Gyroscopic Stabilization for Uniaxial Rotational Hand Tremor

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Abstract

The goal of this project was to create a device to reduce the magnitude of hand tremors in individuals with Parkinson's disease or Essential Tremor. We focused on tremors that caused the hand to rotate about a central oscillator parallel to the forearm. We utilized the physical properties of a spinning gyroscope to act as a stabilization mechanism to dampen the tremor effects experienced by the individual. Our final prototype uses a small electric motor to spin a gyroscope on a swinging cradle, which in turn is mounted to the base mount. This allows the gyroscope to naturally precess due to an input torque and generate a counter torque along the axis of the hand's rotation. To monitor the device, we incorporated an RPM sensor in conjunction with an Arduino to receive sensory information about the speed of the gyroscope.

Final Product Specifications

Product Specifications	Goal	Final
Device Weight	1 lb.	0.9 lbs.
Device Dimensions (mm)	65 x 65 x 50	75 x 67 x 75
Maximum Gyroscope Speed	30,000 RPM	26,400 RPM
Tremor Magnitude Reduction	70%	83%
Runtime	1 Hour	2.5 Hours
Sound Limit from 6 Inches	Under 80 dB(B)	73 dB(B)

Physics

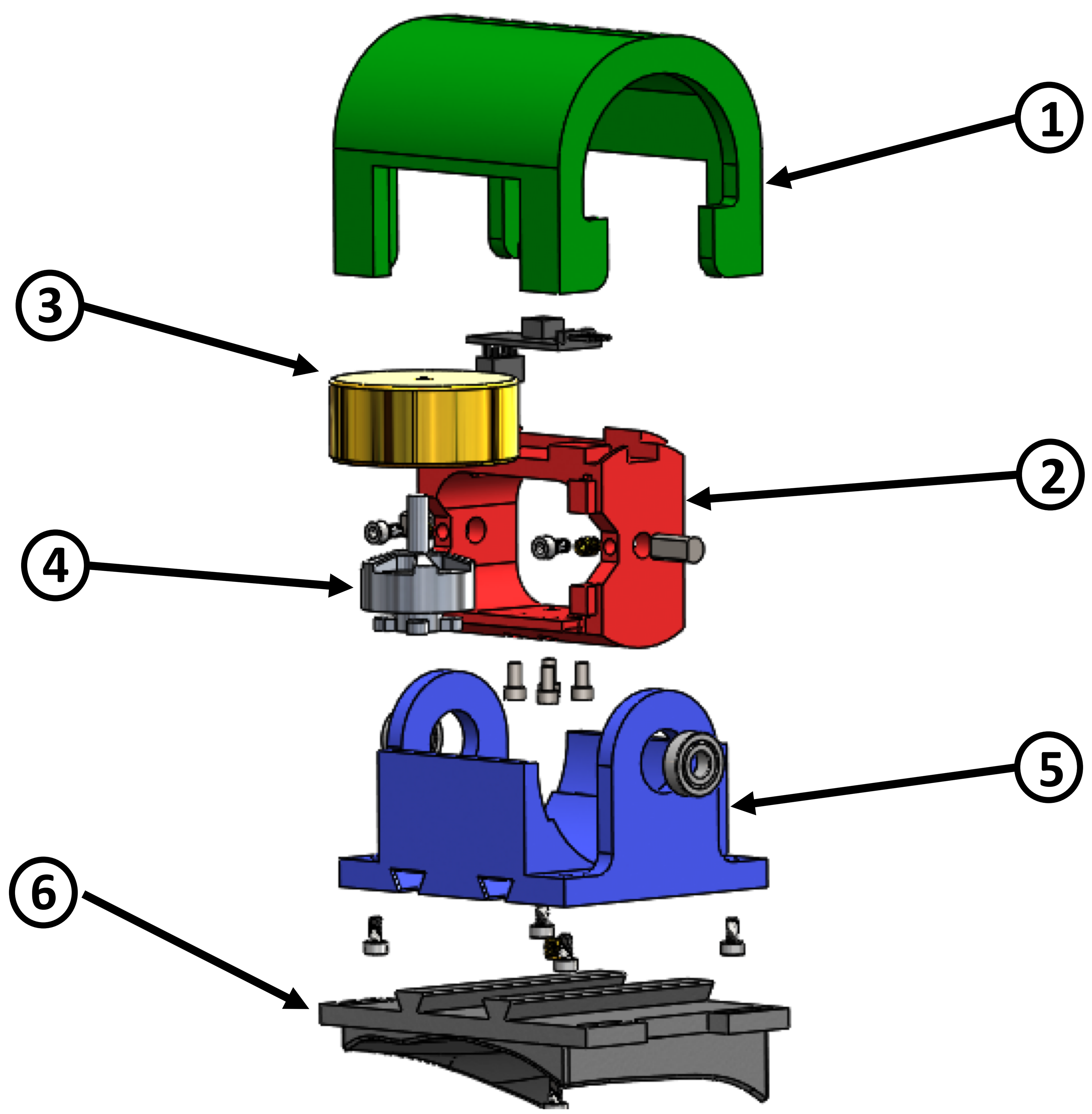
$$H * q_{acc} + C = F$$

- H represents the moment of inertia components of the gyroscope.
- q_{acc} represents the acceleration components about the normal and precession axes.
- C represents the inertias of the other components of the system.
- F represents the torques about the normal and precession axes.

$$H := \begin{pmatrix} m_f \cdot x_p^2 + m_f \cdot y_p^2 + m_f \cdot r_f^2 \cdot \cos(\phi)^2 + 2 \cdot m_f \cdot y_p \cdot r_f \cdot \cos(\phi) + I_{xf} \cdot \cos(\phi)^2 \ldots & -m_f \cdot x_p \cdot r_f \cdot \sin(\phi) \\ + I_{yf} \cdot \sin(\phi)^2 + m_w \cdot x_w^2 + I_{zw} + m_f \cdot x_p \cdot r_f \cdot \sin(\phi) & \\ -m_f \cdot x_p \cdot r_f \cdot \sin(\phi) & m_f \cdot r_f^2 + I_{zf} \end{pmatrix}$$

$$C := \begin{pmatrix} -2 \cdot m_f \cdot \omega \cdot \varphi \cdot r_f^2 \cdot \cos(\phi) \cdot \sin(\phi) - 2 \cdot m_f \cdot y_p \cdot r_f \cdot \omega \cdot \varphi \cdot \sin(\phi) - 2 \cdot I_{xf} \cdot \omega \cdot \varphi \cdot \cos(\phi) \cdot \sin(\phi) \ldots \\ + I_{yf} \cdot \Omega \cdot \varphi \cdot \cos(\phi) + m_f \cdot g \cdot x_p \cdot \cos(\theta) - m_f \cdot G \cdot y_p \cdot \sin(\theta) + m_w \cdot G \cdot x_w \cdot \cos(\theta) \ldots \\ + -m_f \cdot G \cdot r_f \cdot \cos(\phi) \cdot \sin(\phi) - m_f \cdot x_p \cdot r_f \cdot \varphi^2 \cdot \cos(\phi) + 2 \cdot I_{yf} \cdot \omega \cdot \varphi \cdot \sin(\phi) \cdot \cos(\phi) \\ m_f \cdot \omega^2 \cdot r_f^2 \cdot \cos(\phi) \cdot \sin(\phi) - I_{yf} \cdot \omega^2 \cdot \sin(\phi) \cdot \cos(\phi) + I_{xf} \cdot \omega^2 \cdot \cos(\phi) \cdot \sin(\phi) \ldots \\ + m_f \cdot y_p \cdot r_f \cdot \omega^2 \cdot \sin(\phi) - I_{yf} \cdot \Omega \cdot \omega \cdot \cos(\phi) - m_f \cdot G \cdot r_f \cdot \sin(\phi) \end{pmatrix}$$

Final Design

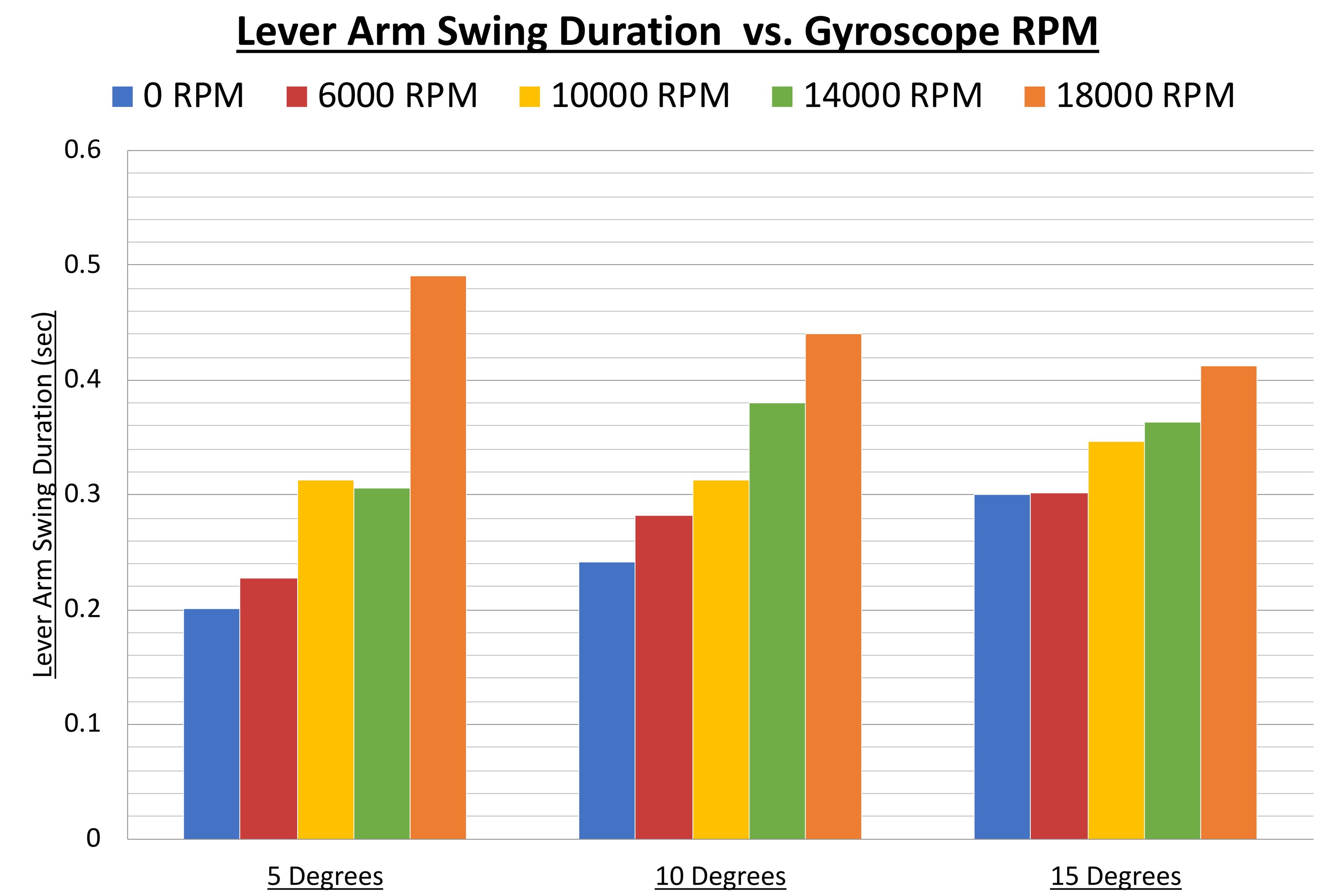


Part	Description
1. Cover	The cover provides a protective layer over the device and reduces the noise of the motor.
2. Cradle	The cradle holds the motor and gyroscope assembly and pivots to allow the gyroscope to precess as the system is rotated.
3. Gyroscope	The gyroscope resists the rotational motion of the hand tremor to dampen the magnitude of its oscillatory motion.
4. Motor	The motor spins the gyroscope between 4,440 and 26,400 RPM.
5. Base	The base piece is responsible for holding all of the components together, and acts as a central mounting location.
6. Hand Mount	The ergonomic plate is used to provide comfort to the wearer and increase effectiveness through secure contact. This platform can be adjusted to 95% of hand sizes.

Testing & Results

We conducted a simple lever arm test to determine the effectiveness of the gyroscope. From the data collected, two main observations were deduced:

- As the RPM of the gyroscope increased, the duration of the swing time increased.
- As the swing rotations of the lever arm were increased, the effectiveness of the device decreased.



Conclusions

Our model proved to be successful in both theory and practice. The device comfortably fits on a hand and greatly reduces the magnitude of hand tremors. The lever arm test demonstrated a potential of up to 83% tremor reduction. These results are further strengthened by the mathematical model indicating a potential of up to 87% reduction.

Recommendations

Our recommendations for future development are as follows:

- Improve the mechanism for attaching the device to the individual's hand
- Expand the sensory components to pursue making the device self-sensing and self-calibrating
- Conduct a hand tremor simulation test based on the model described in our paper
- Condense the electrical components onto a wearable apparatus