6-DoF Prosthetic Ankle (ANKL)

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TEXAS A&M UNIVERSITY Engineering

TEXAS A&M UNIVERSITY ROBOTICS TEAM & LEADERSHIP EXPERIENCE

Problem Definition

Create a working 6 DoF Stewart Platform robot for the use in an advanced below the knee ankle prosthesis.

ROS2 Integration

One of our primary goals for this semester was to refine the robotic kinematics and control scheme. Due to the number of actuators and auxiliary sensors required for the base platform and future gait cycle tracking, ROS2 (Robot Operating System) was selected as our communication protocol.

Inverse Kinematics

Inverse kinematics facilitate the calculation of leg lengths from a known floating platform position. To avoid gimbal lock within the platform, utilized a quaternion based approach when determining the location (x, y, z) and orientation (pitch, yaw, roll) of the moving platform. Quaternions prevent losing degrees of freedom during rotation.

$$q = 0.13 + 0.32i + 0.62j + 0.70k$$
$$q^{-1} = 0.13 - 0.32i - 0.62j - 0.70k$$
$$f(p) = q \cdot p \cdot q^{-1}$$

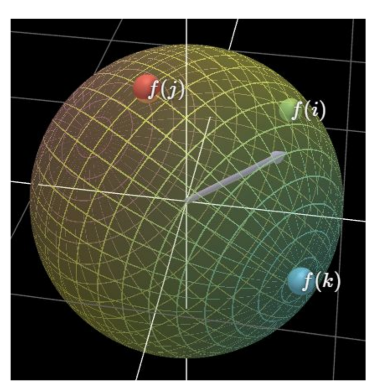

Fig. 1: Visual and formula representation of quaternion math

The inverse kinematics have been fully ported to ROS2 and function as expected when compared with our previous simulation work. We also focused on the addition of inverse rate kinematics, which allowed us to derive a formula for forward kinematics. This also allows for us to easily source inverse acceleration kinematics, which is found from taking the derivative of the formula below.

$$\dot{l} = J_1^{-1} J_2^{-1} \dot{q} = J \dot{q}$$

$$J_1^{-1} = \begin{bmatrix} n_1^T & (R_p^b p_1 \times n_1^T) \\ n_2^T & (R_p^b p_2 \times n_2^T) \\ n_3^T & (R_p^b p_3 \times n_3^T) \\ n_4^T & (R_p^b p_4 \times n_4^T) \\ n_5^T & (R_p^b p_5 \times n_5^T) \\ n_6^T & (R_p^b p_6 \times n_6^T) \end{bmatrix} \qquad J_2^{-1} = \begin{bmatrix} I_{3\times3} & O_{3\times3} \\ O_{3\times3} & \begin{matrix} 0 & -s\phi & c\phi c\theta \\ 0 & c\phi & s\phi c\theta \\ 1 & 0 & -s\theta \end{matrix} \end{bmatrix}$$

Equation 1: Inverse rate kinematics using inverse jacobian matrices [1]

Forward Kinematics

Using the known leg lengths of each actuator, the previously unknown location of the floating platform can be determined. Due to Stewart Platforms containing nonlinear geometry, the forward kinematics cannot be solved analytically and require the use of numerical methods. We chose the Newton-Raphson method of forward kinematics due to familiarity with the content.

$$F(q) = \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \end{bmatrix} = \begin{bmatrix} \sqrt{L_1^T L_1} - l_{m1} \\ \sqrt{L_2^T L_2} - l_{m2} \\ \sqrt{L_3^T L_3} - l_{m3} \\ \sqrt{L_4^T L_4} - l_{m4} \\ \sqrt{L_5^T L_5} - l_{m5} \\ \sqrt{L_6^T L_6} - l_{m6} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$q_{n+1} \approx q_n - J^{-1}(q_n)(L_{in} - L_m)$$

Equation 2: Equations for forward kinematics using the inverse jacobian; derived from the inverse kinematics shown in Equation 1 [1]

Platform Design

Building upon the previous semester, the overall layout of the platform and its joints was examined in more depth. From this analysis, we selected a 3-6 joint configuration with a triangular and a hexagonal plate as the final design for the product based on the following:

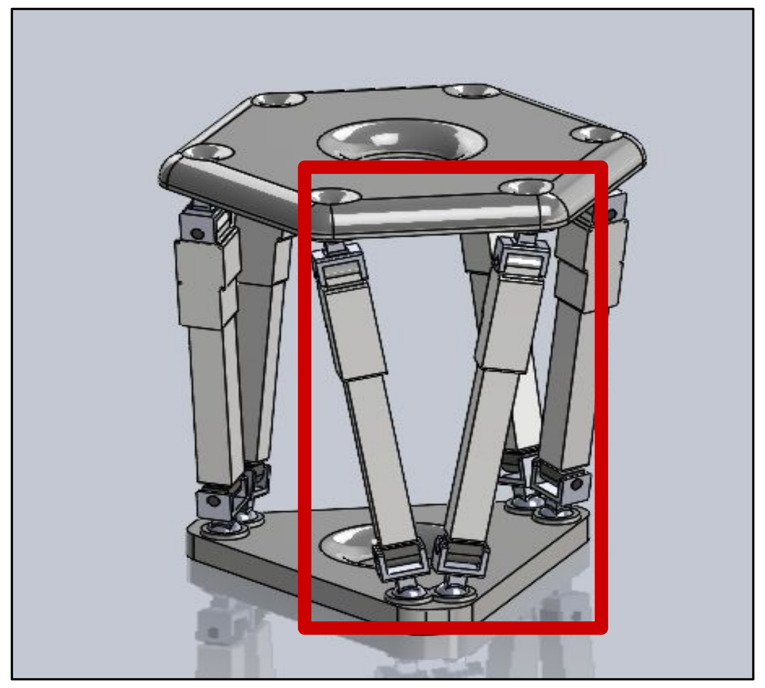

Figure 2 - Stewart Platform Model

- Increased strength and stability compared to previous 6-6 design.
- The hexagonal base platform is more space efficient.
- The 3-6 design contains fewer singularities than the 6-6, thus making it easier to control.

Joint Selection

For joint selection, the obvious choice would be a ball socket joint, however those would highly limit mobility. To counteract this, a COTS pillow joint will be modified as part of our base to allow full range of motion with ease of part replaceability and an ideal failure point.

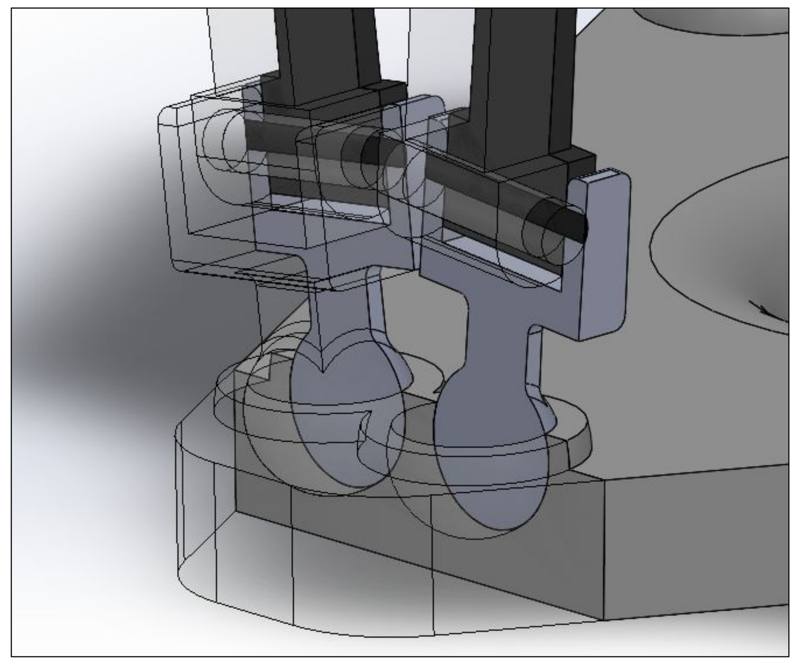

Figure 3 - Joint and Actuator connection

Simulation Updates

Updated the simulation, along with our inverse kinematics to use the 3-6 platform configuration.

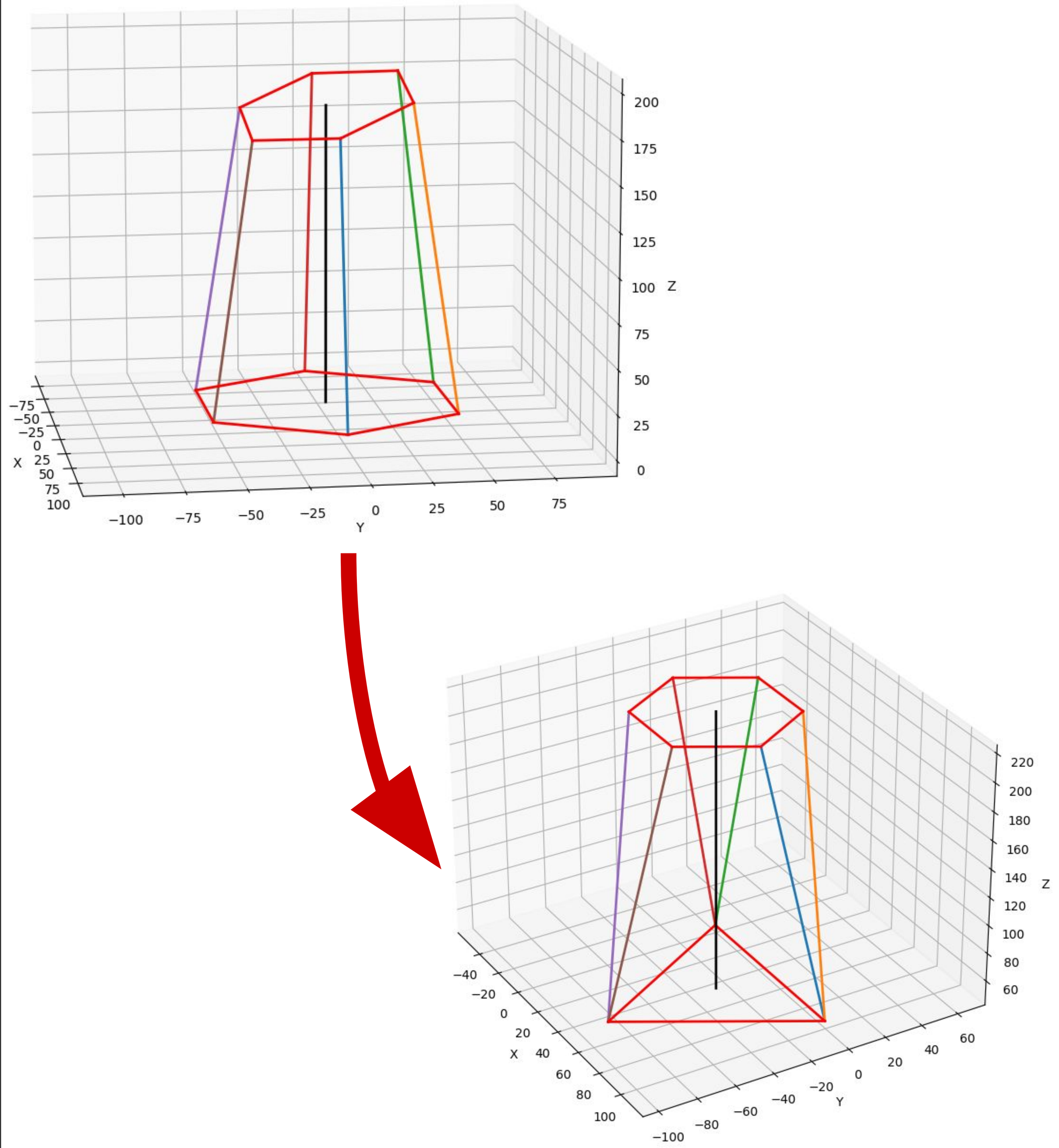

Figure 4 - Simulation Evolution

Circuit / Test Bench

Moving away from the purely software based focus of last semester, a test bench for the linear actuators was developed as a proof of concept.

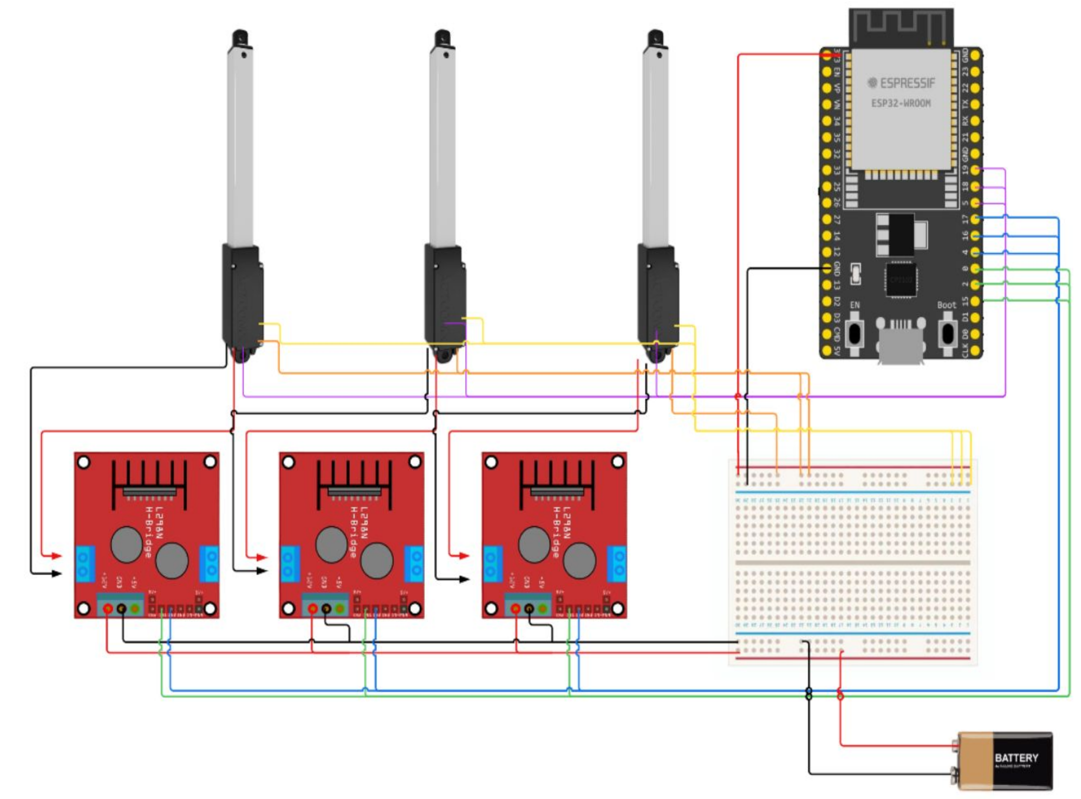

Figure 5 - Test Bench Circuit setup

The Test bench above serve two purposes, one was to prove that our linear actuators can be programmed and second was to verify the accuracy and precision of our hardware.

Some of the parameters we wanted to test with our linear actuators are as follows:

1. Velocity - Can the speed meet our requirements?
2. Current Draw - How much current does it use?
3. Noise - Is it noticeable when used?
4. Repeatability - How accurate are measurements?
5. Voltage Draw - How much voltage does it use?

Future Goals

- Modification of forward kinematics for 3-6 platform configuration.
- Creation of a mechanical test bed for the 3-6.
- Evaluating Python processing speed for forward and inverse kinematics.
- Fully battery powered operation.
- Full integration of electrical and software systems.
- Automated calibration and verification of linear actuators

[1]L. Huang, H. Pang, and H. Zhang, "Research on the Forward Kinematics of Stewart Platform based on Broyden Algorithm and Newton-Raphson Algorithm," pp. 402–406, Oct. 2023, doi: https://doi.org/10.1109/icnisc60562.2023.00013.