Vibrations Damping Glove for Parkinson's disease

A Final Year Project Report

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First and foremost, we would like to praise Almighty Allah for allowing us to use our knowledge, persistence, and courage to complete this project.

With immense pleasure we express our gratitude to our supervisor, Dr. Jawad Aslam PhD., and Professor, School of Mechanical and Manufacturing Engineering, National University of Sciences and Technology (NUST), for giving us the opportunity and providing invaluable guidance throughout this project. We also pay thanks to Dr Usman Bhutta for his guidance and help during the project.

Finally, we are extremely grateful to our parents for their love, prayers, and sacrifices for our education and it was their support that enabled us to finish this project.

ABSTRACT

Hand tremors have become increasingly widespread over the years. Although there are many causes of these tremors like Parkinson’s, anxiety etc. Essential Tremors are the most common cause. This neurological disorder causes uncontrolled shaking of hands that inhibits people from performing daily tasks like eating, cutting their nails etc. As of today, no definitive cure exists. According to an estimation, one million people have Parkinson's disease (PD) in Pakistan, and this number will increase up to 1,200,000 till 2030. Working on this does not just mean that we are making a device for our project, we aim to help a million people who are forced to compromise on their daily lives. Local research on such types of products is negligible if not completely absent, providing us with the perfect opportunity to fill the gap. Furthermore, few companies have tried to monopolize healthcare, making any advancement difficult. We plan to innovate and have an enormous impact while making our project as cost effective as possible so that it is within reach of the average Pakistani!

ORIGINALITY REPORT

We hereby declare that no portion of the work of this project or report is a work of plagiarism and the workings and findings have been originally produced. The project has been done under the supervision and guidance of Dr. Jawad Aslam and has not been a support project of any similar work serving towards and similar degree's requirements from any institute. Any reference used in the project has been cited and we take responsibility if found otherwise.

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ABBREVIATIONS

General

FE Flexion-extension
RUD Radial-ulnar deviation
PS Pronation-supination
COM Center of mass
EOM Equation of motion
SS State-space
LTI Linear time invariant

NOMENCLATURE

Symbol	Definition	Units
$\boldsymbol{mf}$	Mass of Gyroscope	g
$\boldsymbol{mw}$	Mass of Hand	g
$\boldsymbol{D}$	Distance	mm
$\boldsymbol{rf}$	COM of Gyroscope Along Y Axis	mm
$\boldsymbol{xp}$	Center of Precession Axis Along X1	mm
$\boldsymbol{yp}$	Center of Precession Axis Along Y1	mm
$\boldsymbol{t}$	Time	*Seconds (s)*
$\boldsymbol{f}$	Frequency	$Hertz$

$\boldsymbol{\Phi}$	Angular Displacement About the Precession Axis	deg
$\boldsymbol{\Omega}$	Angular Velocity of the Gyroscope	RPM
$\boldsymbol{\omega}$	Angular Velocity about the Wrist Joint	deg/s
$\boldsymbol{\varphi}$	Angular Velocity about the Precession Axis	deg/s
$\boldsymbol{q}$	Angular Displacement Matrix	deg
$\boldsymbol{qacc}$	Angular Acceleration Matrix	$deg/s2$
$\boldsymbol{Tw.in}$	Torque	$N*mm$
$\boldsymbol{Tw.r}$	Reaction torque caused by the system	$N*mm$
$\boldsymbol{Tp}$	Torque generated about the precession axis	$N*mm$
$\boldsymbol{T}$	Net torque in the System	$N*mm$
$\boldsymbol{Ixf}$	Gyroscope Moment of Inertia About the X	$g*mm2$
$\boldsymbol{Iy}$	Gyroscope Moment of Inertia about the Y	$g*mm2$
$\boldsymbol{Izf}$	Gyroscope Moment of Inertia about the Z	$g*mm2$
$\boldsymbol{Izs}$	Moment of Inertia of the Assembly about Z1	$g*mm2$
$\boldsymbol{L}$	Angular Momentum	$g*mm2/s$

CHAPTER 1: INTRODUCTION

1.1. Problem Identification

According to conservative estimates around 1 million people in Pakistan each year suffer from tremors caused by Parkinsons and many more suffer from tremors due to other underlying reasons such as old age. Tremors are caused by a variety of underlying disorders and can range in severity from a minor annoyance to a significant handicap that having a significant impact on one's everyday life. Due to the inability to keep one's arms and hands steady, activities such as eating, dressing, chores, and so on become significantly more difficult. Finding solutions to decrease and eradicate hand tremors is critical for people with these disorders to improve their quality of life. Because hand tremors are caused by a variety of underlying disorders, there is no single treatment that is successful.

Hand tremors can come from a variety of sources within the body, as previously described. Parkinson's disease and essential tremor are the two most frequent. Parkinson's disease, among other symptoms, impairs the brain's ability to produce dopamine, resulting in tremors. Essential tremor is a condition whose causes are still unknown. It is thought to be handed down genetically and causes tremors in a variety of sites and varies by severity level. Current treatments for these disorders are helpful but not permanent. We plan to change that!

1.2. Motivation

We intend to create a prototype gadget and eventually, a finished, cost-effective and ergonomic solution for people suffering from sufferers. For us, the most important motivation is to be catalyst for change and to contribute to society in our own way. As a result, we hope to assist others who are less fortunate, particularly the elderly, in leading more comfortable lives. Previously, this segment only had restricted options at expensive pricing to handle this very essential issue.

1.3. Problem statement

Many people, mostly the elderly, suffer from tremors that affect their daily life. All previous options are either one-dimensional, too costly, or too inconvenient. We are creating a product that leverages the physical phenomenon of gyroscopic precession to dampen tremors, using control systems to monitor and adjust the damping.

1.4. Scope

Several gadgets and solutions have been developed to help lessen the impact of tremors, either by reducing the tremor's influence during a certain activity or by completely eliminating the tremor. These devices can help persons with hand tremors do tasks that might otherwise be difficult. Eating and cooking are made easier with improved tools, while drinking is made easier with self-adjusting mug handles. However, the problem with these two gadgets is limited to the task for which they were created. There are now just a few products on the market that can eliminate or minimize tremors in the hand. The purpose of this research is to use gyroscopic stability principles in order to produce a gadget that actively reduces hand tremors. Attempts to pull rotating items off of their plane of rotation are naturally resisted. The rotating object exerts a greater resistance force as the impulse increases. This means that, while it will resist shakes with high frequency motions, it will allow steady, deliberate motion. This will allow people to live their lives without the limitations of hand tremors, and it can be used for a variety of jobs rather than just one.

CHAPTER 2: LITERATURE REVIEW

2.1. Gyroscope

A gyroscope is a device with a spinning disc or wheel installed on a base that allows its axis to freely rotate in one or more directions while maintaining its orientation regardless of the base's movement. However, in reaction to an external force, orientation shifts accordingly.

2.2. Working Principle

The gyroscope's working mechanism is based on gravity and can be described as the product of angular momentum experienced by the torque on a disc to produce gyroscopic precession in the spinning wheel. This is known as gyroscopic motion or gyroscopic force, and it is described as a rotating object's tendency to maintain its rotational orientation.

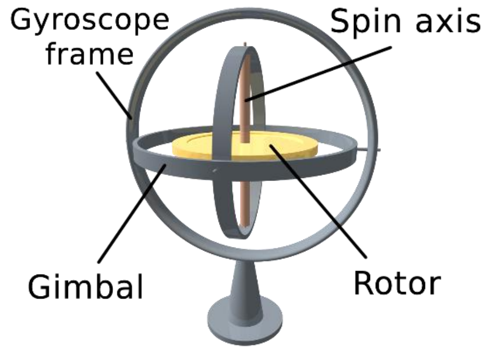


Figure 1: Gyroscope

We already know that the rotating object has angular momentum, which must be preserved. This is because any change in the rotation axis will result in a change in the orientation, which will affect the angular momentum. As a result, the gyroscope's operating principle is based on the conservation of angular momentum.

2.3. Gyroscopic Precession

When an external torque is applied to a spinning item (e.g., a gyroscope), the axis describes a cone in space, which is known as torque-induced precession (gyroscopic precession). Precession is most typically seen in a spinning toy top, but it can happen to any rotating object. If the rotational speed and the magnitude of the external torque are both constant, the spin axis will move at right angles to the direction that the external torque would suggest.

2.4. Uses of gyroscopes

Gyroscopes are employed in a variety of applications, including compasses and automatic pilots on ships and aircraft, torpedo steering mechanisms, and inertial

guidance systems in space launch vehicles, ballistic missiles, and orbiting satellites, to mention a few. For example, Gyrocompasses are preferred over magnetic compasses for navigation aboard ships because they offer two major advantages:

- They find true north as determined by the axis of the Earth's rotation, which is different from, and navigationally more useful than, magnetic north
- They are unaffected by ferromagnetic materials, such as in a ship's steel hull, which distort the magnetic field.

Types of Gyroscopes

The following are the three types of gyroscopes:

- Mechanical gyroscope
- Optical gyroscope
- Gas-bearing gyroscope

2.6 Tremors

A tremor is a shaking movement that occurs in one or more portions of your body in a rhythmic pattern. It is involuntary, which means you have no control over it. Muscle contractions are the cause of the shaking. The hands are most commonly affected, although it can also affect your arms, head, vocal cords, trunk, and legs. It could come and go or be constant. Tremors can occur themselves or as a result of another problem or disease, such as Parkinson's disease.

2.7 Types of Tremors (resting and acting tremor)

They can be divided into two types: resting tremor and activity tremor. Resting tremor is defined by the American Academy of Family Physicians as happening "... in a bodily part that is calm and completely supported against gravity" (Crawford, 2011). Resting tremor is identified when the individual does not purposefully stimulate the appendage in issue, but the body part nevertheless has tremors. Resting tremors are often made worse by mental tension or movement of other body parts, while conscious acts can momentarily alleviate resting tremors.

"Pill rolling" tremor is another name for resting tremor. Due to the circular movements of the hands and fingers, which resemble the rolling of small objects in the hands, such as pills. Parkinson's disease patients are more likely to have resting tremors. On the other hand, action tremor is described as a tremor that occurs when a person moves a muscle or appendage voluntarily or deliberately. The majority of tremors are classed as action tremors, which can be further divided into the tremor subcategories below, some of which overlap:

- *Postural tremor* occurs when the individual is attempting to maintain a specific position against the force of gravity, such as holding the arms in an outstretched position.
- *Kinetic tremor* relates to any deliberate movement, such as opening and closing hands.
- *Intention tremor* is generated with purposeful movement towards an intended target, such as touching the nose with a finger. In most situations, the tremor will get more pronounced as the individual gets closer to their target.
- *Task-specific tremor* is reserved for when the individual is performing a skilled, goal-oriented task, such as handwriting or drawing shapes.
- *Isometric tremor* occurs during a voluntary muscle contraction, which is not accompanied by other movement, such as holding a weight in a still position.

2.8 Parkinson's disease

Parkinson's disease is a neurological condition that causes tremors, stiffness, and difficulty walking, balancing and coordinating. Symptoms of Parkinson's disease normally appear gradually and worsen over time. People with Parkinson's disease may have difficulties walking and speaking as the disease develops. They may also have mental and behavioral changes as well as sleep issues, depression, memory problems, and exhaustion. Parkinson's disease can affect both males and women. However, men are affected relatively more compared to women.

The age of a person is a clear risk factor for Parkinson's disease. Although the majority of people with Parkinson's disease develop the disease around the age of 60, about 5 to 10% of persons with Parkinson's disease develop it before the age of 50. Parkinson's disease is generally inherited, although not always, and some kinds have been linked to specific gene alterations.

When nerve cells in the basal ganglia, a part of the brain that controls movement, become damaged or die, Parkinson's disease develops. These nerve cells, or neurons, normally create dopamine, an important brain neurotransmitter. When neurons die or become damaged, they produce less dopamine, resulting in Parkinson's movement issues. Scientists are still unsure what causes dopamine-producing cells to die.

Nerve endings that produce norepinephrine, the major chemical messenger of the sympathetic nervous system, which controls numerous bodily functions like heart rate and blood pressure, are also lost in people with Parkinson's disease. Some of Parkinson's non-movement symptoms, such as weariness, irregular blood pressure, slowed food movement through the digestive tract, and a quick drop in blood pressure when a person rises up from a sitting or lying-down position, could be explained by the loss of norepinephrine.

Lewy bodies, peculiar clumps of the protein alpha-synuclein, are found in many brain cells of persons with Parkinson's disease. Scientists are striving to learn more about alpha-normal synuclein's and pathological roles, as well as its association to genetic abnormalities that cause Parkinson's disease and Lewy body dementia.

Although some cases of Parkinson's are hereditary, and a few can be linked to specific genetic changes, the illness appears to strike at random and does not appear to run in families in the vast majority of cases. Many scientists now believe that Parkinson's disease is caused by a combination of hereditary and environmental factors, including toxic exposure.

2.9 Parkinsonian tremors

Parkinsonian tremor is a resting tremor that can affect any portion of the body, including the fingers, hands, mouth, and feet, unlike most other tremors. Resting tremors, as previously said, typically affect an individual's appendages when they are at rest. Parkinsonian tremor, on the other hand, can be seen in isometric and task-specific settings. Because parkinsonian tremor impairs the body's capacity to make the smooth and exact motions required to maintain the spoon stable and level, simple tasks like eating soup with a spoon become particularly challenging. Parkinsonian tremor is also an asymmetric condition, which means that the health of both sides of the body is unaffected by the health of the other. Even if one side is afflicted, it will always be the side that is more impacted (APDA).

Parkinson's disease is a movement disorder caused by a degenerative neural system disorder. Failure of nerve cells in the brain, numerous genetic abnormalities that raise the likelihood of Parkinson's, or environmental pollutants, such as exposure to harmful poisons, are the most common causes of Parkinson's. Parkinson's disease can produce slower movement, inflexible posture, decreased balance, and speech impairments in addition to tremors.

2.10 Ways to cure treat tremors

2.10.1 CURRENT TREATMENTS

Tremors have been studied extensively for a long time. A wide number of treatments have been established over that time. Medication, targeted ultrasound/radio waves, and surgery are the three main therapeutic options. Each provides a number of alternatives for combating the consequences of various ailments, each with its own set of benefits and drawbacks. Medication, for example, can be quite effective in reducing tremors, but it often comes with unpleasant side effects and the risk of people developing an immunity to it over time.

2.10.2 MEDICATIONS

Medications are frequently the first course of action recommended by doctors. There are numerous drugs available for each disease, and the one chosen is determined by a number of characteristics, including effectiveness, tolerance, health concerns, and tremor type. The following are details on the numerous drugs available for people suffering from two of the most prevalent tremor-causing conditions: Parkinson's Disease and Essential Tremor

2.10.2.1 ESSENTIAL TREMOR MEDICATIONS

The most prevalent tremor-causing condition is essential tremor (ET), yet there are presently no prescription medications for the treatment of essential tremor (IETF, 2018). Instead, medications are utilized to treat ET symptoms. These are drugs that have already been approved for use in other disorders, such as seizures and convulsions. While these drugs can be useful, they all have major flaws that make them ineffective as long-term remedies. The main issues include a lack of understanding of how these medications diminish tremors and, as previously said, individuals can become resistant to the treatments over time. The drugs are simply a band-aid for symptoms that can endure a long time.

Beta blockers and anti-seizure drugs are the two most commonly prescribed medications nowadays. For essential tremors, beta blockers are the primary line of treatment. Beta blockers like propranolol (Inderal), atenolol, metoprolol, and sotalol are thought to block nerve impulses that induce tremors. Although there may be an improvement as a result of taking the drug, it is only effective in 50-60% of people. The other regularly used beta blocker is Inderal, which is successful in reducing overall tremors but not eliminating them. After a year of treatment, roughly 10% of people taking Inderal for tremors quit benefiting from it, according to studies. Reason for it is currently unknown why this occurs because it is still not fully understood how it works to treat tremors yet.

2.10.2.2 PARKINSONIAN TREMOR MEDICATIONS

Unlike Essential Tremor, Parkinson's Disease has a number of drugs that are designed to treat the disease directly. Levodopa, which has been in use for almost 40 years, is one of the most popular medications. Levodopa is a drug that enters the brain and converts to dopamine. Parkinson's disease generates a dopamine shortage in the brain, which is what causes the tremors. Tremors are lessened when Levodopa is given as a supplemental supply of dopamine. It is effective, especially when used in tandem with dopa-decarboxylase inhibitors (DDCI). DDCI medicines, such as Carbidopa, decrease the conversion of Levodopa to dopamine in the peripheral nervous system, which minimizes adverse effects and extends the half-life of the drug, allowing it to be more effective for longer periods of time.

The procedure is one of the most effective treatments available, but it is not without its drawbacks. These symptoms include somnolence (extreme sleepiness), mood swings, nausea, hypotension, vomiting, and, in rare circumstances, worsening of their disease and depression. Long-term Levodopa administration has been linked to motor difficulties including dyskinesia. Despite these drawbacks, its efficacy in lowering symptoms makes it a better choice. Young patients, in particular, may find this appealing because they want to remain employable and physically active for as long as possible.

2.10.3 SURGERY

There are two basic surgical techniques for tremor-causing disorders. Their goals are distinct, as are the circumstances under which one is chosen over the other. The first procedure, thalamotomy, involves removing a portion of the thalamus that causes tremors. It performs the same function as radiofrequency ablation, but it carries greater hazards and is thought to be less effective, therefore it is no longer widely employed. Deep brain stimulation is the second way (DBS). This procedure involves implanting electrodes in the brain of the patient, which deliver signals to rectify the signals that cause tremors. As testing demonstrates its high level of effectiveness, this is becoming more common.

2.10.3.1 DEEP BRAIN STIMULATION

Deep brain stimulation, or DBS, is a new treatment that uses electrodes implanted in the brain to reduce tremors caused by confused signals. The electrodes are connected to a central hub, which is implanted in the patient's chest, similar to a pacemaker. DBS has been found in studies to be more effective than traditional medicines. In a 2006 study, the patients who received treatment were noted to have improved their symptoms more than the patients who received medication in 50 of 78 pairs. DBS is a promising option for people with Parkinson's disease and other tremor-causing diseases because of its lower risk of adverse effects (64 percent in the drug group, 50 percent in the DBS group).

The biggest disadvantage of this treatment is that when side effects do arise, they can be more severe. Seizures, infections, and stroke are all possible side effects or adverse events. Other negative effects of stimulation include numbness, tingling, muscle stiffness, speech and balance difficulties, and mood disturbances. Deep brain stimulation is a treatment that is always being improved, and with advancements to lessen these side effects, it could be a viable alternative for individuals with tremors.

2.11 PRODUCTS FOR HAND TREMORS

The two primary categories of assistive products are passive and active. Without moving parts, a passive gadget resists tremor. These designs make use of purposeful design elements to assist the user with a certain activity. Tremors are countered in real time by active gadgets. They establish a counteractive response to the tremor by using sensory or motion input from the body.

Products can then be further divided into tools and wearables. Tools are products that are designed for an individual to use in order to do a specific task. A wearable is a device that a person puts or straps to their body to help them lessen tremors. Wearables are also known as orthoses or orthotics, which are externally placed devices that change the anatomical and functional properties of the neuromuscular and skeletal systems.

2.11.1 PASSIVE ASSISTIVE DEVICES

Passive hand tremor devices are usually an ergonomic enhancement or a weighted object that aids the user's movement. Dexterity, which is essential for ordinary, everyday tasks like handling utensils, is one of the most difficult jobs for people with hand tremors. The spoon is a product that reconfigured the practical purpose of a spoon to suit those who can't keep their spoons steady. The broader, smoother handle is the first feature, increasing the amount of contact area with the hand. The hollowed cavity for the spoon's scoop section is the second feature. Users can now put food to their mouths without spilling anything.

Figure 2: Sup Spoon

The Readi-Steadi is a wearable orthotic that straps weights to the hand, wrist, and up to the elbow if needed, similar to how weighted utensils reduce tremor. The Readi-Steadi system reduces unwanted tremor movements by using unique weights. The weights successfully minimize the magnitude of the tremor by slowing down the arm, which is intended to reduce mild to severe tremors.

2.11.2 ACTIVE ASSISTIVE DEVICES

Tremors are reduced by active agents that produce counter movement or force. This category includes devices with moving elements and/or electronics that govern the device's response to tremors. Liftware Steady is a smart modular utensil for eating that comes with a range of utensil attachments.

On the utensil end, the device combines advanced sensor and motor-based cancelling technology to provide active stability. Sensors in the handle monitor the quantity and direction of the motion produced and adjust the utensil end accordingly to keep it level.

Figure 3: Liftware

This technology is like that used to stabilize buildings and structures against earthquakes. The joint contains a dampening fluid that resists the impulses generated by tremors. The developers say that it reduces movements of a frequency greater than 2 Hz (2 movements per second) and does not provide as much resistance to movements less than 2 Hz. The system allows for full range of motion.

CHAPTER 3: METHODOLOGY

3.1 Prototyping Stage 1:

To begin with, we planned on making a simple working prototype that exhibits gyroscopic precession. The axle of the spinning rotor strives to stay pointed in the same direction as the gyroscope is spinning, according to a basic law of physics. Gyroscopes, which are commonly used for ship and aviation navigation, are based on this principle. There is no effect until that hand and arm are shaking. The gyroscope, on the other hand, reacts when brain sends a Tremor signal to that hand, like as twisting or shaking it. The gyroscope's axle would be twisted to modify the orientation of the tremor. The gyroscope reacts by creating a torque that immediately acts to offset the Tremor's twisting movement.

3.1.1 Software Selection:

The first step was to select an appropriate software for design and analysis. Our device incorporates many forces being applied hence we needed a software that incorporated it. Amongst all the design and analysis software's we have used, "SolidWorks" fits perfectly for this hence we settled for it. The same software would also be used to calculate various parameters of respective parts to be used.

3.1.2 Initial Calculations:

Initially we did some rough calculations to obtain an outlook regarding we what we require. We made certain assumptions, at this stage we used the concept of angular momentum and related the angular momentum of the hand to that of spinning gyroscope. The results were as under:

Average Tremor Frequency = 6Hz (From research papers)

Required RPM = 9,654

3.1.3 Motor Selection:

With the RPM figure in hand, we needed a motor that would provide the required RPM. We started our research on motors and came across two types of motor:

1- **Brushed DC motors**

A brushed DC electric motor is an internally commutated motor that uses an electric brush for contact and is powered by a direct current power source.

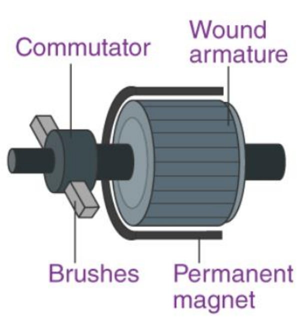


Figure 4: Brushed DC Motor

2- Brushless DC motors

Brushless DC electric motors, also known as electronically commutated motors or synchronous DC motors, are synchronous motors that run on direct current.

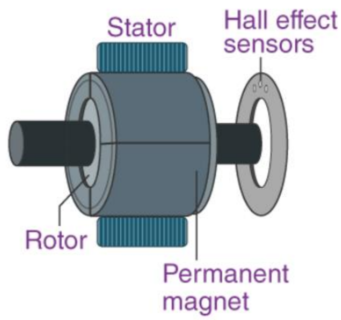


Figure 5: Brushless DC Motor

Since we required a higher Torque to weight ratio and high RPM hence, we choose to further down our research on brushless DC motors.

Now we had to decide a specific motor out of all the available on the market. Since we were at a very basic stage of prototyping, we chose the most easily available and economic motor.

Figure 6: A2212 Kv1000 Brushless Motor

The motor specifications are as under:

- Model : A2212
- RPM/V : 1000KV
- No Load Current : 10V / 0.5A
- Max Current : 12A / 60s
- ESC Current : 30A
- LiPo Battery : 2-3S
- NiCD / NiMH Battery : 6-9S
- Shaft Diameter : 0.125? / 3.175mm
- Dimensions : (5.51 x 7.09 x 3.94)" / (14 x 18 x 10)cm (L x W x H)
- Weight : 9.7oz / 275g

3.1.4 Designing a gyroscope

The next step was designing a gyroscope that could be mounted onto the motor's shaft, for this purpose we chose Nylon as it was readily available, and it has a certain bit of weight to it as per initial requirements. The designing was done on SolidWorks after which we machined it using lathe according to our requirements.

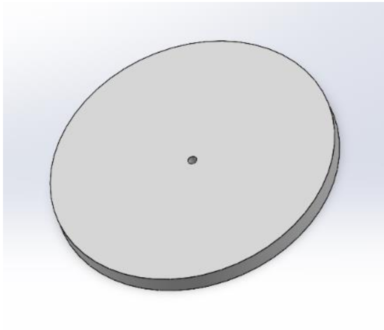


Figure 7: Nylon Disc

3.1.5 Speed Controller

In order to make the motor functional we got a 30A ESC that would be powered by a 1000mAh 2s battery. For varying the RPM, we got a servo tester.

Figure 8: Servo Tester

3.1.6. Sketching/ designing

With all the initials and sourcing the basic design was sketched, and the result was

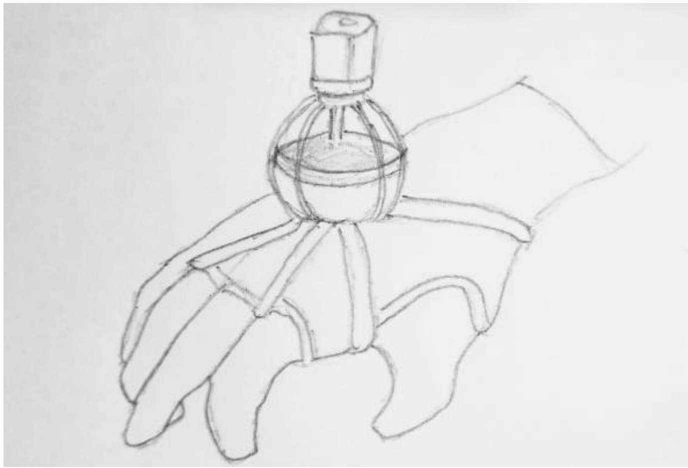


Figure 9: Sketch Prototype 1

An uncomplicated design encompassing a hand glove with a motor that rotates a gyroscope.

3.1.7 Bill of Materials

The total cost of prototype 1 including all of the individual parts are given in the following table

description	amount
Motor	Rs 1,500.00
Controller	Rs 750.00
Wires and connectors	Rs 1,200.00
Nylon	Rs 200.00
Misc	Rs 350.00
Total	Rs 4,000.00

Table 1: Material list and cost

3.1.8 Fabrication

All the individual components were attached together. The wiring was pretty basic hence with some soldering, the motor was ready to be used. The motor came with a base which was used to mount it on the glove. Attaching the Nylon Disc to the shaft came with a bit of challenge and in this regard, we used a tight fit so the disc is properly attached to the motor and there isn't any kind of slipping. Overall, after attaching everything, the glove looked something like:

Figure 10: Prototype 1

3.1.9 Testing

The first prototype was tested on several humans under various conditions and various results were obtained. A point to note here is that the prototype was never intended to be the final product but as a base for the final prototype.

Figure 11: Close view of prototype

3.2 Prototyping Stage 2:

With the various results obtained from prototype 1, we realized that we need to make major modifications into the whole glove and hence an entirely different design approach was required.

3.2.1 Modifications

We needed to amend or modify 4 segments of the device

1- Reconfiguration of the whole device
2- Redesigning the gyroscope
3- Using a different motor
4- Automatic Speed Control using sensors

3.2.1.1 Reconfiguration of the whole device:

Currently the motor was fixed but according to tests the motor should have the ability to rotate hence, we had to adapt a gimbal like structure with movement possible along one axis. To achieve this, we adapt an axis travelling through the center of the wrist joint which restricts hand movement. The gyroscope rotates about the spin axis of motor while the motor is capable of rotating about the precession axis. The wrist joint axis was able to point in one of the three cardinal directions:

1. Wrist flexion-extension (FE)
2. Wrist radial-ulnar deviation (RUD)
3. Forearm pronation-supination

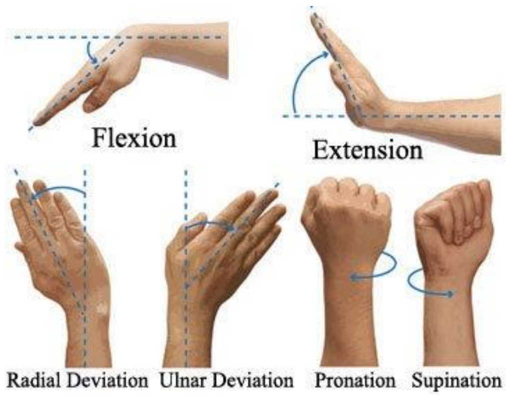


Figure 12: Various axis wrt hand orientation

Gyroscopes can be oriented in six different ways. There are 18 possible cardinal configurations when the 6 possible ways are combined with the 3 distinct ways of describing the joint axis.

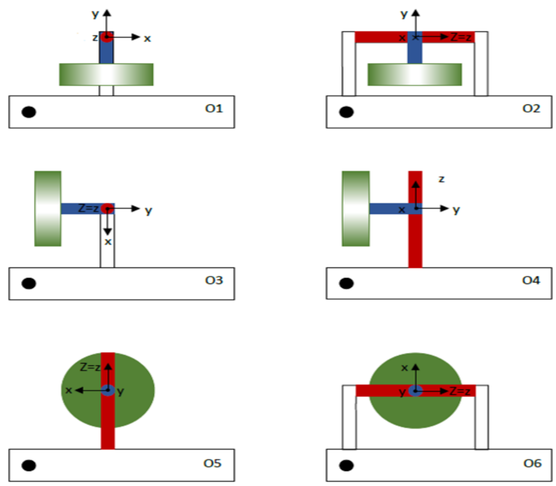


Figure 13: Possible Configurations

Due to the wrist joint axis being parallel to the precession axis, conservation of angular momentum would not hold, and hence torque would not be imposed on the wrist joint axis in 6 of the 18 configurations which leaves us with 12 configurations. If the axis of the wrist joint is parallel to the spin axis, the initial torque will be orthogonal to the axis of the wrist joint, but with further precession, a component will form around the axis of the wrist joint. That leaves us with 6 configurations from which we must choose one.

According to research majority of tremors occur due to flexion-extension movement hence, **configuration of O2 will be considered** for further development.

3.2.1.2 Redesigning the Gyroscope

The gyroscope plays a pivotal role in the device. Many aspects of the final design, such as weight, comfort, noise, and efficacy, are determined by the qualities of this component. The gyroscope needed to have a big enough moment of inertia to create a stabilizing force for the gadget to work. However, it had to be as tiny and light as possible to keep its size and weight to a minimum. When the gyroscope was being produced, special care was also required. Small abnormalities in the gyroscope might cause the gyroscope to oscillate at a high frequency due to the high working RPMs. This might cause the gadget to vibrate excessively, making it noisy, unpleasant, and ineffective.

The gyroscope is designed using moments of inertia concepts to optimize angular momentum while being as tiny and light as feasible. The form and mass of an item determine its moment of inertia. The team built the gyroscope to be as efficient as possible to optimize the moment of inertia while keeping the weight to a minimum. This was accomplished by combining the form of a ring, which has the greatest geometric constant, with the geometry of a disc, which has the second highest constant and serves as a contact point for the motor shaft.

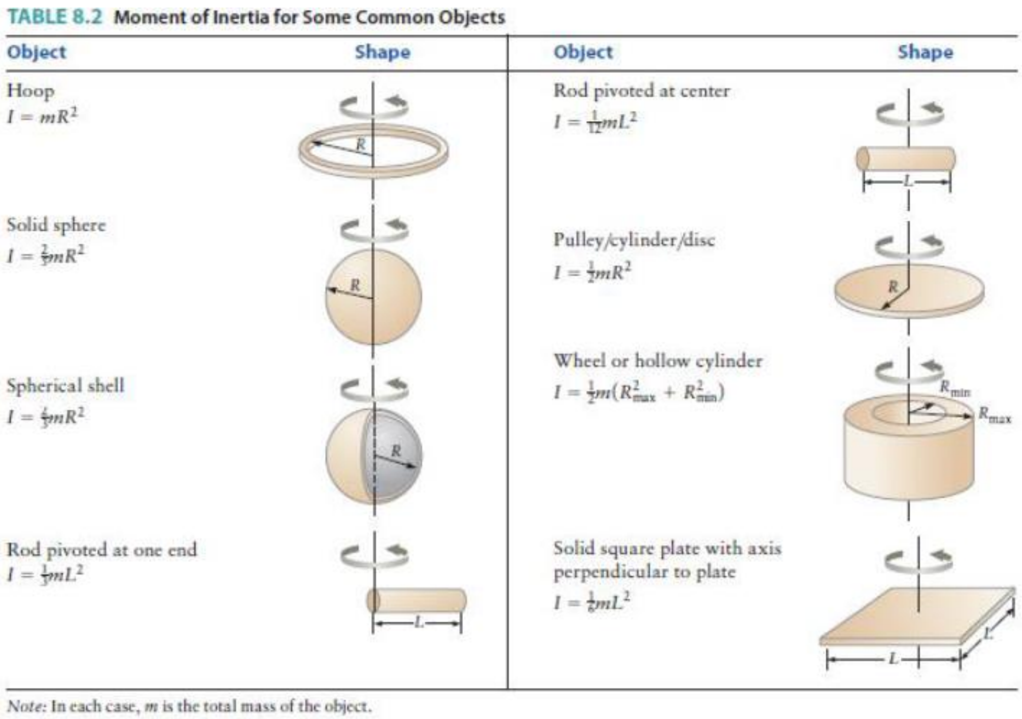


TABLE 8.2 Moment of Inertia for Some Common Objects

Object	Shape	Object	Shape
Hoop $I = mR^2$		Rod pivoted at center $I = \frac{1}{12}mL^2$	
Solid sphere $I = \frac{2}{5}mR^2$		Pulley/cylinder/disc $I = \frac{1}{2}mR^2$	
Spherical shell $I = \frac{2}{3}mR^2$		Wheel or hollow cylinder $I = \frac{1}{2}m(R_{max}^2 + R_{min}^2)$	
Rod pivoted at one end $I = \frac{1}{3}mL^2$		Solid square plate with axis perpendicular to plate $I = \frac{1}{6}mL^2$	

Note: In each case, *m* is the total mass of the object.

Figure 14: MOI of different shapes

The gyroscope was made of brass, which is the densest material that the WPI Machine Shop could cut. We opted to increase the gyroscope's density since it would provide the most moment inertia while taking up the least amount of space.

3.2.1.3 Using a different motor

We needed to accommodate two things in our motor:

1- We needed a more powerful motor that could rotate brass at high RPM.

2- Instead of a simple shaft, we needed a threaded shaft so we can thread the internal hole of the gyroscope too and attach the two parts tightly. Threading also caters for the potential wobbles during rotation which may arise during simple rotation of disc on a shaft.

3- It should be economical.

Keeping these points in mind, we started our research on the potential motors. The motor which seemed most suitable to us and was easily available in our region was **Tmotor f80 pro.**

Figure 15: T motor F 80 pro

The specs of the motor are as following

- KV: 2500
- Rated voltage: 3-4s
- Shaft Diameter: 4mm
- Motor weight w/ cable: 39.7g
- Motor weight without cable: 36.4g
- Peak current: 47.6 amps
- Max Power (60s): 706W
- Configuration: 12N14P
- Motor Wire: 150mm

The battery rating for this motor is 2-5S, which indicates the voltage range that the motor can receive from the battery. The voltage range for this motor is 7.4-21V. With a kV rating of 2,500, the theoretical maximum RPM is 46,250 RPM when paired with the maximum voltage rating. The motor has a diameter of 24 millimeters and a height of 20 millimeters.

3.2.1.4 Automatic Speed Control using sensors

The brain of the machine is the most important component, and its significance cannot be overstated. Especially when clever control is required to accommodate the wide range of vibration intensities that can occur during hand tremors. The electronic systems and components that control and power the gyroscope is covered in this section. The many subsystems are divided into four categories: power, control, sensory, and data processing.

3.2.1.4.1 Power System

The power system's job is to provide energy to the motor that spins the gyroscope. The power system is critical for generating the spin required to counterbalance the torque produced by hand tremors. The power supply, the speed controller, and the motor are the three components of the power system. Each component was carefully chosen using a decision matrix to assess competing products and verify compatibility to prevent other components from being damaged.

The team decided to use a rechargeable battery to provide power to the system because of its portability. As previously stated, the brushless motor and ESC specs determine the battery specifications. The type of battery and the battery capacity were also taken into account. The energy density and output current are the driving characteristics to consider for the type of battery. When compared to other batteries currently on the market, a lithium polymer (LiPo) battery provides the best energy density. Based on our system requirements, 2S LiPo battery was selected. The 2S refers to the battery's two cells that are connected in series and have a nominal voltage of 3.7 volts each. This battery was also chosen because of its huge capacity, which immediately boosts the motor's potential runtime. However, the battery's size and weight had to be considered, as the battery would be put on the portable pack and would need to be light and pleasant to wear. The 2S battery provided adequate runtime as well as the requisite compactness.

3.2.1.4.2 Sensor System

Sensors are required to give input data for an adaptive control system. An Arduino microcontroller was utilized to connect with the sensors, as previously described. The sensors that were chosen for this project, as well as their capabilities, are listed below.

Gyroscopic stability is created by the gyroscope's angular velocity and moment of inertia. The moment of inertia, on the other hand, remains constant, whereas the disk's RPM can be changed. Three basic types of tachometers to measure the RPM of a spinning item were found currently available on the market: mechanical, optical, and stroboscopic. The optical tachometer was chosen for this project because it uses an infrared (IR) emitter and receiver device that is wired to an integrated chip. A reflective tape or surface must be placed over a piece of the rotating surface for the IR sensor to detect speed. When the emitter sends out an infrared signal, the tape reflects it for the receiver to read. Each time a reading is made, one revolution has passed.

Hand tremors are movements that revolve around the hand's core. To accurately quantify that motion, an inertial measurement unit (IMU) was utilized. To measure translational and rotational motion, an IMU incorporates a microelectromechanical system (MEMS) accelerometer and gyroscope transducer. When choosing a transducer for monitoring hand tremors, there are numerous aspects to consider. Axis, range, and resolution are the most important elements. The top and lower limits of what each sensor can measure are referred to as range. Hand tremors are defined as occurring at a frequency of 3Hz or greater for the purposes of this project. When converting an analogue voltage to a digital value, resolution refers to the level of detail in a measurement. The six-axis MPU 6050 was chosen for this project. The accelerometer has a range of +/16g, and the gyroscope has a range of +/- 2000 degrees per second.

It's also worth noting that a voltage sensor was connected to the battery because the motor speed is also affected by the power source's input voltage. This monitors the battery voltage and provides real-time information on the battery's capacity to the system.

3.2.1.4.3 Control system

The control system oversees the ESC in the power system. The goal was to make the control mechanism adaptable to tremors in the hands. This meant that if the system detected strong or high amplitude hand tremors, the RPM of the motor would be increased, and if the system detected minimal or less severe tremors, the RPM of the motor would be decreased. The ESC requires a pulse width modulation (PWM) signal to control the motor's RPM. To do so, a HJ digital servo tester is used to generate a changeable PWM signal. With a frequency of 50 Hz, the signal pulse length ranged between 800 and 2200 microseconds.

To make the system smart the ESC was connected to an Arduino after the round of testing using the servo speed controller. The Arduino was programmed to send PWM signals to the ESC. A Micro Electro-Mechanical System (MEMS) sensor was used to make reading of the hand tremors that were to be dampened. MPU6050 was selected as it has a gyroscope as well as an accelerometer built in that fulfilled all the requirements from the sensor.

An important point to note is that the reading used to measure the intensity and in return control the speed (rigidity) of the gyroscope was that of acceleration and not the instantaneous angle or frequency of tremors. The reason for this is that the gyroscope dampens the vibrations but does not affect the frequency of the vibrations and hence cannot be used with frequency measurements for control. The amplitude of the acceleration waveforms was the most crucial measurement, and it was used to measure the tremor intensity.

3.2.1.4.4 Data Processing System

The data processing system's job is to log sensor data and offer input for the adaptive response to be created. Analyses can be performed based on the sensory input to ascertain the tremor's characteristics and the effect of the disk's dampening.

The Arduino microcontroller is used to interface and manipulate the gyroscope speed in the control and sensor system. Arduino is used to interpret data from the sensors and send appropriate values to the ESC to control the motor speed, hence the rigidity of the gyroscope. Following a part of the data logged from the MPU6050 which shows the yaw, pitch and roll values.

ypr	-1.23	69.85	-14.53
ypr	-1.24	69.85	-14.52
ypr	-1.22	69.85	-14.47
ypr	-1.23	69.84	-14.45
ypr	-1.22	69.83	-14.46
ypr	-1.24	69.80	-14.45
ypr	-1.26	69.77	-14.44
ypr	-1.26	69.77	-14.44
ypr	-1.27	69.76	-14.46
ypr	-1.24	69.75	-14.46
ypr	-1.16	69.75	-14.43
ypr	-1.11	69.73	-14.38
ypr	-1.03	69.74	-14.35
ypr	-1.01	69.73	-14.31
ypr	-0.97	69.73	-14.29
ypr	-0.92	69.75	-14.26
ypr	-0.83	69.78	-14.30
ypr	-0.74	69.83	-14.35
ypr	-0.65	69.87	-14.39
ypr	-0.57	69.90	-14.41
ypr	-0.51	69.92	-14.44
ypr	-0.45	69.94	-14.46
ypr	-0.44	69.93	-14.47
ypr	-0.41	69.92	-14.47
ypr	-0.40	69.94	-14.42
ypr	-0.40	69.95	-14.39
ypr	-0.39	69.97	-14.39
ypr	-0.39	69.97	-14.41
ypr	-0.40	69.95	-14.43
ypr	-0.43	69.93	-14.41
ypr	-0.46	69.89	-14.38
ypr	-0.47	69.8	

ypr	0.73	3.92	-1.80
ypr	0.86	4.13	-1.80
ypr	1.02	4.35	-1.79
ypr	1.17	4.56	-1.79
ypr	1.32	4.75	-1.78
ypr	1.47	4.93	-1.76
ypr	1.62	5.06	-1.74
ypr	1.74	5.15	-1.71
ypr	1.83	5.21	-1.68
ypr	1.90	5.22	-1.65
ypr	1.94	5.18	-1.62
ypr	1.95	5.09	-1.59
ypr	1.94	4.97	-1.56
ypr	1.91	4.83	-1.54
ypr	1.86	4.66	-1.53
ypr	1.78	4.49	-1.50
ypr	1.69	4.31	-1.48
ypr	1.59	4.12	-1.47
ypr	1.49	3.94	-1.46
ypr	1.39	3.78	-1.46
ypr	1.28	3.66	-1.45
ypr	1.19	3.57	-1.45
ypr	1.12	3.52	-1.45
ypr	1.05	3.50	-1.45
ypr	1.00	3.53	-1.45
ypr	0.98	3.59	-1.46
ypr	0.97	3.68	-1.46
ypr	0.97	3.79	-1.47
ypr	0.98	3.93	-1.47
ypr	1.02	4.08	-1.47
ypr	1.06	4.25	-1.48

3.2.2 Designing the Final Device

3.2.2.1 Cradle

The cradle is the most crucial component that was added to the design. The cradle is a rotating component that permits the gyroscope to precess within the base. The gyroscope's COM was centered around the cradle's rotating axis, guaranteeing that the system would be generally balanced once constructed. The final model can be seen below:

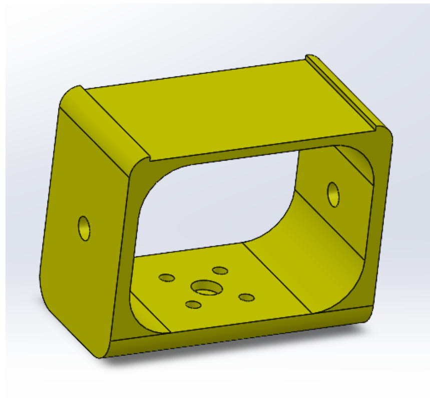


Figure 16: Cradle CAD

3.2.2.2 Base

The base is what keeps the cradle in place, initial base was designed without any barriers hence the cradle would get struck in the wirings. During the next step, two boundary walls were introduced which stopped the cradle from rotating beyond a certain angel. The base had extruded cuts on its bottom to accommodate the fitting of it to the other part.

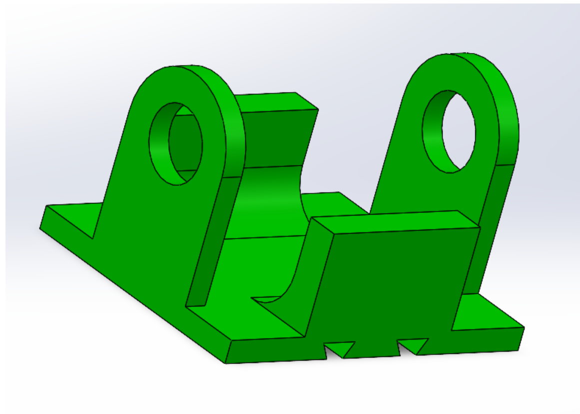


Figure 17: Base CAD

3.2.2.3 Hand Mount

The hand mount's goal is to offer a secure and comfortable manner for the gadget to be mounted on a hand. The mounting surface must be comfy since the user will not want to wear it if it is not. The gadget must also be securely connected to the hand, as this has a direct effect on the device's performance. If it is allowed to shift and slide, the gadget will be unable to respond appropriately to hand motions. The hand mount's initial design was based on the size of an average male's hand; however, the scale of the device may be adjusted, allowing it to accommodate 95 percent of hand sizes. The finished hand mount design is seen below

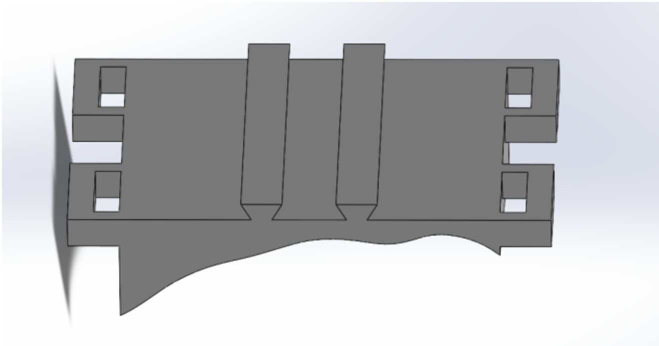


Figure 18: Hand Mount CAD

3.2.2.4 Gyroscope

The gyroscope was designed keeping in view the size constraints and required moment of inertia. An M5 hole was drilled to accommodate the threading of motor. The outer diameter is 36mm.

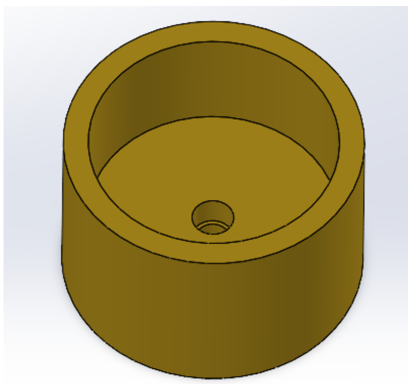


Figure 19: Gyroscope CAD

3.2.2.5 Cover

The cover was designed not only to conceal the device but also to suppress the sounds produced by motor. The cover has two opening on both sides to accommodate the entry and exit of wires and provide a route for proper heat dissipation. The cover is a perfect fit for the device and nothing inside is visible once it is intact.

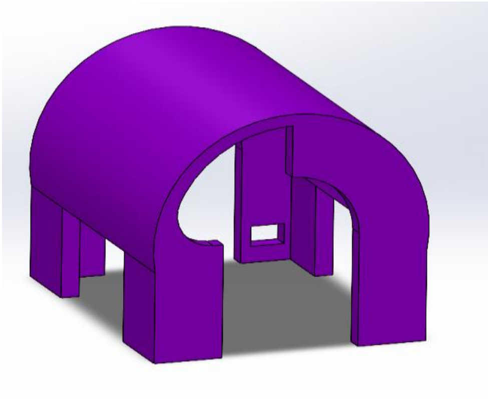


Figure 20: Cover CAD

3.2.3 Final Design

Except for the gyroscope, which was machined on a lathe, all the components detailed above were created using PLA plastic and a 3D printer. The infill for each component varied which was according to how much load it had to bear. The hand mount and cradle were made with 100% infill, the base was made with 80% infill while the cover was made with 50% infill. The exploded view of the final assembly is as follows:

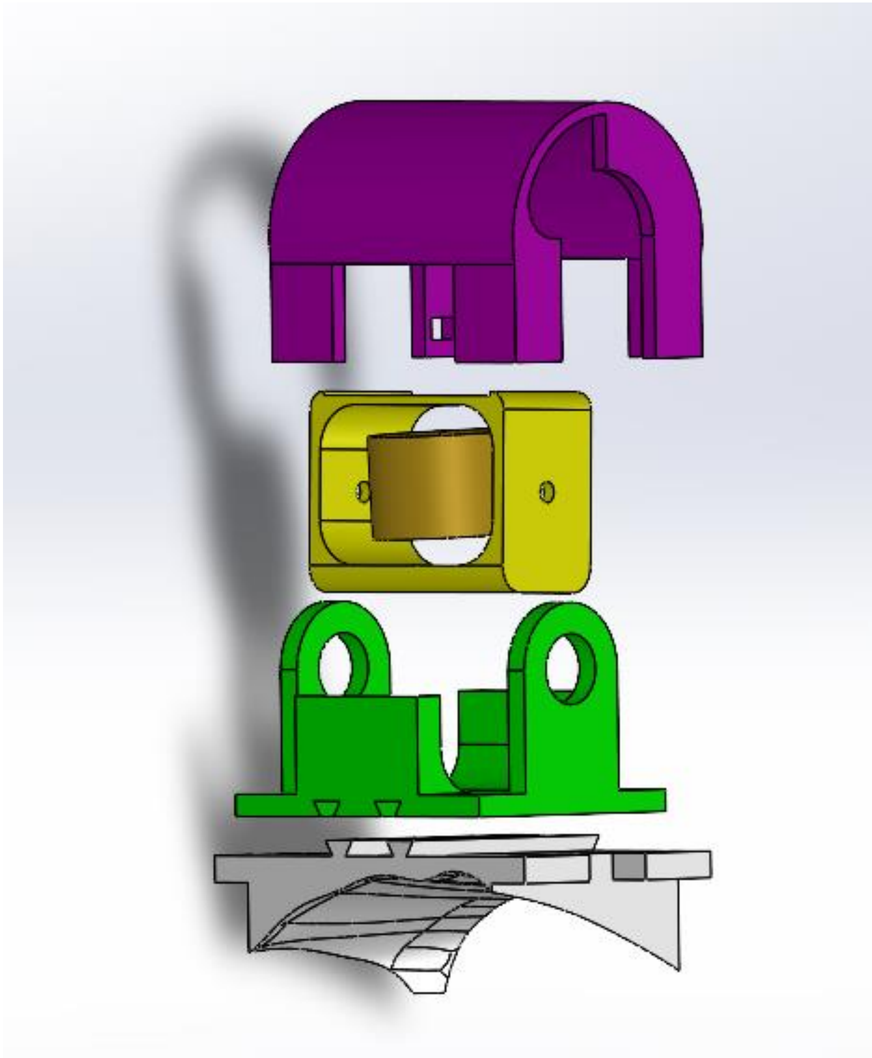


Figure 21: Exploded View

The parts were assembled with each other. 625zz ball bearing were used to join the cradle with the base. To make the hand mount wearable, custom straps were made with stick on. As previously indicated, the hand mount platform may be customized to accommodate 95% of hands.

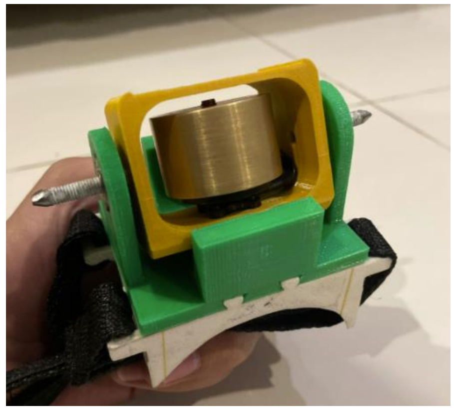


Figure 22: Fully Assembled Model

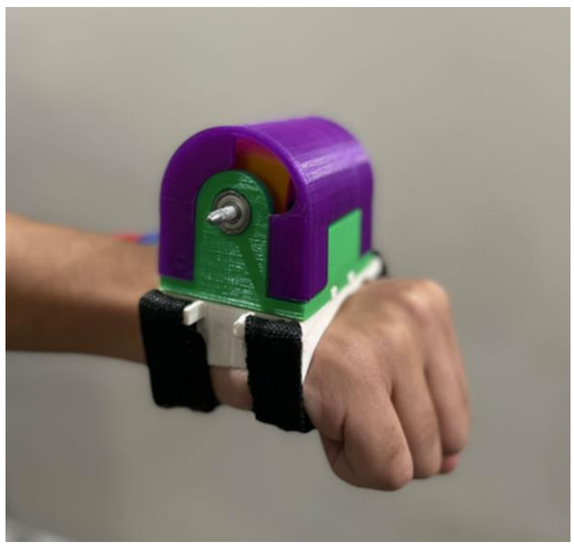


Figure 23: Final model worn on hand

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Introduction

Our main aim as stated before was to make a simple wearable device which can prove to be an assistive gear for patients suffering from Parkinson's and essential tremors. Due to lack of research available online, we had to make two prototypes instead of one so we can build upon the conclusions if the first prototype. 4.2 Prototype 1 results

Prototype 1 was very simple in nature. It constituted of a brushless DC motor which rotated a gyroscope thus catering for the tremors.

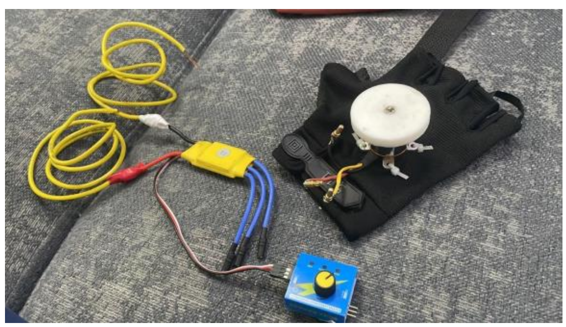


Figure 24: Prototype 1

After initial testing of the device on various people and putting it in different situations we found the lacking where our device needed some major amendments. The major problems that we noted were

4.2.1 Fixed structure problems

The motor was fixed on the glove and there was no tendency for it to rotate. Even though the glove was catering for the tremors produced but they were far too low and the reason for this was that for the counter torque to act efficiently, the gyroscope should have the tendency to rotate about precession axis.

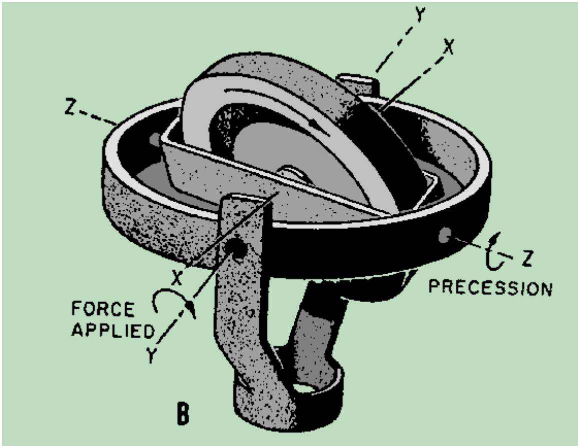


Figure 25: Gyroscope

Hence a total reconfiguration of the device was required.

4.2.2 Issues with the gyroscope

Despite being a tough material, Nylon disc had some major drawbacks which forces us to change it. For starters the threading on the disc is not at all feasible at high rpms, the disc melts incase if slipping which cause size issues.

The major problem though with the material was its low density. We required a disc with a certain moment of inertia, but to obtain that on nylon, our disc had to be exceptionally large making it very inconvenient. Thus, we needed to look for alternatives, to accommodate all these issues.

4.2.3 Issues with the motor

The **A2212 Kv1000 Brushless Motor** had some major drawbacks, the motors threshold RPM was too low thus not sufficient. The disc was very difficult to attach onto the shaft. After research, **Tmotor f80 pro** was used which overcame all these issues.

4.2.4 Need of some automated speed control

Parkinson's as well as essential tremors vary from person to person. The first prototype has fixed speed options, meaning the rpm of motor would stay the same irrespective of whether the tremors are being catered or not. Also, in order the vary the rpm of motor, a separate nob has to be rotated making it very inconvenient and highly unlikely to be used.

There's a need of some automatic sensing system which would sense the frequency of tremors in the hand and adjust the speed of the motor accordingly. That would make the device very easy to use and thus the only way the user would interact with the device would be a simple switch.

4.3 Prototype 2

The prototype 2 was built on the shortcomings of prototype 1. All issues stated were dealt with step by step. After reconfiguration of the whole device, the parts were designed on SolidWorks and 3D printed.

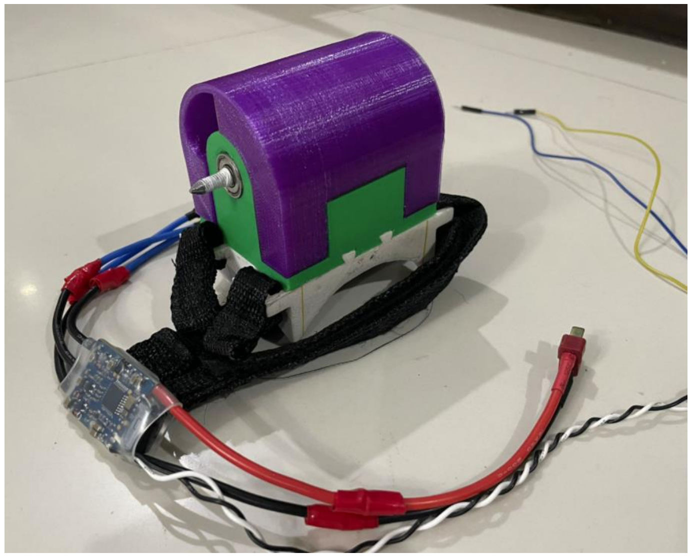
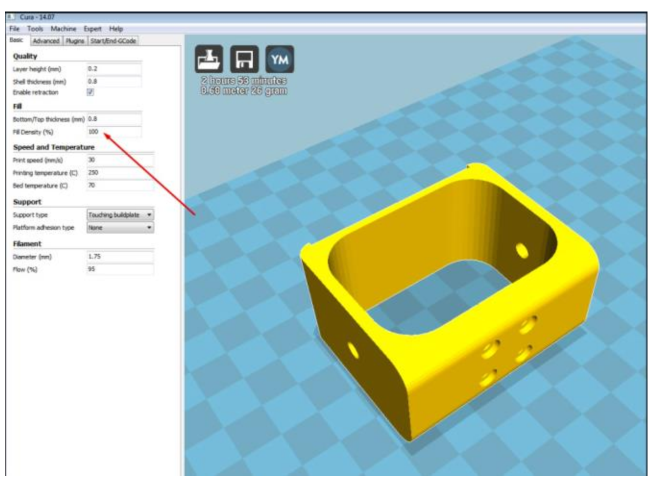


Figure 26: Final Prototype

A breakdown of individual parts is shown as follows:

4.3.1 Cradle

The cradle is what’s going to hold the whole motor in place and move about the precession axis hence it was carefully made and 100% infill was used to provide maximum strength.



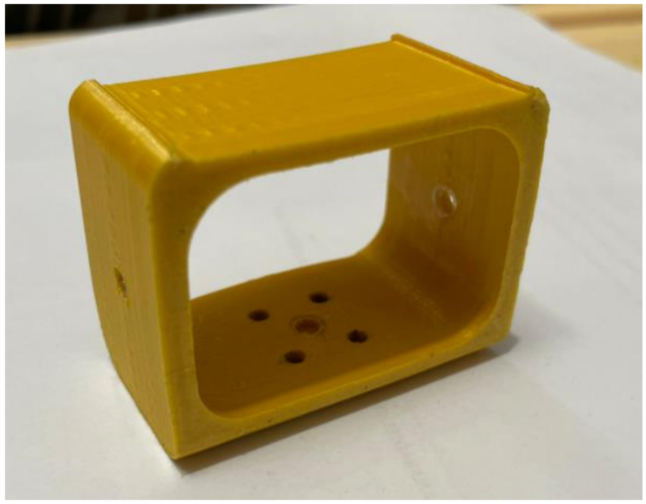
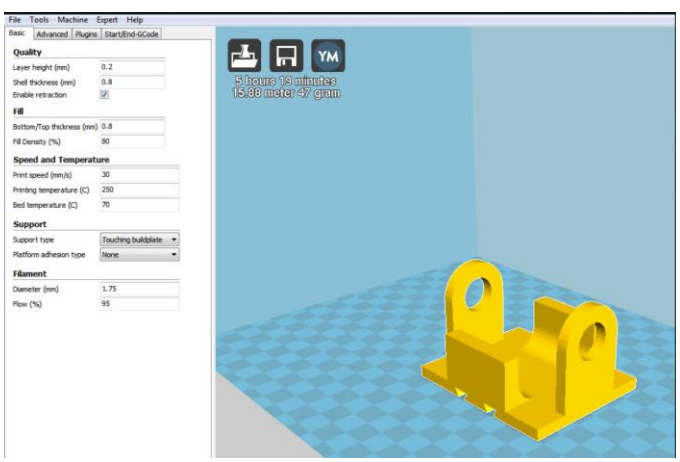


Figure 27: 3d model and printed model of cradle

4.3.2 Base

The base which was going to hold the cradle would be attached to it via a pair of screws using ball bearing. The base was made with 80% infill as stress analysis deemed the design to be safe at this value.



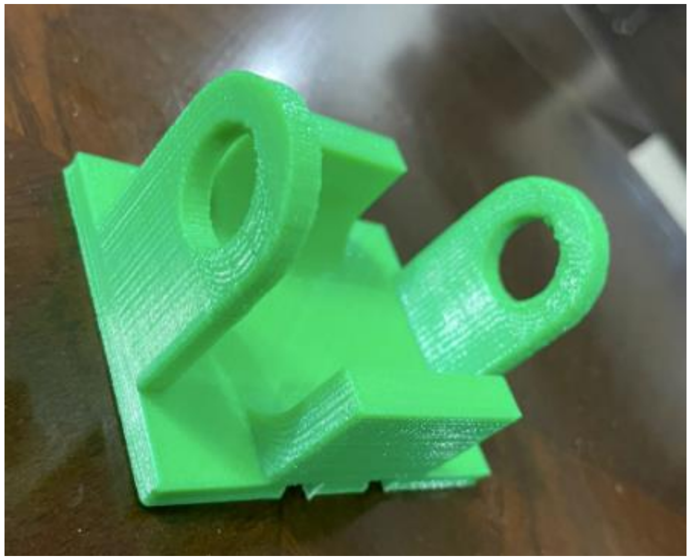
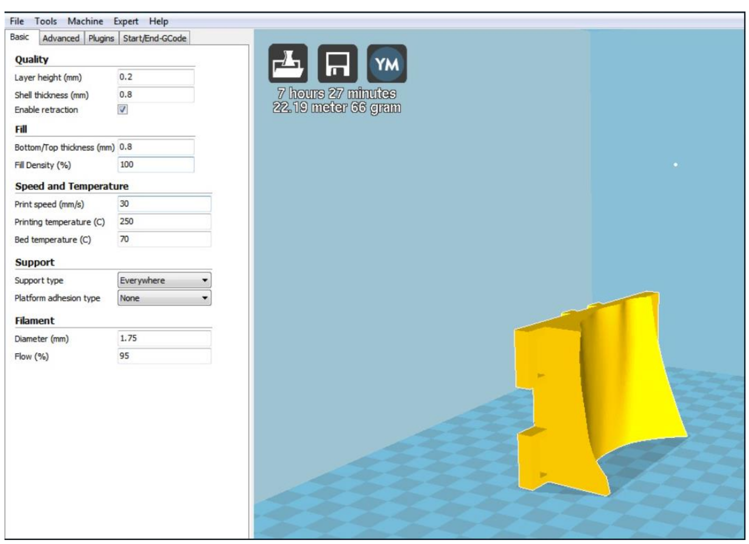


Figure 28: 3d model and printed model of base

4.3.3 Hand Mount

The hand mount was made using 100% infill due to the required strength as the whole model was resting on it and it'll be susceptible to most forces.



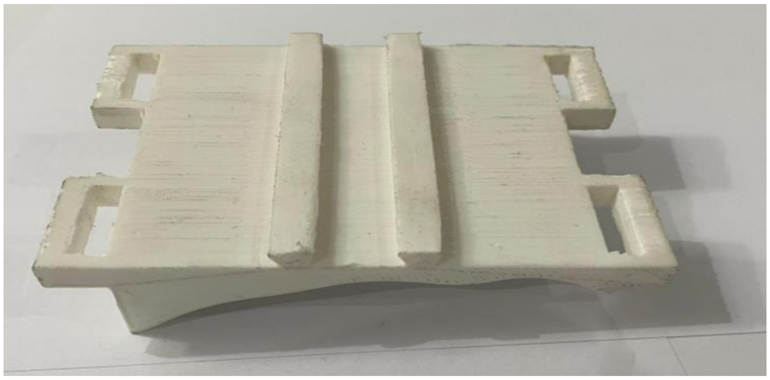
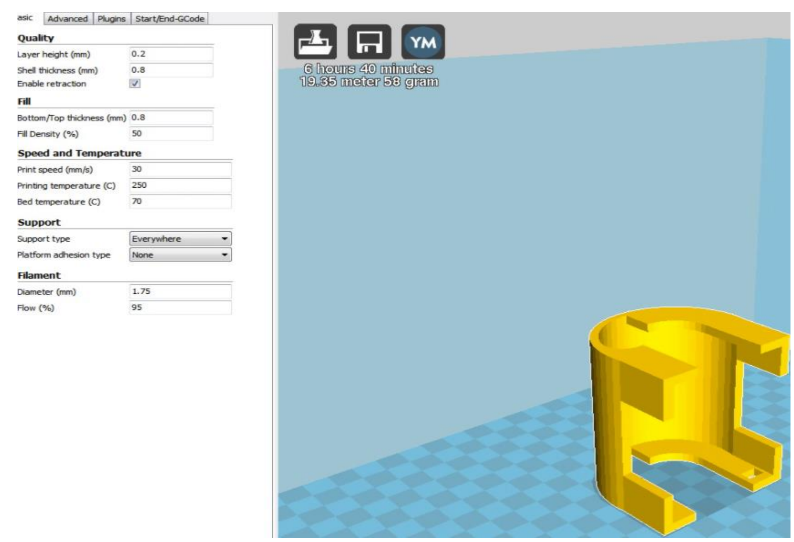


Figure 29: 3d model and printed model of mount

4.3.4 Cover

The cover was made to act as a housing for the whole device and act as a sound barrier between the motor and the external environment. It was made using 50 % infill.



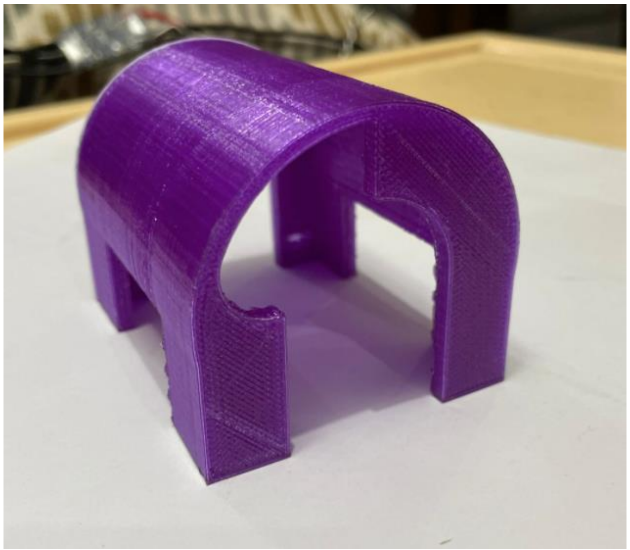


Figure 30: 3d model and printed model of cover

4.3.5 Sensor

MPU6050 accelerometer was the sensor used to measure tremor amplitudes and frequencies.

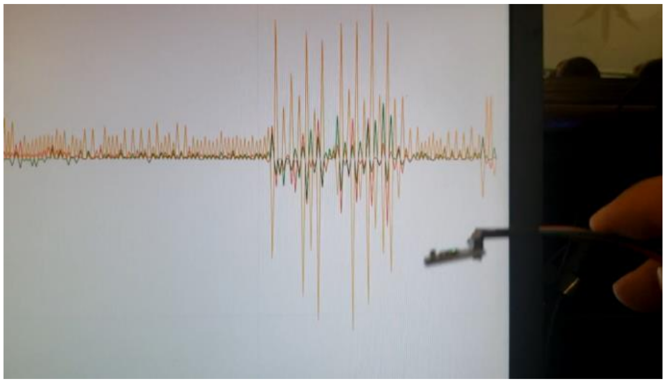


Figure 31: MPU6050 graph

Allowing the gyroscope to precess to its maximum displacement provides for a wider spectrum of tremor reduction. The average displacement of a hand tremor was shown to be proportional to the gyroscope displacement in tests. We were able to evaluate the efficiency of our gadget in minimizing tremors using the accelerometer as mentioned.

4.3.6 Measured Parameter

The device actively reduces hand tremors by reducing the angular displacement of each tremor, thereby reducing the acceleration force produced at the crests and troughs. The frequency of the tremors remains the same with or without the device.

Green: Normal hand tremors
Yellow: Reduced Tremors with Gyrox
Red: Reduced Tremors with Gyrox (2)

Achieving tremor reduction up to **65% to 75%!** A point to note here the results obtained here are subject to various other factors as well which include the inaccuracies involved with machining components and physical tolerances in machined parts/joints. The sensor used is also not industrial grade and produces noise. Efficiencies can be improved manifolds with industrial machining processes on a larger scale and use of compact electronics.

4.3.8 Final Testing: Actual Patient

As a final test we took our device to test on real patients suffering from Parkinson's disease. The patient aged 76 had been suffering from tremors for the past 9 years. The results obtained were as following

Before

(Values from accelerometer)

aworld	-56	12	818
ypr	165.84	-8.02	-89.42
aworld	-21	6	821
ypr	165.71	-8.05	-89.41
aworld	12	0	835
ypr	165.58	-8.07	-89.40
aworld	12	-9	870
ypr	165.54	-8.09	-89.40
aworld	-12	23	877
ypr	165.52	-8.12	-89.40
aworld	-28	51	894
ypr	165.50	-8.14	-89.40
aworld	-40	81	889
ypr	165.51	-8.16	-89.40
aworld	-31	81	882
ypr	165.64	-8.16	-89.41
aworld	0	74	881
ypr	165.78	-8.17	-89.42
aworld	33	44	880
ypr	166.01	-8.17	-89.44
aworld	49	14	883
ypr	166.19	-8.18	-89.46

After

(Values from accelerometer)

aworld	0	-8	-8
ypr	0.76	0.03	0.11
aworld	-11	-7	-21
ypr	0.77	0.03	0.11
aworld	-14	-5	-38
ypr	0.77	0.03	0.11
aworld	-12	-5	-27
ypr	0.77	0.03	0.12
aworld	-14	-12	-38
ypr	0.77	0.03	0.12
aworld	-17	-14	-36
ypr	0.77	0.02	0.11
aworld	-13	-10	-27
ypr	0.77	0.02	0.11
aworld	-7	-5	-18
ypr	0.77	0.02	0.12
aworld	-11	-5	-17
ypr	0.78	0.02	0.11
aworld	-10	-6	-14
ypr	0.78	0.02	0.11
aworld	-3	-2	-12
ypr	0.78	0.03	0.11

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In any engineering problem it is crucial to identify variables and their effect on the possible outcomes. Considering the scope of this project and the future prospects, the results show that this project was a success. The subsequent prototyping stages proved to be very beneficial in the long run and saved precious time. The prototypes made it possible to remain pointed in the right direction and also build upon our previous learnings and results.

The glove proved to be beneficial for use by patients suffering from Parkinson's and other related diseases that cause hand tremors. The feedback system makes it possible to adjust to different hand tremor types as well making it a universal device that does not require user input; hence the error probability is reduced. All the learnings and results from testing and prototyping were used and improved in order to create a refined prototype that can lead to an ergonomic product at the end which is both efficient and cost effective.

Overall, both in principle and in practice, the prototype was a success. The device is comfortable to use and helps to minimize the severity of hand tremors. Testing revealed an 80 percent reduction in tremors, as seen in our findings. Further testing with the tremor simulation device described above, according to the team, could yield more enlightening results. We concluded from the mathematical model that our design has the potential to reduce tremors by up to 87 percent.

As with any engineering problem, there are several areas where one can improve upon to further increase the efficiency of the product/process. Similarly, there are areas that we can modify that will not only improve the overall performance but also make the product even more cost-effective. Such recommendations have been discussed ahead.

5.2 Future Recommendations

To further improve this device there are several recommendations. These will improve the performance and efficiency of the device and make it more viable as a daily driver. Following are areas where more work can be done.

1. Compactness of the device

The device is currently cumbersome to wear, and the electrical components are housed in a huge acrylic box. Because the structure was made of 3D printed PLA plastic, it required a particular thickness to maintain structural stability of the components, which increased the size. The dimensions of the base, cradle, and cover may be lowered if they were made via plastic injection molding. Another good option can be a frame made of metal such as aluminum. Not only will that make it light weight but decrease the required volumetric size of the device. Furthermore, the electronics can be organized to be worn, such as in a fanny pack.

2. Gyroscope efficiency

The efficiency of the gyroscope can be increased by using a material even denser than brass. Increasing the gyroscope's efficacy comes at the expense of angular velocity and mass. Brass was used for the device because of its density and ease of machining. However, employing denser materials than brass is recommended since it can improve the gyroscope's efficacy without reducing the disk's size.

3. Balancing the Gyroscope

The dynamic balancing of the gyroscope was one area of research that was not explored due to its intricacy. The vibration and noise generated within the system would be reduced if the gyroscope was balanced.

4. Incorporating more sensing elements

The team contemplated incorporating smart sensing onto the prototype. The goal was to construct a self-sensing device that would modify the motor RPM when a tremor was detected using a variety of sensors such as the accelerometer and gyroscope. To enable for interconnectivity between the sensors and the PI to store the sensor data and provide a signal to modify the motor speed, a combination of an Arduino and a Raspberry PI was proposed. Research of the relationship between tremor levels and transducer readings had been conducted, however due to the intricacy of this feature, it was discarded.

5. Improve Hand Mount

The team believes that creating a new hand attachment mechanism would improve the device's comfort. The 3D printed mount plate enables for modification to a variety of hand sizes, although the Velcro strap attachment mechanism may be improved. The team contemplated utilizing a fingerless glove with the mount glued, stitched, or slotted into the glove. A stiff leather strap would also be a lot more comfortable and also serve the purpose equally well.

These are some of the suggestions that can be implemented on the next level that will improve the project in terms of efficiency, performance, cost and ergonomics.

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APPENDIX I: LEVER ARM TEST

This test is based on the idea that a gyroscope has resistance to its own motion changes. We may evaluate the variations in motion induced by the gyroscope at different angular speeds by putting it to a pivoting lever arm or pendulum. A test gadget that permits the gyroscope assembly to be coupled to a pendulum is required for this test.

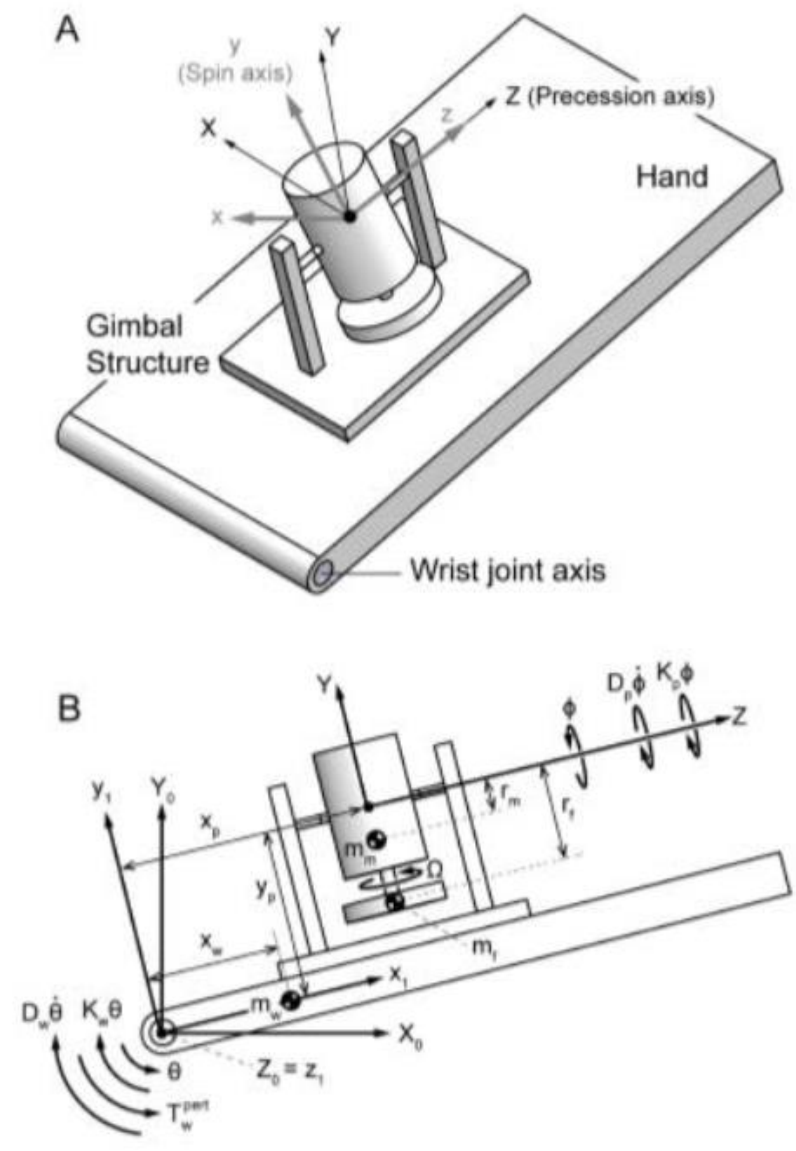
Required Materials:

- Pendulum Rig
- Gyroscope Prototype
- (High Speed Camera)
- Poster with Marked Angles of Rotation

Procedure:

1. Position the pendulum at 5 degrees with the gyroscope turned off.
2. Record the rotation of the pendulum with the camera.
3. After the pendulum swings, stop the recording.
4. Repeat steps 1-3, running different trials with different angles, the gyroscope at various motor speeds with at least 3 trials per each change in independent variable.
5. Set Angles 5, 10, 15, 20 degrees

APPENDIX II: MATHEMATICAL MODEL



Lever Arm Test Calculations

Nomenclature:

Definition of Gravity: $G := g$ *Definition of a gram:* $g := \frac{1}{1000}$

Angular Dispisplacement About Pivot Pin: $\theta := 5deg$

Angular Velocity of Gyroscope $\Omega := 10000rpm$

Angular Dispisplacement About Precession Axis: $\phi := 90deg$

Mass of the Gyroscope: $m_f := 196.47g$

Center of Precession Axis Along X1: $x_p := 482mm$

Center of Precession Axis Along Y1: $y_p := (38.5 + 25.4)mm$

COM of Gyroscope Along Y: $r_f := 5mm$

Gyroscope Moment of Inertia About X: $I_{xf} := 36525.22g \cdot mm^2$

Gyroscope Moment of Inertia About Y: $I_{yf} := 60069.65g \cdot mm^2$

Gyroscope Moment of Inertia About Y: $I_{zf} := 36525.22g \cdot mm^2$

Mass of Lever $m_w := 141g$

COM of Lever Along X1: $x_w := \frac{514}{2}mm = 257 \cdot mm$

Mass of Lever: $m_L := 141g$

Mass of Device: $m_D := 460g$

Lever Length: $L_L := 514mm$

Dist. of Device: $L_D := 482mm$

COM: *Distance of the Center of Mass of the lever arm assembly from the pivot poi*

$$L := \frac{m_L \cdot \left(\frac{L_L}{2}\right) + m_D \cdot L_D}{m_L + m_D} \qquad L = 0.429\,m$$

Base Time: *Time for pendulum system to fall without the gyroscope spinning, ass angle.*

$$t_{cycle} := 2 \cdot \pi \cdot \sqrt{\frac{L}{G}} = 1.314\,s$$

$$t_{base} := \frac{t_{cycle}}{4} = 0.329\,s$$

Note: *The cycle time is divided by 4 becau swing only represents a forth of its full mot*

Moment of Inertia: *Inertias of Lever, Device and then combined for a total*

$$I_{beam} := \frac{1}{3} \cdot m_L \cdot L_L^{\,2} = 0.012\,kg \cdot m^2 \qquad I_{device} := m_D \cdot L_D^{\,2} = 0.107\,kg \cdot m^2$$

$$I_{zw} := I_{beam} + I_{device} \qquad I_{zw} = 0.119 \cdot kg \cdot m^2$$

Input Torue: *The amount of input torque caused by gravity.*

$$\theta = \theta_0 + \frac{1}{2} \cdot \alpha \cdot t^2 \qquad \alpha := \frac{2 \cdot \theta}{t_{base}^{\,2}} = 92.599 \cdot \frac{deg}{s^2}$$

$$T_{w.in} := I_{zw} \cdot \alpha = 0.193 \cdot N \cdot m$$

Angular Velocity About the Wrist Joint:

$$\omega := \frac{\theta}{t_{base}} = 15.215 \cdot \frac{deg}{sec}$$

Angular Velocity About the Precession Axis:

$$\varphi := \frac{T_{w.in}}{I_{yf} \cdot \Omega} = 175.596 \cdot \frac{deg}{sec}$$

Angular Acceleration of the Hand and Precession Movements:

$$q := \begin{pmatrix} \theta \\ \phi \end{pmatrix} = \begin{pmatrix} 5 \\ 90 \end{pmatrix} \cdot deg \qquad q_{acc} := \begin{pmatrix} \frac{T_{w.in}}{I_{zw}} \\ \frac{\varphi}{t_{base}} \end{pmatrix} = \begin{pmatrix} 92.599 \\ 534.341 \end{pmatrix} \cdot \frac{deg}{s^2}$$

Torques About the Hand and Precession Axis:

$$F = \begin{pmatrix} T_{w.r} + T_{w.in} \\ T_p \end{pmatrix}$$

NOTE:
T.w.r is the reactionary torque caused by the system.
T.p is the torque generated about the precession axis.

Moment of Inertia Components of the Gyroscope:

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

Torques Based of the Moment of Inertias and Movements of the System:

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

Equilibrium Torues:

$$F = H \cdot q_{acc} + C$$

$$\begin{pmatrix} T_{w.r} \\ T_p \end{pmatrix} := H \cdot q_{acc} + C - \begin{pmatrix} T_{w.in} \\ 0 \end{pmatrix} = \begin{pmatrix} 1.355 \\ -0.01 \end{pmatrix} \cdot N \cdot m$$

Based Off of These Conditions, the Realized Torque and Percentage of Reduction Are:

$$T_{realize} := T_{w.r} = 1.355 \cdot N \cdot m$$

$$Percent := \frac{T_{w.in}}{T_{realize}} = 0.142$$

$$Time_{realize} := t_{base} \cdot (1 + Percent) = 0.375\,s$$

APPENDIX III: ARDUINO CODE

```
#include <Servo.h>
#include <arduino-timer.h>
Servo esc_signal;
#include "I2Cdev.h"
#include "MPU6050_6Axis_MotionApps20.h"
#if I2CDEV_IMPLEMENTATION == I2CDEV_ARDUINO_WIRE
   #include "Wire.h"
#endif
MPU6050 mpu;
#define OUTPUT_READABLE_WORLDACCEL
#define INTERRUPT_PIN 2  /
#define LED_PIN 13
bool blinkState = false;
long maxnum;
// MPU control/status vars
bool dmpReady = false;
uint8_t mpuIntStatus;
uint8_t devStatus;
uint16_t packetSize;
uint16_t fifoCount;
uint8_t fifoBuffer[64]; // FIFO storage buffer
// orientation/motion vars
Quaternion q;
VectorInt16 aa;
VectorInt16 aaReal;
VectorInt16 aaWorld;
VectorFloat gravity;
float euler[3];
```

```
float ypr[3];           // [yaw, pitch, roll]   yaw/pitch/roll container and gravity vector
volatile bool mpuInterrupt = false;     // indicates whether MPU interrupt pin has gone high
void dmpDataReady() {
   mpuInterrupt = true;
}
void setup() {
   esc_signal.attach(12);
   esc_signal.write(30);   //ESC arm command
   delay(3000);
   // join I2C bus
   #if I2CDEV_IMPLEMENTATION == I2CDEV_ARDUINO_WIRE
      Wire.begin();
      Wire.setClock(400000); // 400kHz I2C clock
   #elif I2CDEV_IMPLEMENTATION == I2CDEV_BUILTIN_FASTWIRE
      Fastwire::setup(400, true);
   #endif
   Serial.begin(115200);
   while (!Serial);
// initialize device
   Serial.println(F("Initializing I2C devices..."));
   mpu.initialize();
   pinMode(INTERRUPT_PIN, INPUT);
   // verify connection
   Serial.println(F("Testing device connections..."));
   Serial.println(mpu.testConnection() ? F("MPU6050 connection successful") : F("MPU6050
connection failed"));
   // wait for ready
   Serial.println(F("\nSend any character to begin DMP programming and demo: "));
   //while (Serial.available() && Serial.read()); // empty buffer
   //while (!Serial.available());                 // wait for data
```

```
//while (Serial.available() && Serial.read()); // empty buffer again
// load and configure the DMP
Serial.println(F("Initializing DMP..."));
devStatus = mpu.dmpInitialize();
// supply your own gyro offsets here, scaled for min sensitivity
mpu.setXGyroOffset(220);
mpu.setYGyroOffset(76);
mpu.setZGyroOffset(-85);
mpu.setZAccelOffset(1788); // 1688 factory default for my test chip
// make sure it worked (returns 0 if so)
if (devStatus == 0) {
  // Calibration Time: generate offsets and calibrate our MPU6050
  mpu.CalibrateAccel(6);
  mpu.CalibrateGyro(6);
  mpu.PrintActiveOffsets();
  // turn on the DMP, now that it's ready
  Serial.println(F("Enabling DMP..."));
  mpu.setDMPEnabled(true);
  // enable Arduino interrupt detection
  Serial.print(F("Enabling interrupt detection (Arduino external interrupt "));
  Serial.print(digitalPinToInterrupt(INTERRUPT_PIN));
  Serial.println(F(")..."));
  attachInterrupt(digitalPinToInterrupt(INTERRUPT_PIN), dmpDataReady, RISING);
  mpuIntStatus = mpu.getIntStatus();
  Serial.println(F("DMP ready! Waiting for first interrupt..."));
  dmpReady = true;
  packetSize = mpu.dmpGetFIFOPacketSize();
} else {
  Serial.print(F("DMP Initialization failed (code "));
  Serial.print(devStatus);
```

```
        Serial.println(F(")"));
    }
    // configure LED for output
    pinMode(LED_PIN, OUTPUT);
}
void loop() {
        if (!dmpReady) return;
   if (mpu.dmpGetCurrentFIFOPacket(fifoBuffer)) { // Get the Latest packet
        #ifdef OUTPUT_READABLE_WORLDACCEL
            // display initial world-frame acceleration, adjusted to remove gravity
            // and rotated based on known orientation from quaternion
            mpu.dmpGetQuaternion(&q, fifoBuffer);
            mpu.dmpGetAccel(&aa, fifoBuffer);
            mpu.dmpGetGravity(&gravity, &q);
            mpu.dmpGetLinearAccel(&aaReal, &aa, &gravity);
            mpu.dmpGetLinearAccelInWorld(&aaWorld, &aaReal, &q);
            //Serial.print("aworld\t");
            //Serial.print(aaWorld.x);
            //Serial.print("\t");
            //Serial.print(aaWorld.z);
            //Serial.print("\t");
            //Serial.println(aaWorld.y);
            long n = aaWorld.y;
    if (n > maxnum){
      maxnum = n;
    }
            delay(200);
            Serial.println(maxnum);
     if (maxnum < 600)
   {
```

```
        esc_signal.write(70);
        Serial.print("Motor speed:70");
        Serial.print("\t");
        delay(1000);
        }
        if (600 < maxnum && maxnum < 2000)
  {
        esc_signal.write(85);
        Serial.print("Motor speed:85");
        Serial.print("\t");
        delay(1000);
        }
         if (2000 < maxnum && maxnum < 3000)
  {
        esc_signal.write(100);
        Serial.print("Motor speed:100");
        delay(1000);
        }
        if (3000 < maxnum && maxnum < 25000)
  {
        esc_signal.write(130);
        Serial.print("Motor speed:130");
        delay(1000);
        }
        #endif
        // blink LED to indicate activity
        blinkState = !blinkState;
        digitalWrite(LED_PIN, blinkState);
    }
}
```