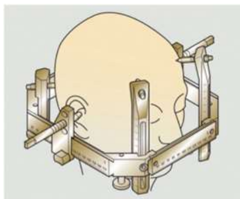
Automating the Leksell Frame Adjuster: Incorporating Phi and Theta Movement to Achieve 5 Degrees of Freedom using Matrix Transformations

Shania Lee[1], Prof. Jit Muthuswamy[1], Dr. Baltazar Zavala, MD, PhD[2]
[1]Tempe, AZ, School of Biological and Health Systems Engineering, Arizona State University
[2]Phoenix, AZ, Barrow Neurological Institute

Introduction

The Leksell Frame was invented in 1949 and is used in stereotactic surgery, mainly Deep Brain Stimulation, by assisting in the placing of electrode leads in the brain.

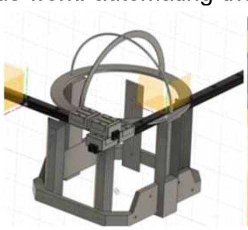


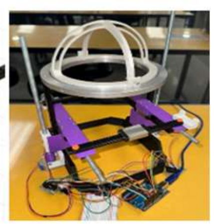
Biomedical Problem: The current Leksell Frame Adjuster requires manual soft tapping of the frame with a screwdriver to set the X, Y, and Z coordinates. This is an outdated, slow, and tedious process that could impose a risk of human error.

Aim: To achieve 5 degrees of movement in the Leksell Frame Adjuster with 5 degrees of freedom, implementing the Phi and Theta movements and finding a suitable motor for the Phi direction.

Background

Previous work: automating the X, Y, and Z movements.





Issues with design:
1. Incomplete: only achieved 3 degrees of freedom (X, Y, Z)
2. Did not meet that target speed and acceleration

Methods

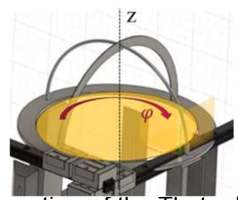
A. Matrix Transformation

1. Conversion of cartesian coordinates to spherical coordinates

$$r = \sqrt{x^2 + y^2 + z^2}$$
$$\varphi = \arctan\left(\frac{y}{x}\right)$$
$$\theta = \arccos\left(\frac{z}{r}\right)$$

2. Matrix transformation of the Phi direction. Circular frame must rotate around z-axis.

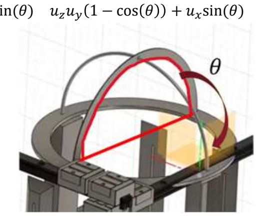
$$R_z(\varphi) = \begin{vmatrix} \cos\varphi & \sin\varphi & 0 \\ -\sin\varphi & \cos\varphi & 0 \\ 0 & 0 & 1 \end{vmatrix}$$



3. Matrix transformation of the Theta direction using Rodrigues's Rotation Formula. After the Phi transformation, the Theta Transformation is applied.

$R_{\hat{u}}(\theta)$=

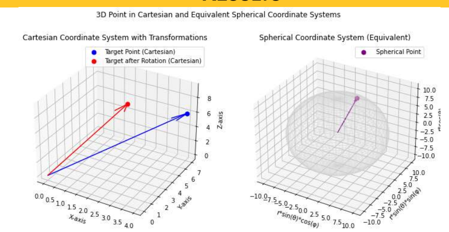
$$\begin{vmatrix} \cos(\theta) + u_x^2(1-\cos(\theta)) & u_x u_y(1-\cos(\theta)) - u_z\sin(\theta) & u_z u_z(1-\cos(\theta)) + u_y\sin(\theta) \\ u_y u_x(1-\cos(\theta)) + u_z\sin(\theta) & \cos(\theta) + u_y^2(1-\cos(\theta)) & u_y u_{zz}(1-\cos(\theta)) - u_x\sin(\theta) \\ u_z u_x(1-\cos(\theta)) - u_y\sin(\theta) & u_z u_y(1-\cos(\theta)) + u_x\sin(\theta) & \cos(\theta) + u_z^2(1-\cos(\theta)) \end{vmatrix}$$



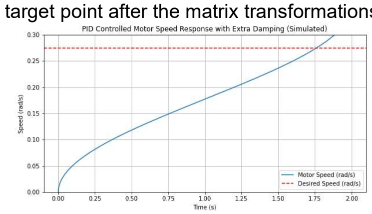
B. Motor and PID Tuning

- Using torque, load, speed requirements to determine suitable motor.
- Tuning of K_p, K_i, and K_d parameters in PID controller to optimize performance

Results



A python program calculates angle of rotation and tilt and displays the final spherical target point after the matrix transformations.



Graph showing the increase in speed of the motor represented by the blue line and the ideal speed of the motor in the red dotted line.

Summary, Conclusions and Future Directions

- successfully simulated the Phi rotations and Theta stereotactic tilt of the circular frame.
- demonstrated high accuracy and produced minimal errors when tested with random points.
- NEMA 34 DC motor fits the load, torque and speed requirements.

Future Directions

- scale of the testing needs to be larger to fit the scope of the device in real life.
- PID controller tuning for the motor needs more refinement to reduce overshoot and instability
- incorporation of feedback sensors for real-time positioning
- Physical prototyping

Conclusion

- The goal of automating 5 degrees of freedom and creating full freedom of motion was achieved.

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