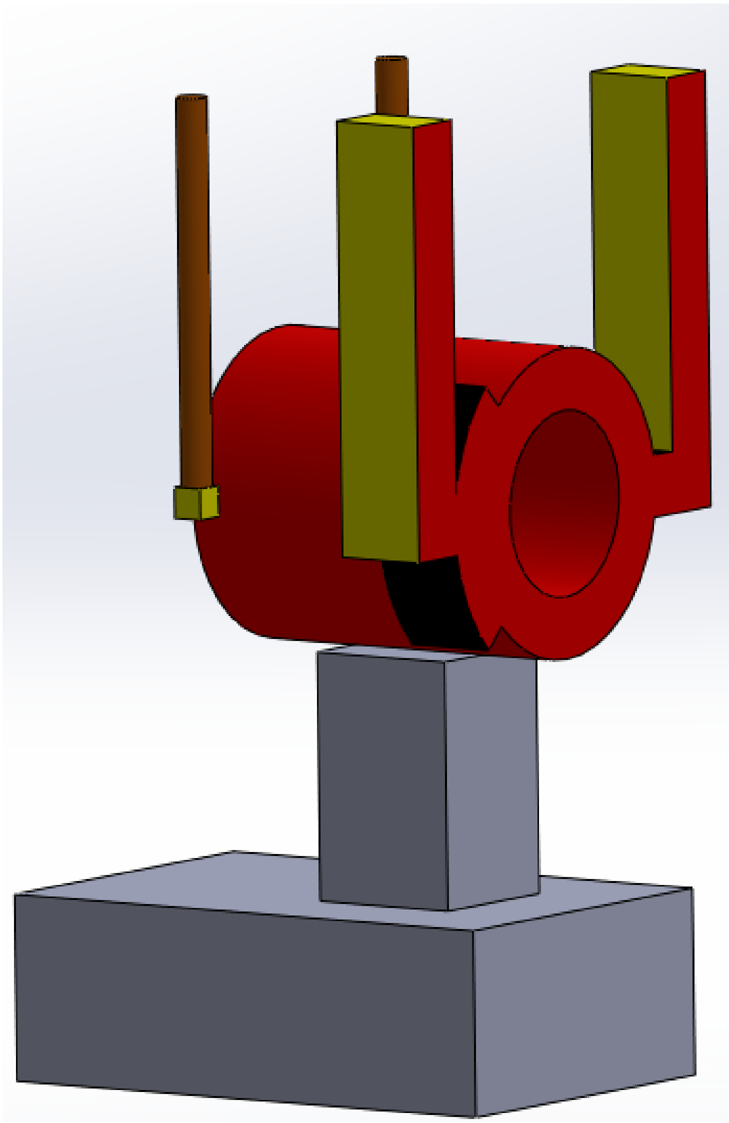
By using two cylinders, I could control both roll and pitch with minimal actuation.

This idea turned into a concentric cylinder design:





In this design, the inner red cylinder would direct the rolling movement, and the outer blue cylinder would direct pitch movement.



This led to a rough CAD design of the red cylinder with two ways to attach the actuation in the back of the foot and some unknown tension support in the cylinder's front.

Challenges and Problems

One challenge I am facing is understanding how the outer blue cylinder previously mentioned in the design would fully connect to the ankle shaft without interfering with the red cylinder. I am also wondering if I could only just have the red cylinder and have it control both roll and pitch. A concern is over actuation, that is we don't want to have four actuators on all four corners of the cylinder. Thus, to avoid this our design needs to be more creative. Further down the road, I envision the issue of programming the actuation, sensor integration, torsion spring implementation, and how the cylinders will be attached to the actuators, each other, and the ankle shaft to all be issues. This project is pretty intricate and I still have a lot to learn, but I'm excited to see where things go!