Development of an Effective Portable and Flexible Glove for Hand Tremor Suppression

Abdulrahem Turkistani
Western Michigan University

DEVELOPMENT OF AN EFFECTIVE PORTABLE AND FLEXIBLE GLOVE FOR HAND TREMOR SUPPRESSION

by

Abdulrahem Turkistani

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Thesis Committee:

Tycho Fredericks, Ph.D., Chair
Ikhlas Abdel-Qader, Ph.D.
Steven Butt, Ph.D.

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Abdulrahem Turkistani, M.S.

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This paper presents the work carried out in designing and developing a prototype for a tremor suppression system that reduces hand tremor by counteracting vibrations initiated from a patient's shaking hand. This system includes a glove with a built-in vibration simulation module that oscillates and mimics the hand vibration. The oscillation is generated by a DC motor mounted on the top of the glove, and can vary in degree of vibration. The glove is also equipped with an accelerometer-gyroscope based micro-electromechanical system (MEMS) and vibrating coin motors mounted on each finger, both interfaced with a microcontroller. The microcontroller used in this design is an Arduino Uno3, the MEMS is the GY-521 model, and the vibrating coin motors are 3V DC, 10mm micro flat button motors. The design allows mounting up to four motors on each finger based on which axis the generated counteract is needed. Further, the performance modeling of the system was carried out using SerialChart software, which plots raw data received from the MEMS. The plotted data represents the X, Y, and Z vibration changes. These changes in vibration were suppressed to some extent, especially in the X axis. The placement of the vibration motors had an important role in reducing the hand tremor. The maximum vibration suppression was accomplished by using four vibration motors, two motors on each side of the finger. This motors' arrangement demonstrated that tremor reduction is possible, and at some instances, the reduction was close to 40%.

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CHAPTER I

INTRODUCTION

Hand tremor affects millions of people worldwide. *Tremor* is defined as an unintended, rhythmic muscle movement. According to Plumb and Bain (2006), tremor is one of the most spread disease among the population of patients diagnosed with movement illnesses (p. 75). This is one of the reasons why medical scientists take tremor so seriously. Tremor can affect different parts of the body, including hands, legs, head, or face. In the worst situations, tremor can affect voice and swallowing, but most tremor cases occur in the hands.

Although many studies suggest tremors are caused by damage in the complex nerves pathway of the brain, the real cause of tremors is unknown (National Institute of Neurological Disorders and Stroke, 2012). Some tremor cases are described as familial tremors, wherein the patient gets the gene from a parent and develops the disease, which runs in the family. An example of this is Essential Tremor (ET), which affects more than 10 million people in the United States alone. Nearly 50% of ET patients have family history of the disease (Plumb & Bain, 2006).

According to the U.S. Department of Health and Human Services, in some patients, tremor happens in conjunction with a neurological disorder, while in other patients it happens due to use of certain drugs. Nevertheless, the National Institute of Neurological Disorders and Stroke (2012), notes “The most common form of tremor, however, occurs in otherwise largely healthy people” (para. 1). Although most tremors neither cause severe health problems nor threaten life, most patients experience many difficulties in performing daily activities. It is very embarrassing to many people, especially older individuals. Tremor has a negative impact on quality of life, and reduces the ability to perform daily life tasks such as eating, drinking, writing, and changing clothing. Some patients with mild tremor do not visit doctors if tremor does not hinder their daily life activities. Their situations often worsen over time. Tremor can rarely affect children, and there is no data on the popularity of the disease in childhood (Harvard Medical School, 2004).

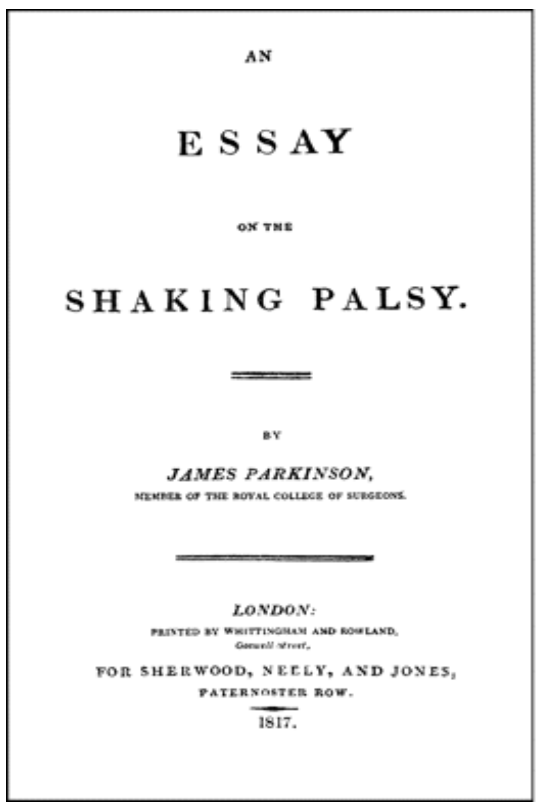
This thesis proposes a portable, flexible, and economical device to reduce hand tremor. The device consists of a glove and other attached modules, including a tremor simulation module, an Arduino Uno3 microcontroller module, an MEMS sensor, vibration coin motors, and connection wires. The device helps in detecting vibrations through sensors at several points on the fingers. The microcontroller is used to measure the frequency and amplitude of those vibrations and generate signals to activate the coin motors. The vibration generated by the coin motors counteracts the hand vibrations in order to minimize the tremor.

CHAPTER II

BACKGROUND

Origin of Tremor

The study of tremor is not new. It can be found in old transcripts and documents of antiquity coming from India 5000 BC and Greece 200 AD (Chou, Grube, & Patil, 2012). According to Harvard Medical School (2004), medical texts from ancient Indian and Greek civilizations mentioned tremors and described medication to treat its symptoms. In the last two centuries, famous neurologists including Maragliano, Nagy, Raymond, and Charles Dana wrote medical reports about Essential Tremor (ET). James Parkinson wrote the first clear medical description of Parkinson's disease (PD) in detail in 1817, indicated in Figure 1.



AN

ESSAY

ON THE

SHAKING PALSY.

BY

JAMES PARKINSON,

MEMBER OF THE ROYAL COLLEGE OF SURGEONS.

LONDON:

PRINTED BY WHITTINGHAM AND ROWLAND,

FOR SHERWOOD, NEELY, AND JONES,

PATERNOSTER ROW.

1817.

Figure 1. James Parkinson's first medical description on Parkinson's disease (Goetz, 2011).

The real cause of the tremor is not precisely known. The latest studies on PD, as mentioned by Harvard Medical School (2004), suggest PD is caused by the death of brain cells or a shortage of brain chemicals involved in movement. These dead cells are located in cerebellum, which is the part of the brain located at the back of the skull. It controls balance and movement activities. Unlike PD, ET does not involve depletion or shortage of dopamine in the brain. According to the National Institute of Neurological Disorders and Stroke (2012), many ET cases appear to result from a genetic mutation. This form of tremor is referred to as familial tremor. There is a 50% chance parents with ET could pass it on to their children. It is not clear what causes ET in people without a known genetic mutation.

Tremor Classifications

Tremors are classified into different groups, which is critical for medical practice and treatment. In particular, classification is necessary for clinical assessment, which plays a significant role in the diagnoses of the disease and the managing of treatment. Tremor classification is based on its clinical characteristics and other parameters such as frequency, amplitude, and whether it occurs at rest, during action, or with a specific posture. Three main types of tremor include: *postural tremor, rest* or *static tremor,* and *action* or *kinetic tremor.* Crawford and Zimmerman (2011) and Rana and Hedera (2014) classified tremor into two groups: *action tremor* and *rest tremor.* They consider postural tremor as part of action tremor, basically because both postural and action tremors occur while the affected body part is at motion involving voluntary contraction of the muscles (i.e., tremors during movement). It means that more than one type of tremor can affect the same part of the body.

Table 1 summarizes main types of tremor including their frequency, subdivisions, and treatment. *Postural tremor* occurs when the limb is placed in a fixed position against gravity, and may continue or increase during movement. It can be seen for example, when a patient is holding the arms out in front of his body. This type of tremor is divided into physiologic tremor, ET, alcohol or drug withdrawal, metabolic disturbance, drug-induce tremor, and psychogenic tremor. *Rest tremor,* as described by Louis and Ferreira (2010), takes place when the limb is completely at rest against gravity. Essentially, the affected body part continues shaking when the patient is sitting and relaxed; however, the affected part can stop shaking when the patient intentionally moves it. This type of tremor is subdivided into Parkinson's disease, multiple-systems atrophy, supranuclear palsy, and drug-induced tremor. *Action tremor* takes place once the affected part moves to change its position intentionally. Action tremor is subdivided into three types: cerebellar lesion, rubral tremor, and psychogenic tremor (Charles, Esper, Davis, Maciunas, & Robertson, 1999).

Postural Tremor

As stated above, postural tremor occurs when the limb is placed in a fixed position against gravity, and may continue or increase during movement. Postural tremor is subdivided into physiologic tremor, ET, alcohol or drug withdrawal, metabolic disturbance, drug-induce tremor, and psychogenic tremor. Each subtype of tremor is discussed in the paragraphs below.

Physiologic tremor. Physiologic tremor exists in all mankind including people who are healthy; however, it is typically undetectable due to its small amplitude. Physiologic tremor can become visible in some people while performing specific tasks such as focusing a camera or threading a needle. It can also become visible in some people as a result of drug use, too much alcohol, caffeine, nicotine, or being under pressure. This tremor usually disappears when the underlying cause is terminated. Its amplitude can barely be seen, and its frequency is between 8 and 12 Hertz (Hz).

Table 1

Classification of Tremors and Their Characteristics and Treatment (Charles, Esper, Davis, Maciunas, & Robertson, 1999)

Type of Tremor	**Frequency**	**Occurrence**	**Etiology**	**Treatment** [a]
Postural tremor	5 to 9 Hz	When limb is positioned against gravity	Physiologic tremor, essential tremor, alcohol or drug withdrawal, metabolic disturbances, drug-induced tremor, psychogenic tremor	Beta blockers, primidone (Mysoline), acetazolamide (Diamox), clonazepam (Klonopin), botulinum toxin, brain gabapentin (Neurontin), deep stimulation, thalamotomy
Rest tremor	3 to 6 Hz	When limb is fully supported against gravity and the muscles are not voluntary activated	Parkinson's disease, multiple-systems atrophy, progressive supranuclear palsy, drug-induced tremor, rubral tremor, psychogenic tremor	Levodopa-carbidopa (Sinemet), anticholinergics and other antiparkisonian agents, deep brain stimulation, pallidotomy, thalamotomy
Action tremor [b]	3 to 10 Hz	During any type of movement	Cerebellar lesions, rubral tremor, psychogenic tremor	Wrist weights, isoniazid

[a] Drugs and other treatments are generally listed in the order in which they should be tried. An adequate trial of each medication must be tried before the agent is judged to be ineffective. Many of these drugs are not specifically labeled for the treatment of tremor or have not undergone extensive studies to support their use in the treatment of tremor.
[b] Action tremor includes intention tremor (exacerbation toward the end of goal-directed movement), kinetic tremor (during any type of movement) and task-specific tremor (only during performance of highly skilled activities, such as writing or playing a musical instrument).

Essential tremor (ET). ET is the most common pathologic tremor, with nearly 10 million people being affected with this disease in the United States alone. Although many doctors believe the cause of ET is abnormal activity of the brain, the real cause of the disease is unknown. About half of all ET cases are believed to be familial (Mayo Clinic, 2016). This disease causes rhythmic oscillation of body parts, most commonly wrist and hand, and sometimes head, voice, and legs. This tremor has a mild amplitude, with a high frequency between 8 and 12 Hz, and is visible.

Alcohol or drug withdrawal. This symptom occurs in people who suddenly stop the heavy use of illegal drugs or alcohol after been addicted. It also could happen after significantly reduce the consumption. This leads to a decrease in the amount of the drug or alcohol in the blood and the tissues. Several hours after quitting, patients may experience shakiness, seizures, weakness, confusion, high heartbeat, and fever. The situation can become complicated, and the patient could face the risk of death.

Metabolic tremor (Wilson's disease). Metabolic tremor is also known as *Wilson's disease.* This disorder is caused by an excessive amount of copper in the body, which the liver cannot expel. This can result in damage and malfunction of organs such as the kidneys, brain, and eyes. Patients with Wilson's disease may also exhibit rest tremor, intention tremor, and an action tremor when trying to write or drink. An estimate for frequency of Wilson's disease in most populations is about 17 per million (Grimaldi & Manto, 2013).

Drug-induced tremor. Drug-induced tremor is an involuntary tremor, caused by a response in the human nervous and muscular systems when using a specific medication. There are some medicines that can cause or intensify tremor, including some cancer, seizure, asthma, and mood stabilizer medications, as well as some antibiotic and antivirus medications. Caffeine, nicotine, and alcohol can also cause drug-induced tremor in some people.

Psychogenic tremor. Unlike other movement disorders, psychogenic tremor is usually caused by an underlying psychological condition, develops suddenly, and may include any part of the body, such as face, neck, trunk, or limbs. Some patients show difficulties with their balance and gait with psychogenic tremor as well. This tremor affects both sides of the body, but with an unusual pattern of oscillation and involuntary muscle contractions. According to Elble (2000), in situations of stress, both the amplitude and frequency of psychogenic tremors commonly increase. If the patient is distracted with motor tasks, then tremor will be reduced.

Rest Tremor

Rest tremor occurs when the limb is completely at rest against gravity; that is, the affected body part continues shaking when the patient is sitting and relaxed (Louis & Ferreira, 2010). The affected body part, however, can stop shaking when the patient intentionally moves it. This type of tremor includes Parkinson's disease, multiple-systems atrophy, supranuclear palsy, and drug-induced tremor, each discussed in the paragraphs below.

PD. PD as originally described by James Parkinson in 1817 is a progressive neurodegenerative disorder (Goetz, 2011). Parkinson's disease is considered the second greatest neurodegenerative disease in elder patients, following Alzheimer's disease. In the United States alone, nearly 1.5 million people have been diagnosed with PD. This estimate is expected to double by 2030 (Brandt, 2010). PD's amplitude is considered mild, and its frequency is between 3 and 6 Hz.

Multiple-systems atrophy (MSA). The cause of the multiple-systems atrophy is unknown. MSA is a rare neurological disease that affects people age 50 and above. This disease develops faster than Parkinson's disease, and usually affects the nervous system, which is responsible for controlling involuntary actions in the body such as digestion and blood pressure. It also affects the normal movement of body parts. MSA patients experience progressive loss or death of nerve cells in the brain and spinal cord. Symptoms that may be seen in MSA patents include difficulties with speech and gait, slowness of movement, tremor, irregular heartbeat, unstable blood pressure, and uncontrolled urinary problems. MSA is a rare disease that affects between 15,000 to 50,000 Americans from all races and genders. There is no specific medicine to stop the progress of this disease completely. Some symptoms of MSA can be treated with a few medications (National Institute of Neurological Disorders and Stroke, 2014).

Progressive supranuclear palsy (PSP). Progressive supranuclear palsy is an unusual brain illness. The exact cause of the damage to brain cells is unknown; nevertheless, PSP can affect the patient's control of walking, gait, speech, swallowing, and vision. This disease is much less common than Parkinson's disease. According to National Institute of Neurological Disorders and Stroke (2012), only about 3 to 6 in every 100,000 people worldwide are affected with this disease. The symptoms of the PSP are similar to PD, but PSP is more rapidly progressive. PSP patients usually have a habit of standing by inclining their heads backward as if they will fall backward. PSP worsens over time and becomes life threatening.

Drug-induced Parkinsonism (DIP). The next type of rest tremor is known as Drug Induced Parkinsonism. It is very similar to the drug-induced tremor that happens in the postural tremor patients due to treatment with some medications. Unlike PD, however, this disease affects both sides of the body and there is no tremor while the body part is at rest. That is why DIP has been described as symmetric Parkinsonism, and indicates absence of the tremor when the affected limb part is at rest. Many cases of patients with DIP are misdiagnosed with PD due to the similar clinical symptoms. These patients are often given anti-Parkinsonian drugs for long periods of time, and develop PD by using unnecessary medications. The recovery process may take weeks or even months simply by discontinuing the wrong medication (Grimaldi & Manto, 2013).

Action Tremor

As indicated, action tremor takes place only when an affected body part moves to change position intentionally. Action tremor is subdivided into three types: cerebellar lesion, rubral tremor, and psychogenic tremor. Cerebellar lesions and rubral tremors are discussed in the paragraphs below (Grimaldi & Manto, 2013).

Cerebellar lesion. A cerebellar lesion is a tremor related to cerebellar disorders. It happens after a patient suffers a stroke that causes cerebellum damage. The damage to the cerebellum impairs muscle coordination and deactivates the brain's control of a body part's movement. It is mainly composed of low frequency oscillations. This can lead to an inability to coordinate balance while walking, and trouble stabilizing eye movements. Cerebellar tremor patients usually suffer from error in movement. The movement error is always linked to the side of the body where the brain damage took place. The lower limbs are the most affected parts, and the movement can be observed as a staggering gait with impaired arm movements. Classic cerebellar tremor symptoms are sluggish intention, and disabling. It is mainly caused by stroke or in some cases by multiple sclerosis. This tremor's amplitude is classified as mild to severe, and has a frequency between 3 and 4 Hz (Grimaldi & Manto, 2013).

Rubral tremor. Rubral tremor is referred to as *Holmes' tremor* or *midbrain tremor.* The main cause of this disease includes damage of the nerve cells insulating covers in the brain, and the spinal cord multiple sclerosis. Stroke and cerebellar injury can also cause this disease (Lee, Choi, & Son, 2015). When the tremor takes place during a stroke, it may appear after weeks, or sometimes months. The tremor is generally one-sided and has three components: rest, postural, and kinetic. It is usually severe and disabling. Some medications have reported benefits, including propranolol, clonazepam, levodopa, and levetiracetam (Striano et al., 2007). However, response to drugs is usually poor in many cases and requires surgical intervention. Rubral tremor is a mild amplitude tremor and has a low frequency below 4.5 Hz.

Other Types of Tremors

Types of tremors other than those mentioned above include isometric tremors, task-specific tremors, dystonic tremors, and orthostatic tremors. Each type of tremor is discussed in the paragraphs below (Grimaldi & Manto, 2013).

Isometric tremor. Isometric tremors are present during voluntary muscle contractions and not accompanied by movement, for example, when standing or when making a fist.

Task-specific tremor. Task-specific tremors typically occur at a frequency between 5 and 7 Hz. As the name implies, this type of tremor takes place only during specific activities, such as writing (known as primary writing tremor), singing, or playing an instrument. The most common task-specific tremors are postural and kinetic tremors.

Dystonic tremor. Dystonic tremor is a type of tremor that can affect any individual under any age. This disease takes place in conjunction with a neurological disorder called *dystonia.* When incorrect message from the brain affects some muscles, it results in abnormal movements of body parts. Its amplitude and frequency are unknown.

Orthostatic tremor. Orthostatic tremor is described by periodic muscle contractions that take place in the legs and trunk instantly after standing. Its amplitude and frequency are unknown.

Differences Between Essential Tremor and Parkinson's Disease

Essential tremor, as described earlier, is not only considered the most widespread of abnormal neurological diseases, but also the most widespread among all other tremor diseases. Parkinson's disease is rest tremor that is a progressive neurodegenerative disorder, originally described by James Parkinson in 1817. According to the Mayo Clinic, many people confused ET and PD, though they differ in many aspects:

- **Genetic.** Many cases of ET occur in family while PD never transfer in family and is caused by the damage of neurons in the brain.
- **Associated conditions.** ET causes other health problems, but PD correlated with a slow movement, a shuffling gait, and sometimes stooped posture. However, people with ET may sometimes develop other neurological signs and symptoms, such as an unsteady gait called ataxia (Mansur et al., 2007).
- **Parts of body affected.** ET mainly affects hands, and sometimes it may affect head, and voice. PD usually affect hands, and sometimes affects the legs. but r body. It never affects voice or head.

Table 2

Differences Between PD and ET Characteristics (Essential Tremor (ET) vs Parkinson's Disease, 2010)

Parkinsonian Tremor Signs and Symptoms	**Essential Tremor Signs and Symptoms**
High amplitude. Lower, slower frequency.	Low amplitude. Amplitude is more variable, ranging from barely perceptible tremor to a high amplitude tremor. Higher, faster frequency.
Mostly seen at rest.	Mostly seen during action.
Generally, involves slow movements (bradykinesia), rigidity (stiffness), and problems with walking or balance.	Tremor is primary symptom – slowness, stiffness, walking and balance problems are not commonly seen.
Rarely a family history (<10%).	Family history of tremor reported in the majority of patients (>50%).
Resting and postural (re-emergent); postural tremor observable after mean latency of 5 sec; rarely kinetic	Postural, kinetic; postural tremor immediately observable; resting tremor less common.
Onset generally at ages between 55-65.	Onset most common in middle age but can occur at any time in the lifespan.

Table 2—Continued

Parkinsonian Tremor Signs and Symptoms	Essential Tremor Signs and Symptoms
Usually starts on one side of the body and progresses to the other side; usually remains asymmetrical.	Usually affects both sides of the body initially (bilateral; symmetrical).
No effect from consumption of alcohol.	Alcohol often improves tremor.
Usually improves with levodopa treatment.	Improves with primidone and propranolol in some cases.
Hands affected more than legs, voice and head almost never affected.	Hands predominantly affected, but tremor also present in the head and voice; rarely in the legs.
Worsens with emotional stress.	Worsens with emotional stress.

Source: Herekar, A., Jankovic, J., & Lyons, K. (2010). Essential tremor ET vs Parkinson's disease: How do they differ? Retrieved from http://essentialtremor.org/wp-content/uploads/2013/07/ETvsPD092012.pdf

Impact of Tremor on Quality of Life and Challenges Patients can Experience

Tremor patients can face many difficulties and challenges in performing their daily life activities. The effects on quality of life vary depending on the severity of the tremor disorder, which might, in some cases, affect the mental ability of the patient or the ability to walk properly. A study by Lorenz, Schwieger, Moises, and Deuschl (2006) at Christian Albrechts University Germany was conducted on 105 ET patients. The results emphasize that the impact of tremor on patients' lives has various dimensions, captured by questionnaires for tremor severity, disability, handicap, and quality of life. Quality of life is substantially decreased mainly for mental domains, indicating a major impact of psychosocial aspects.

Some of the physical challenges associated with tremor can include an inability to hold a spoon or fork while eating, or to hold a cup while drinking. Other challenges can include difficulty in writing, shaving, applying makeup, and wearing clothes. Some tremor patients could have a minor balance problem, which may affect walking and make it very difficult. In some severe cases of tremor, swallowing can become a problem. According to the University of

Maryland Medical Center (2012), “Swallowing problems (dysphagia) are sometimes associated with shorter survival time. Loss of muscle control in the throat not only impairs chewing and swallowing, which can lead to malnourishment, but also poses a risk for aspiration pneumonia” (sect. Swallowing Problems).

Besides physical disability and negative effects on quality of life, tremor can be a social barrier and cause patients to feel socially isolated. The shaking hands, face, change in voice, and difficulty with regular talking can all lead to depression and embarrassment, which negatively affects patients and make the disease worse. Tremor disorder can increase the risk of developing other diseases. ET itself also seems to increase the likelihood of developing other degenerative diseases of the central nervous system, including PD and Alzheimer’s disease, so that ET may be viewed on some level as a risk factor for these other conditions (Louis & Ferreira, 2010).

Occupational and Non-Occupational Diseases

Occupational diseases are human illnesses that mainly arise from work activities (International Labor Organization, 2010). Workers in extremely hazardous environments can be exposed to harmful fumes and gases, such as in chemical factories. Other workers can be exposed to loud noise and vibrations in aircraft maintenance areas. In the metal casting environment, workers can be exposed to high temperatures, loud noise, and toxic fumes. The worst cases are when workers are exposed to radioactive rays in the nuclear reactor atmosphere. Extreme care and precaution must be taken when working in such environments.

Non-occupational diseases are human illnesses that did not occur as a result of work. This involves any negative behavior in people’s lifestyles. Eating unhealthy food, smoking, using drugs, and not performing regular exercise can all have negative impact on people’s health.

On the other hand, there are some illnesses with unknown etiology. The origin of these illnesses is not clearly known, like in Alzheimer's disease and Gulf War syndrome. Other diseases seem to be familial (genetic), like cystic fibrosis and Down syndrome.

In tremor disease, as mentioned earlier, the real cause of the illness is not precisely known, although some studies on PD suggest it is caused by the death of brain cells. The cause of the death of those cells is not clearly know. Furthermore, while many cases of ET prove to be familial, some cases of ET do not show any family history.

Occupational Risk Factors Associated With Tremor

The cause of ET is not known, but some studies suggest the part of the brain that controls muscle movement does not work properly. ET is sometimes referred to as familial when more than one member of a family are affected, suggesting genes have an important role in its cause. ET is non-work related and there is no evidence that the use of vibrated electric power tolls can cause ET. A recent study by Shin and Chung (2012) focused on unilateral hand tremor in PD patients. They used a neurophysiological method to investigate whether the progress of carpal tunnel syndrome (CTS) in PD has any relation to the frequent use of mechanical tools or not. The outcome of this study showed hand tremor was not precisely related to the increase of CTS. In contrast, repetitive use of a fully functioning hand with no tremor with heavy mechanical loading may cause CTS in those hands.

Another study by Edlund, Burström, Hagberg, Lundström, Nilsson, Sandén, and Wastensson (2014) at Goteborg University, Sweden was conducted to assess whether the regular use of hand-arm vibration (HAV) tools increase hand tremors or not. The study concluded that the increase in hand tremor is not associated with repetitive use of HAV. Aging and using nicotine are considered to be the crucial forecasters of hand tremor.

Non-Occupational Risk Factors Associated With Tremor

Beyond occupational risk factors associated with tremor, research indicates several non-occupational factors are also associated with increased risk for tremor. Some of these factors include gender, age, alcohol, use of tobacco, and emotional stress. Each of these factors is explored in the paragraphs below.

Gender

According to several studies, most women affected with ET have their head and voice more significantly affected than any other parts of the body. On the other hand, men have their hands more affected than any other parts of the body. A study by a group of neurological doctors and researchers, for example, was conducted to investigate the hypothesis that gender and age might impact ET inconsistency (Hubble, Busenbark, Pahwa, Lyons, & Koller, 1997). The examination included 450 ET patients. Results showed head/voice tremor was notably more common among female ET patients. Men had more ET tremor of the hand (Hubble et al., 1997).

Age

There is no exact age at which ET can take place. In general, the occurrence of ET increases with age. ET is more common in people age 40 and older (Louis & Ferreira, 2010). A study on 1,214 of participants was conducted by group of researchers in the School of Physiotherapy and Exercise Science in corporation with the Applied Cognitive Neuroscience Research Centre, Griffith University, Queensland, Australia, and the School of Human Movement and Exercise Science, University of Western Australia, Crawley (National Institute of Neurological Disorders and Stroke, 2014). This study concluded that even though tremor outlined to be the same among all age groups, older patients demonstrated higher tremor amplitude on their hands and fingers. Furthermore, there was higher EMG motion across all postural conditions (National Institute of Neurological Disorders and Stroke, 2014). As per the International ET Foundation, 20% of people over age 65 are affected with ET.

Alcohol

People who drink more alcohol everyday are more likely to be at risk of developing ET. According to Jaques (2009), a study by a Spanish Research Group:

> …assessed lifetime alcohol consumption and neurological symptoms in more than 3,000 people aged 65 years or older. At initial assessment, more than half (1,838 people; 56%) of the participants were found to have had at least one alcoholic drink per day over their lifetime. During the subsequent 3 years, 76 people developed essential tremor. (para. 4)

Another study suggests ET can be reduced for 45 to 60 minutes after the digestion of alcohol. This could contribute to chronic alcoholism in addition to tremor, which can worsen when the effect of alcohol is over (Kiriyama et al., 2011).

Smoking Cigarettes/Chewing Tobacco

Some specialists insist excessive amounts of nicotine or caffeine can cause tremor. Shiffman et al. (1983) explored the effects of cigarette smoking and oral nicotine on hand tremor. The study was conducted with 33 people of two age groups and gender, and included three experiments. Results of this study indicate there was a noticeable increase in hand tremor after smoking a cigarette and chewing 4 mg of nicotine gum (Shiffman et al., 1983).

Louis, Benito-León, and Bermejo-Pareja (2008) also conducted a study on 3,348 participants in Spain exploring the relationship between smoking and essential tremor. These researchers were from the Department of Neurology at Columbia University, New York and the Department of Neurology University Hospital Madrid, Spain. The majority (3,271) of the participants were ordinary people (392 among whom were smokers), and 77 participants had incident ET (5 among whom were smokers). This study verified the relationship between baseline heavy cigarette smoking and lower risk of incident ET.

Two former studies inspected smoking habits in prevalent ET cases and non-ET cases smokers (Jacob, 2010; Striano et al., 2007). Although the proportion of ET cases and non-ET smokers did not differ in the Striano et al. (2007) study, the number of cigarette packs per year was significantly lower in ET cases. The second of these studies focused on the association between smoking and prevalent ET (Jacob, 2010). In this study, "ever-smokers" were one-half as likely to have ET when compared with "never-smokers" (Jacob, 2010).

An interesting study presented the possibility of using nicotine to reduce the effect of Parkinson's disease. According to the results of this study of 20 subjects, there is no strong evidence of the effectiveness of nicotine to reduce the effect of Parkinson's disease, with no agreement on daily dosage, method, or process.

Emotional Stress

Stress exists in our daily life and anyone can experience stress anywhere and at any time. When stress takes place, the body responds mentally, physically, and emotionally. The reaction to stress varies from one person to another. In some people, emotional reactions to stress can include sadness, anger, less concentration, and mood change. Other people have unintentional physical reactions to stress, like sweaty palms, shaking, or weight loss or gain. Still other people might develop rest tremor. The cause could be the stress of a work interview, during an exam, when angry or during extreme fatigue, for example. This is called *physiological tremor.* Furthermore, there are studies that suggest emotional stress can make a vocal tremor even worst.

Approximately 25% of individual with essential tremor have vocal tremor (Hansen, Snyder, Qiu, Brooks, & Moreau, 2012).

Diagnosis of Tremor

According to Louis and Ferreira (2010), "ET is a highly variable disorder. Age of onset, progression, tremor distribution, and severity can vary greatly from one individual to another." There are symptoms associated with ET doctors can observe during medical exams, such as uncontrollable shaking of hands and arms, shaking voice, and slight head shaking. Part of the face may appear panicked, and in the worst cases, the face is unbalanced and abnormal. In rare cases, tremor can occur in the feet or legs. The diagnosis of ET is achieved by a review of the patient's history and a physical examination. Thus, there is no particular test to confirm a clinical diagnosis of ET. To aid in the diagnosis, several clinical criteria have been proposed, including those by the Movement Disorder Society (Deuschl et al., 1998), which were modified slightly by the Tremor Research Group (Elble, 2000). The history review of the disease should consider the age of the patient, the disease progression over time, the use of caffeinated beverages, tobacco, alcohol, and the use of any medication for ET treatment.

The physical examination can include Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) scans. During the exam, the characteristic of the movement should be evaluated precisely to confirm the involuntary movements are rhythmic and oscillatory. It is important to distinguish ET patients from those with PD. Patients with PD often manifest a mild to moderate postural tremor or kinetic tremor (Albert & Knoefel, 2011). It is also important to distinguish ET from enhanced physiological tremor. Enhanced physiological tremor is an 8 to 12 Hz postural and kinetic tremor that may occur in the limbs and voice (but not the head), and may be further exacerbated by emotion and by medications. While the amplitude of kinetic tremor in

ET is generally higher and the frequency lower than that of enhanced physiological tremor, mild ET and severe enhanced physiological tremor may have similar tremor amplitudes (Elble, 2000). The final stage of ET assessment is the lab evaluation. Thus, if symptoms or signs of hyperthyroidism are present, then thyroid function tests should be performed. In younger patients (i.e., under 40 years old) with no family history of ET or dystonia, the possibility of Wilson disease should be explored with a serum ceruloplasmin, which may be reduced; this is usually not an issue in older patients (Louis & Ferreira, 2010).

Treatment of Tremor

Treatment of tremor can involve the following:

1. **Non-surgical treatment (medications):** All medications doctors prescribe for essential tremor disorder have side effects, so the decision to treat ET patients with medications should only be made if the level of discomfort outweighs the side effects of treatment. Side effects of common medications include drowsiness and nausea caused by Topamax, fatigue and sedation caused by Xanax, and slow heart rate and drop in blood pressure caused by Beta-blockers (Harvard Medical School, 2004).
2. **Non-medical therapy:** Non-medical therapy includes physical therapy and exercises to enhance muscle strength. Other therapy treatment can involve adaption of wrist weight or using a wide-grip pen. Although physical therapies can improve coordination and muscle control of some individuals, these therapies are long time treatments and cannot remain with patients all day long. Since anxiety and stress typically make the tremor worse, non-medical relaxation performances and biofeedback can be effective in some patients (Paula F., 2008).
3. **Surgical treatment:** Various forms of surgical treatment can be used to control ET disorder when medications are ineffective. This can include Deep Brain Simulation (DBS), which

involves implanting electrodes within specific areas in the brain. This device produces electrical pulses to interrupt signals from the thalamus. There is no guarantee the tremor will be completely relieved with DBS (Johns Hopkins Medicine, n.d.). There are also some after surgery side effects, which include weakness, problems with balance, difficulty speaking, and headache. This surgery is costly. Moreover, according to some experts, surgical efficiency loss cases have been reported over time after DBS surgery. There is also gradual worsening of the disease cases following DBS surgery (Oxford Brain Journal, 2012).

4. **Surgical lesion:** Placing a surgical lesion in an area of the brain called the ventral intermediate thalamus (VIM) has been used to treat ET for decades. Between 80% and 90% of patients have benefited from this surgery. On the other hand, this surgery is only effective to control tremor on one side of the body. It is very dangerous to use this procedure to control tremor on both sides of the body due to the increased threat of developing speech problems (Johns Hopkins Medicine, n.d.).

Vibration

Vibration is a continuous shaking movement about an equilibrium point (Takacs & Rohal, 2012). It exists in many electrical, pneumatic, and hydraulic systems, and in most machines. In some applications, vibration is necessary and can be useful, such as in musical instruments, body vibration therapy devices, loudspeakers, and mobile phones. In contrast, there are many cases in which vibration can have a critical role in reducing machine performance and reliability, and cause energy losses. Some industrial applications require a vibration-free environment, and their process cannot be completed if any vibration exists. An example of an application is semiconductor wafers production lines. The vibration in many mechanical devices such as pneumatic drills, grinders, and sanders create dangerous noise that is disturbing, harmful, and has a negative impact on human health. When vibration exceeds the normal level of any mechanical machine, it can affect its lifetime and can be worn out rapidly due to imbalance or looseness of some mechanical parts. In a human being, some people suffer from vibration of one or more parts of their bodies. This unwanted vibration has a destructive impact on those patients, and makes their daily life activities very challenging and frustrating.

Vibration Cancellation Techniques

According to Hansen et al. (2012), vibration and noise are related and share many common concepts and depends on each other. For that reason, vibration control and noise control have been treated in a combined manner by researchers (Hansen et al., 2012, p. xvii). There are two different techniques used in the industry to cancel and control vibration: the active control and the passive control. In the active control method, there are sensors, actuators, and feedback logic controls involved in the design. The sensors measure the vibration, and the feedback system controls the actuators to generate the necessary force to counteract the unwanted vibration motion. In contrast, the passive control system acts passively, without requiring any power supply. The damping action mainly counts on the properties of materials used in the system (Harris & Piersol, 2002). Both active and passive damping techniques primarily use three methods for cancelling vibration. These methods include vibration damping, vibration isolation, and anti-vibration.

Active Vibration Isolation System

In the active vibration isolation system process, the vibration’s sensitive area is isolated from the source of vibration. This involves a feedback circuit to control the vibration isolation process. The feedback circuit consists of sensors to detect displacement, velocity, and acceleration, as well as an actuator for power generation, an amplifier, and a microcontroller.

Active vibration isolation is typically used in small structure systems such as medical devices, photonics, and the semiconductor industry (Harris & Piersol, 2002).

Active Vibration Damping System

The active vibration damping system is a closed loop system that involves sensors, actuators, and a feedback controller. It comes in different configurations and materials based on its application. This method is used when there is a need for a greater performance or when the passive technique is ineffective. Instead of using a spring as in passive method, active damping uses a servomechanism and gyro, which detects rotational velocity (Harris & Piersol, 2002). This method is effective when there are several vibration sources involved, as it is capable of damping all vibration at once.

Active Anti-Vibration System

The active anti-vibration system is a closed-loop system that uses actuators, sensors, and an electronic feedback controller. This method is usually used when the unwanted vibration area cannot be isolated from the vibration source, and also when the vibration is not amplified by the mechanical structure. In this technique, an out of phase force with equal frequency and amplitude is generated to interfere with the vibration source in order to minimize or cancel it. This system uses at least two sensors (Micromega Dynamics Industry, n.d.).

Passive Vibration Isolation System

In the passive vibration isolation method, the main focus is on minimizing the level of vibration transferred from the foundation to its equipment or vice versa. The simplest form of this method primarily involves a rubber pad or mechanical spring, a mass, and a damper. This technique is used in large scale structures and equipment (Harris & Piersol, 2002). Some area of applications are heavy load pumps, large air conditioning units, compressors, building and large structures, and car suspension systems.

Passive Vibration Damping System

Unlike the active technique, the passive vibration damping system does not involve electronic components. This system is used when the isolation methods cannot reduce the vibration sufficiently (Harris & Piersol, 2002). In this method, the structural design of the system generates a potential energy. This energy acts as a control force to absorb the vibration. There are several passive damping materials used today. These materials include viscoelastic materials, oil, rubber, and spring. Viscoelastic material carries the properties of both a liquid and a solid. It converts the absorbed vibration energy into heat.

Passive Anti-Vibration System

The passive anti-vibration system method is used whenever the sensitive area cannot be isolated from the vibration source. This system uses a Tuned Mass Absorber (TMA), wherein an oscillating spring-mass is linearly attached to the structural mass to reduce the amplitude of the mechanical vibration. This technique is widely used in a car's crankshaft pulley to control the angular vibration (Krenk & Hogsberg, 2014). The TMA technique today is employed in the solid fuel booster of spacecraft and many other applications (Micromega Dynamics Industry, n.d.).

Current Devises for People With Tremor

Several devices have been developed by researchers to assist patients with tremor. Among the most common devices is the assistive pen, which was designed to improve writing quality through control of hand tremors. This system was proposed by researchers from Malaysia (Yusop, Zain, Hussein, Musa, & Ishak, 2015). It depends on a linear voice actuator, which acts as an anti-tremor, and an accelerometer, which provides a feedback signal to the actuator.

Although the system provides some improvement to handwriting for tremor patients, it is still limited to writing purposes only. Yusop et al. (2015) did not mention the cost of the system.

Mouse Cage software is an application designed to help tremor patients control their mouse cursor (Mouse Cage, 2006). This software provides visual feedback by displaying the actual location of the hand movement, allowing the user fine control over the mouse. It is a free software application developed by Nico Cuppen. The disadvantage of this system is that it is only limited to use of the mouse. Another tool designed for fine motor control is Magna Ready (Magna Ready, 2015). Magna Ready offers classic dress shirts with magnetically-infused buttons. Thus, Magna Ready makes it easy for anyone with a hand tremor to button the shirt independently. The disadvantage of this shirt is that while it is easy to close the buttons, it becomes very difficult to open them. Another disadvantage is that it is only applicable to shirts. The price is $65 per shirt.

The tremor suppression orthosis with electromagnetic brake was developed in 2013 at Simon Fraser University in British Columbia, Canada (Herrnstadt & Menon C., 2013). This system involves two MEMS gyros installed on the forearm to calculate the elbow joint velocity. An advanced potentiometer was used to track joint angular data. Although the system succeeds in reducing hand tremor to some extent, the system still bulky, rigid, has mechanical parts, and involves some weight. Another disadvantage of this system is the weight. Weight may be annoying to patients, particularly the elderly, because it may restrict their movement. The cost of this system was not mentioned in the study. Another device was a kit introduced in 2013 by Lift Ware (Lift Lab of Verily Life Science LLC). It comes with a plastic holder that can hold a spoon or a fork that counteracts the vibration from a patient’s hand and minimizes the spilling of food. This device uses active stabilization technology similar to that used in cameras and guns. The spoon has some deficiencies like a chunky handle, no on/off switch, and sensitive electronic circuit and sensors that could be affected if dropped. The device costs $300 and each additional fork or spoon costs $20. It is limited for eating purposes and cannot be used to hold bottled drinks or writing pens/pencils.

All of the above-mentioned devices are either limited to perform one specific task or are bulky, heavy, and stationary. Although there have been many respectable studies to help tremor patients, there is still a need for a portable, flexible, and durable device that can perform several tasks instead of one or limited tasks. The aim of this research was to develop and design a tremor suppression system that can be used by tremor patients to perform their daily tasks such as eating, drinking, writing, and holding and gripping things.

CHAPTER III

RATIONALE AND OBJECTIVES

Rationale

As previously stated, this thesis proposes a portable, flexible, and economical device to reduce hand tremor. The following paragraphs describe the research rationale used to achieve this aim. There are several practices that need to be considered when developing a new product or service. Among those practices are *customer segmentation* and *value proposition.* Customers differ in the way they think, their lifestyles, purchasing habits, and other attributes. There is no one solution that is considered to be suitable for all customers. Thus, a one-size-fits–all approach is a bad practice and far from reality. Customer segmentation is a very important factor that needs to be considered when developing a new product or service. Another important factor is value proposition. This is because regardless of what is done, there will always be bigger competitors. This competition gets even bigger when the product or business moves across borders and overseas. This project is considered to be a needs-based segmentation, wherein the customers are ET patients. This does not include severe cases of tremor patients who suffer from head shaking, face changes, and difficulty speaking. The objective of this part of the project was to segment the customers who will benefit from this product. This segmentation includes: ET patients, both genders, and all ages.

Objectives

The objective of this part of the project was to achieve the following goals:

1. Design a new product for hand tremor patients that is not limited to one task only. This device can be used for several purposes such as writing, eating, closing shirt buttons, or holding a knife, fork, or cup. Thus, it will improve the quality of life of these patients.

2. Produce a low-cost device most tremor patients can afford to buy.
3. Design a portable device that can be used anywhere, anytime, and by any patient. It does not involve mechanical or stationary monitoring systems.
4. Develop a light device that uses light electronics components, which are assembled on top of a glove instead of heavy mechanical parts consistent with other products.

CHAPTER IV

METHOD AND PROCEDURES

The following sections describe the methods and procedures used to conduct this project, including the glove design, circuit design, interfacing Arduino with MPU6050, power supply connection, experimental method, and programming.

Glove Design

The glove is designed for the right hand, although it can be built for the left hand as well. There are six main modules involved in the design. Figure 2 indicates Modules 1 through 6.

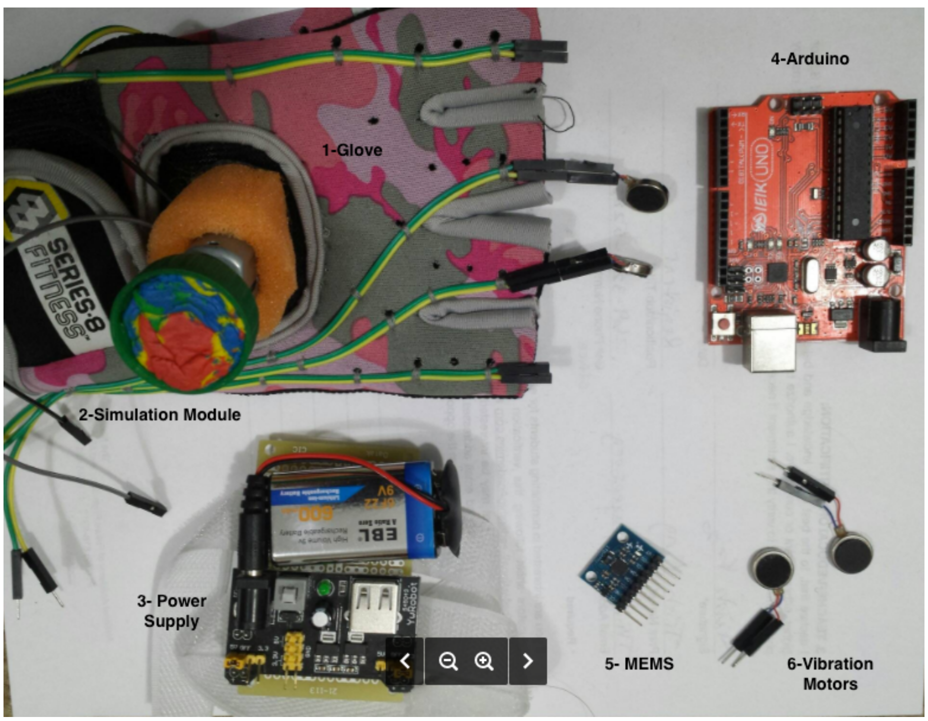


Figure 2. Hand glove and various modules and parts.

Module 1: Glove

The first module is the glove module, with connection wires installed on the glove. These wires are arranged in a way that makes them easy to connect to vibration motors from one end, and to the output pins of Arduino from the other end.

Module 2: Tremor Simulation

This module is built to provide and simulate human hand shaking. The difficulty to provide a vibration machine that satisfies the need for this project was the main reason for building this module. All vibration machines available in the College of Engineering and Applied Science at WMU were too big and could not be used for this project. Another alternative was to provide a tremor simulation device made specifically for hand tremor study and analysis. This system was expensive ($25,000). The solution was to build a simulation module. This module included a small 3-5V dc motor, plastic bottle covers, a Velcro strap, a 9V battery, clay, and a power supply circuit. The magnitude of the vibration depends on the size of the plastic cover and the location of the hole made in the cover, as indicated in Figure 3. The bigger the plastic cover, the more clay it can take and the weaker the vibration will be, and vice versa. A heavy material such as a little stone or a piece of metal can be added to make the plastic cover heavier. The further from center the hole in the plastic cover is made, the stronger the vibration will be, and vice versa. The oscillation generated by this unit could be used to mimic X, Y, and Z, with different amplitudes and frequencies.

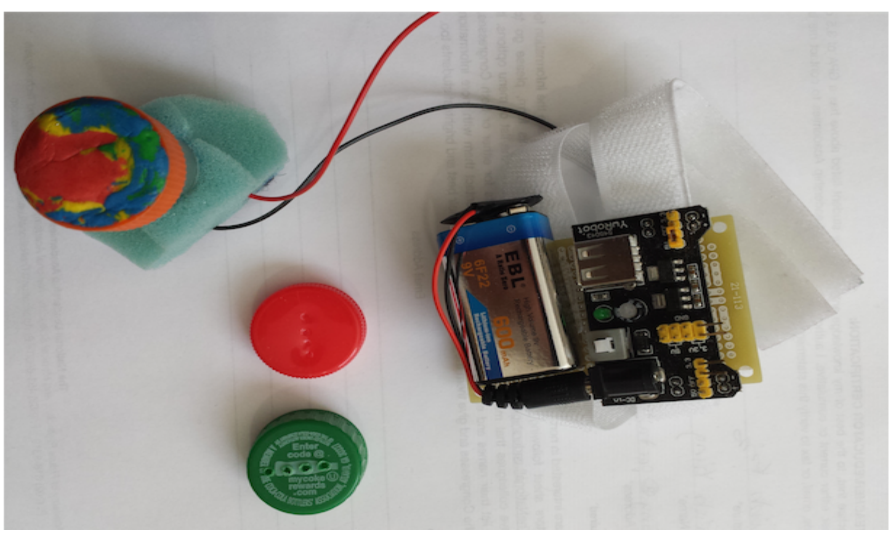


Figure 3. Hand tremor simulation module.

Module 3: Power Supply

This unit is used to supply the necessary voltage to run the vibration motors, 3.3VDC motor, and the Arduino (YwRobot).

Module 4: Arduino-Uno3

Melgar and Diez (2012) described Arduino as an open-source development board based on the ATMEGA microcontroller. It was introduced in 2005 at the Interaction Design Institute in Ivera, Italy. Unlike other microcontrollers, there are Arduino clones that are less expensive and have a simple programming environment. The open-source software is easy to use for beginners who do not have any programming experiences. Arduino software can run on Windows, Mac, or Linux. It is published as an open source, and is written in programming language similar to C/C++. Any experienced programmer can modify and extend Arduino programming capability. Any inexperienced circuit designer can develop and extend his or her own Arduino or Arduino shield boards (Melgar & Diez, 2012, p. 2).

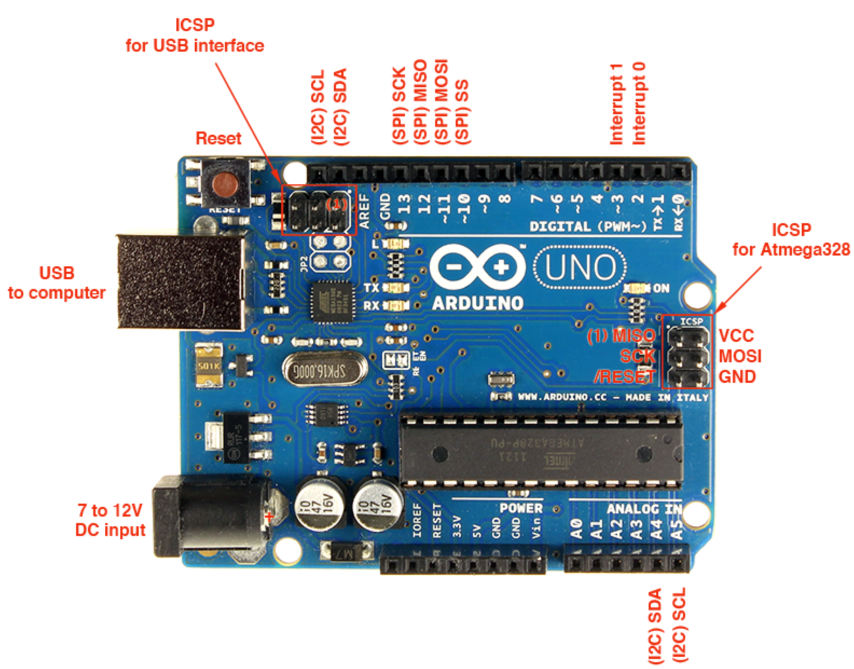


Figure 4. Arduino Uno R3 pinout diagram.

As shown in Figure 4, the Arduino hardware includes the main board that houses the ATMEGA microcontroller. It has other built in integrated circuit (ICs) modules like memory, a user interface chip, and a 5V voltage regulator chip. The power supply can be connected through the DC power input, which can handle any DC voltage between 7 and 12 volts. There are 14 digital pins numbered from 0 to 13 for sending or receiving digital signals. These pins can be used as INPUT or OUTPUT, depending on their need in the application. Six of the digital pins (0 to 5) can be used for pulse width modulation (PWM) purposes. Beside the power connector, there are four pins for power connection through wires or batteries. These pins are 3.3V, 5V, and two pins for ground (GND). There are also six analog input pins, which are used for receiving analog signals and converting them to digital signals. This unit is used to receive data from the MEMS sensor to send to the computer for analysis. It is also used to activate the vibration motors once the hand shaking is detected by the MEMS sensor.

Module 5: Accelerometer and Gyroscope

Advancement in new technologies have helped researchers to develop tiny microscopic and sophisticated sensors. The use of these sensors is becoming increasingly significant in many applications in daily life. They have been essential for the development of navigational systems, tablets, mobile phones, consumer virtual reality, medical devices, space, and military applications. The most common of these sensors are the accelerometer and the gyroscope.

Accelerometer. The accelerometer is a device that measures the magnitude of linear acceleration along any axis. By using a built-in microscopic crystal, the accelerometer can detect an object movement when it changes its position from standstill to any velocity. When this acceleration (vibration) occurs, the crystal inside the accelerometer goes under stress and generates a voltage. The amount of generated voltage depends on the level of vibration and can be used to determine the position data history of that object.

How the accelerometer works can be understood by reviewing high school mathematics and physics. *Velocity* is defined as the rate of change in the position of an object with respect to time. *Acceleration* is defined as the rate of change in the velocity of the same object with respect to time. The rate of change with respect to time is known as *derivative.* According to this, velocity is considered the derivative of the position and acceleration is considered the derivative of velocity. If the acceleration of a body is given, then the preceding position data of that object can be found easily by applying double integration on the acceleration. Therefore:

If velocity $V = \int (a)\, dt$ and position $S = \int (v)\, dt \Rightarrow S = \int (\int (a)\, dt)\, dt$

Where a = acceleration, V = velocity, and S = position.

Gyroscope. Gyro measures the rate of rotation of an object (orientation) around any axis, X, Y, or Z, using the principle of angular momentum. In other words, gyroscope is used to determine how fast an object can spin about an axis (angular velocity), which is represented in rotation per minutes (RPM). The mechanical gyro as displayed in Figure 5 consists of a high speed, free spinning wheel called a *rotor.* The rotor is surrounded by three suspended frame rings called *gimbals,* which have almost frictionless bearing. If the gyro is tipped, the gimbals change their orientations to keep the rotor spinning along the same original axis and same direction. The capability of the rotor to remain stationary regardless of any change in the gimbals axis makes the gyroscope useful in many applications. In this particular case, it is useful in detecting the orientation of the hand (Scarborough, 1958).

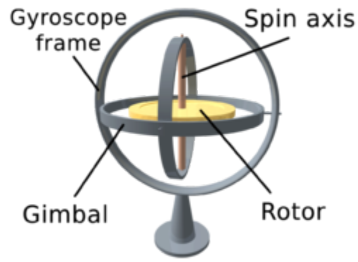


Figure 5. Mechanical gyroscope.

In modern electronics technology, microscopic gyros are used to reach the same outcome of mechanical gyros. These microscopic gyros use a different principle of operation and structure than those used in mechanical gyros. In recent years, two other kinds of gyros were introduced and found their way in many applications. These are *optical gyros* and *vibration gyros,* with the later being the most common in advanced technology. Armenise, Ciminelli, Dell'Olio, and Passaro (2011) suggest all vibration gyros are based on the Coriolis Effect. This effect occurs when an object moves on a spinning system and experiences a force perpendicular to the direction of rotational motion. This force causes the object to deflect right or left instead of going straight. The vibration angular degree can be simply represented by a two degree-of-freedom spring mass damper structure (Armenise et al., 2011, p. 12). These gyros are made out of different materials like crystal, ceramic, and silicon. Their structures can also take several shapes like a double-t, tuning fork, or h-shape, depending on their use and applications. Gyroscopes are used in aircraft navigational systems, large boats, unmanned vehicles, camera-shake correction, game controllers, motion sensing, and car navigational systems.

Combining accelerometers and gyroscopes together can lead to very powerful sensing capabilities and give a quicker, more accurate position and orientation determination. These micro size devices are called *microelectromechanical systems* (MEMS) and involve tiny mechanical and electronic parts. MEMS become very significant in applications where the highly accurate and complex movement of an object is required. Based on their uses and applications, they can vary from being very simple structures without any moving parts, to extremely complex structures with tens of integrated parts. The integrated mechanical parts can comprise springs, levers, and vibrating structures. The integrated electrical parts can comprise capacitors, resistors, inductors, and transistors. Armenise et al. (2011) showed the reduction in power consumption, size, cost, and weight made MEMS the optimal choice for small-scale controlling technologies (p. 97). Figure 5 shows the MEMS accelerometer/gyro sensor used in this project. This sensor is called GY-52, and contains three accelerometers and three gyros in one single chip.

The GY-521 is a breakout board that contains a Micro Processor Unit 6050 (MPU6050), a KB33 voltage regulator, pull-up resistors in both clock lines (SCL) and data lines (SDA), and the auxiliary I2C lines. The MPU6050 consists of three MEMS accelerometer and three MEMS gyros. The accelerometer range is: ±2, ±4, ±8, and ±16g, and the gyro range is: 250, 500, 1000, and 2000/s. The MPU has a 16-bit analog to digital converter for each channel, which makes it very accurate by capturing the X, Y, and Z channel at the same time. The MPU6050 is integrated with a Digital Motion Processor (DMP). DMP performs a fast calculation of six axes positions, and gives a precise reading of the motion at any time. This offloads the timing and processing power required by the MPU6050. The KB33 voltage regulator enables the GY-521 to be connected to any voltage source between 3.3 and 5 DCV. The auxiliary line I2C is a serial protocol for a two-wire interface to connect low speed devices such as the microcontroller and analog to a digital converter in the integrated system. It also can be used to allow the MPU6050 to act as a master to other devices such as a microcontroller if needed (Iven Sense, 2013).

The number of sensors built inside the MEMS is referred to as *degrees of freedom* (DOF). The GY-521 contains a three-axis accelerometer and a three-axis gyro; hence it has six degrees of freedom. This is useful for detecting the acceleration of the hand in any of the axes.

Module 6: Vibration Motors

Although vibration motors have been around for many decades, they became widely spread in mobile phone vibration alerting in the 1990s. These motors are also used in different products and applications, such as global positioning systems (GPS) trackers, medical instruments, haptic feedback devices, the automotive industry, and much more. Based on their applications, vibration motors can vary in shapes (i.e., coin, cylinder, spring) and sizes (i.e., diameter 3 mm to 48 mm).

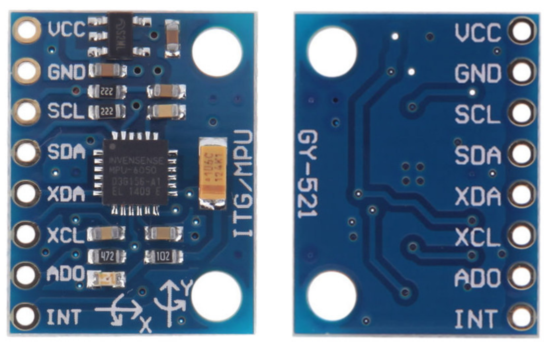


Figure 6. GY-521 board (Iven Sense, 2013).

Coin vibration motors are small, thin, and light weight motors, with no external moving parts. Figure 6 indicates the internal construction of coin motor, which consists of a magnet, weight, and a rotor with commutation points attached with a coil. The power supply brushes are attached to the magnet. One end of the commutation points is in contact with the brushes, and the other end is attached to the small electric wires. Once the power is connected, the electrical coils in the rotor are energized, which in turn produces a magnetic field. This magnetic field is capable of rotating the motor and producing a force that causes the weight to displace. The repeated displacement generates the vibration. Whenever voltage applied to the motor increases, both the speed of the motor and the vibration frequency will increase.

Figure 7 displays the direction of spinning of the vibration motor. If the shaft is in Y axis, the vibration will take place in the X and Z axes.

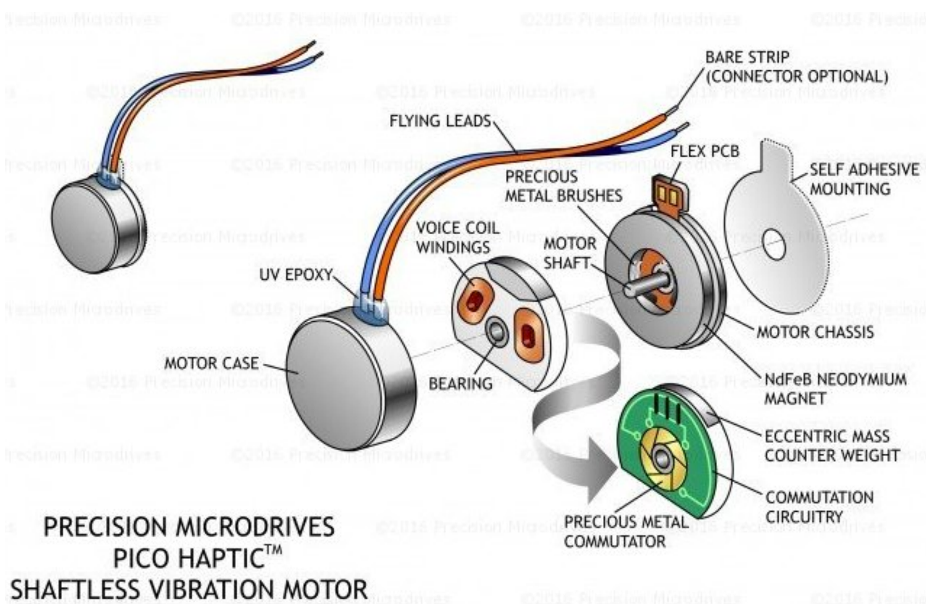


Figure 7. Internal construction of coin motor (Precision Microdrive, n.d.).

The frequency(f) of the motor is calculated by: $f_{vib} = (\text{Motor RPM})/60$

The produced force(F): $F_{vib} = m \times r \times w^2$

Where: m = the mass of eccentric mass

r = mass offset distance (the weight distance from the shaft)

w = speed of the motor (rad^{-1})

$w = 2\pi f$

From the equations above, the displacement can increase if:

1. The attached weight increased.
2. The mass offset distance increased.

3. The speed of spinning shaft increased.

4. The applied voltage increased.

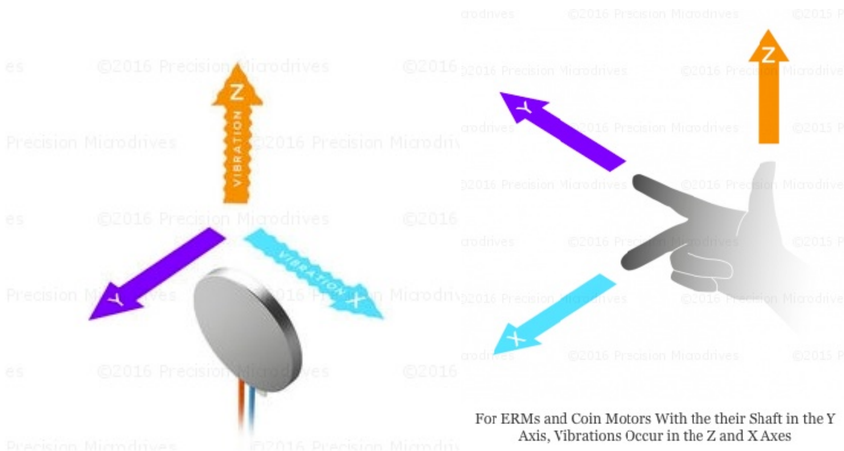


Figure 8. Vibration direction in coin motors (Precision Microdrive, n.d.).

Circuit Design

The design of this circuit involves five different modules: the glove module, the tremor simulation module (3-5V DC motor, power supply circuit), the Arduino board, the MPU6050 sensor, and the vibration motors. In real applications, the same circuit is used with the exceptional of the 3-5V DC motor, as this motor is used to generate vibration for hand shaking simulation purposes only.

Interfacing Arduino With MPU6050

The wiring diagram in Figure 9 indicates the connection of the various modules. As shown in Figure 9, GND and VCC of the MPU6050 are connected to GND and 3.3V of the Arduino, respectively.

Any device attached to the MPU6050 can act as master or slave. In order to let Arduino be the master and MPU6050 acts as a slave, the I2C-bus needs to be interfaced with Arduino. The I2C is a two-wire interface bus inside the MPU6050, and it compromises the serial data (SDA) bus and serial clock (SCL) bus. When the SDA pin on the MPU6050 is connected to

Arduino's analog pin 4 and the SCL pin on the MPU6050 is connected to Arduino's analog pin 5, then Arduino puts the slave address on both buses. The MPU6050 matches the address on these buses to acknowledge Arduino as a master device. This enables Arduino to capture X, Y, and Z channels at the same time.

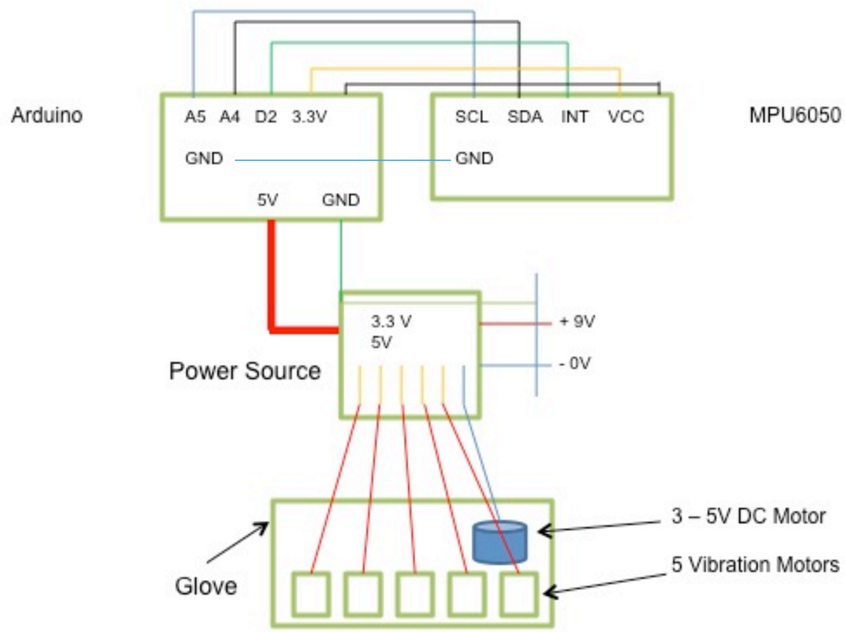


Figure 9. Wiring diagram of the complete project.

Finally, the interrupt (INT) pin on the MPU6050 is connected to Arduino's digital pin 2. The interrupt is used for noticing the Arduino if an intermittent event takes place. Thus, Arduino can save its current execution state and wait until the interruption is over to then go back to its previous status. This very important feature enables Arduino to save its execution state when the interruption takes place so there is no need to reload the program again. This saves time by saving the executed cycle of the program unchanged.

Power Supply Connection

The power supplied to this circuit is provided through a 9V battery that is connected to the DC input plug of the YwRobot power regulator. The input of this regulator can accept any voltage ranging from 6.5 to 12 volts. The output can supply 3.3V, 5V, or combination of both, up to six output voltages. This voltage regulator circuit supplies the voltage to the Arduino, 3.3 to 5 DC motor, and vibration motors, as displayed in Figure 9. The vibration motors can be mounted any place on top of the hand or fingers. Up to five vibration motors can be used. This power supply is useful for this project because it provides several output DC voltages at different levels. It supplies the needed power to all modules involved in this project.

The block diagram of the propose system is shown in figure 10.

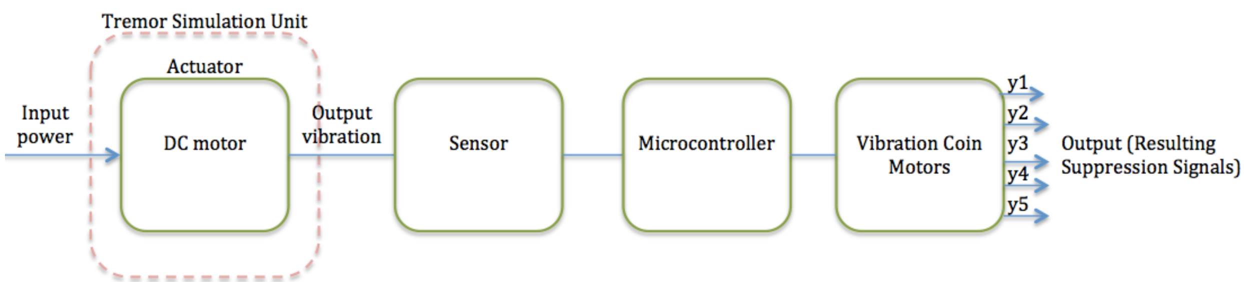
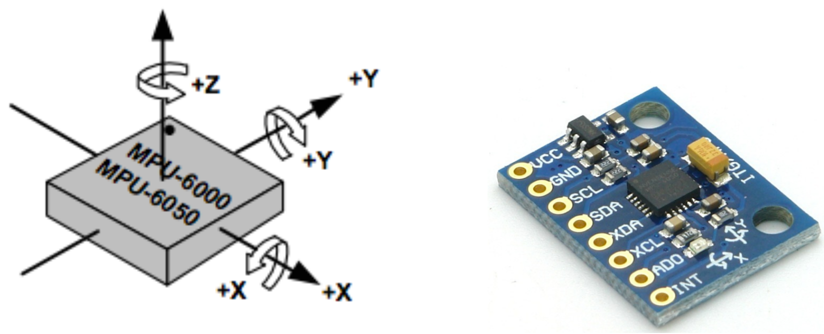


Figure 10. The Block diagram of the proposed system.

Experimental Method

The aim of this project as explained before is to reduce hand tremor by using vibration motors, which are controlled by Arduino. The vibration of the hand is being sensed by the MPU6050. Before proceeding, it is necessary to understand the orientation the MPU6050 axes. Figure 11 indicates the X, Y, and Z orientation of the MPU6050, or pitch, roll, and yaw as described by others. Figure 11 also shows the orientation of the axes, labeled on the MPU6050. If the MPU6050 sensor is held stable on a flat surface like a table, its output should indicate 0 in all three axes.



a b

Figure 11. Orientation of the MPU6050 axes and orientations (Iven Sense, 2013).

Programming Arduino to Talk to MPU6050

Two software were involved in this phase of the project. The first software is the Arduino IDE, which is similar to the JAVA programming environment. It makes it easy to write code and upload the code to Arduino. The other software is called SerialChart, which is an open source free program by Starlino. This software allows one to plot the real time data of a serial port like Arduino. There are tens of programs on the Arduino webpage library that are written to let Arduino talk to and control the MPU6050 (playground.arduino.cc//Main/MPU-6050). The program in the Appendix is adopted from the same source and has been modified to fit the need of this project. This program enables the MEMS sensor to communicate with the Arduino unit. It reads the fast calculated accurate position data from each axis. After that, it sends those raw data to the serial output for further manipulations. The SerialChart program plots those raw data in signal forms representing any changes in orientation and acceleration of the hand.

CHAPTER V

RESULTS AND DISCUSSION

The final aspects of this thesis present the results of the methods and procedures discussed above, along with conclusions and recommendations.

Results of the Arduino and MPU6050 Programming

This program basically reads the values of the three accelerometer and three gyros involved in the design of this project, and prints these values in comma-separated values format, as shown in Figure 12.

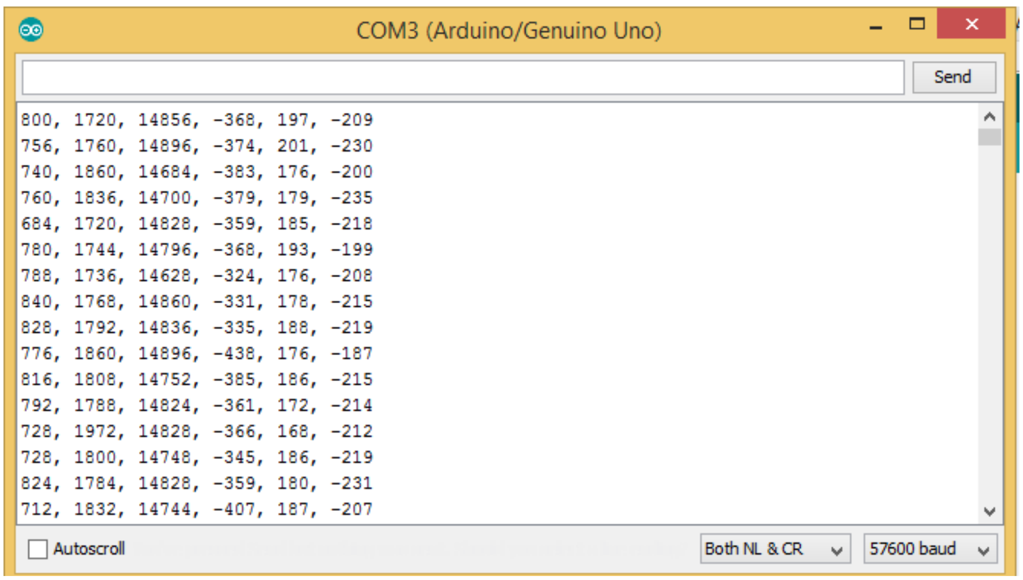


Figure 12. Screen shot of the real time value of the accelerometers and gyros.

The first three columns represent accelerometer values, and the last three columns represent gyro values. The window of the values in Figure 12 is called the *serial monitor* of the Arduino program. These values will continue running forever, as long as the Arduino and the MPU6050 are interfaced and connected to the computer. Notice that these values are not totally stable, there is a little fluctuation in the values. This is due to the environment surrounding the MPU60505 sensor. The sensor, as described earlier, is sensitive and can be affected by noise, signals, or temperature. The change in values in any of the axes increases as the sensor moves back and forth in that axis.

The next step in the project involved reading the raw data of accelerometers and gyros values and plotting them. It was necessary to ensure the baud rate in both software were matching. In this case, the baud rate is 57,600. There are configuration files in the SerialChart program that need to be setup. This includes selecting the colors for each axis. Here, the blue color represents the X-axis, green represents the Y-axis, and red represents the Z-axis. As shown in Figure 13, when the MPU6050 is set on a flat surface, there should be a nearly smooth line in all axes, which indicates there is no vibration in any axes. Figure 13 shows what the plot looks like after running SerialChart.

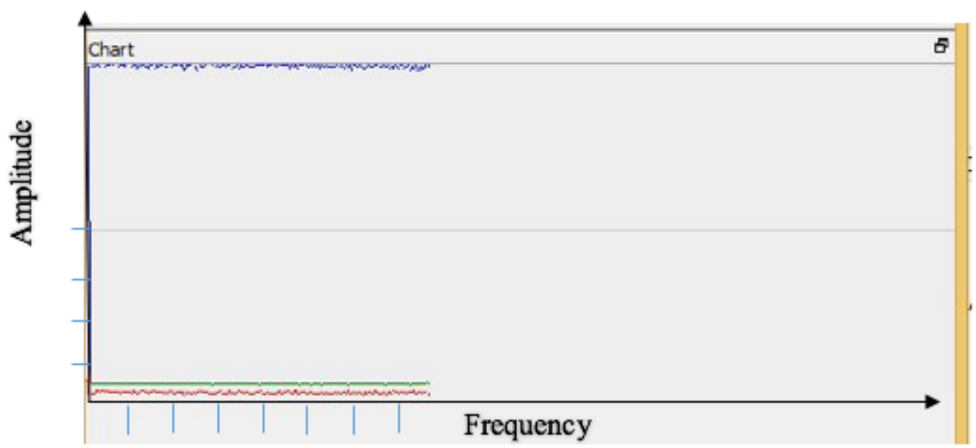


Figure 13. All three axes plot almost smooth.

Fingers are easier to place vibration motors on top of them. Thus, the test was focused on the middle finger and thumb. The MPU6050 sensor was attached to the bottom of the middle finger and the thumb. Due to the similarity of the results of the middle finger and the thumb output signal, the middle finger case study was chosen.

When the 5V vibration motor ran to simulate the hand vibration, the plot of the data looked like Figure 14. In this step, no vibration motors were attached to the fingers yet.

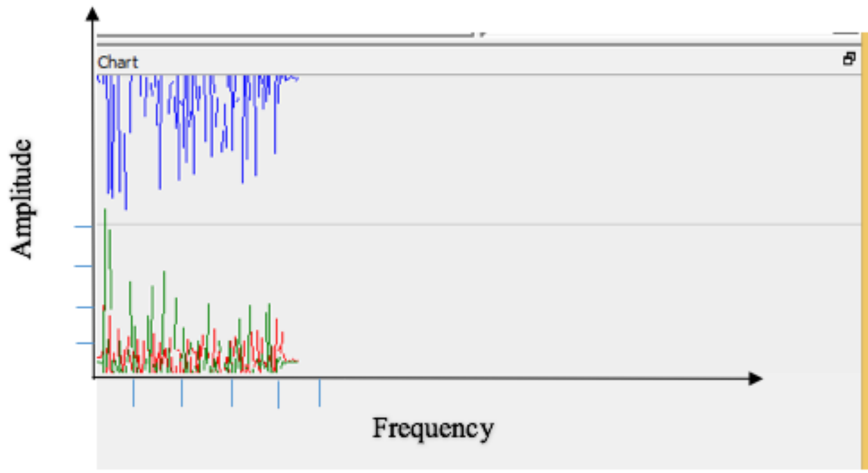


Figure 14. Plot display of three axes after running tremor simulation motor.

From Figure 14, it is clear that the tremor on hand is more obvious on the X-axis, and Y-axis while it is less in the Z-axis (Yaw). For any pair of six degree of freedom MEMS, x-accelerometer and y-gyroscope will always depict the maximum tremor motion. This analysis has been conducted and proven by Fred, Filipe, and Gamboa (2011) and Teskey (2011).

In the next experiment five vibration motors were attached to the fingers in a random manner. The generated plot is displayed in Figure 15. Notice there was no improvement in the hand tremor suppression.

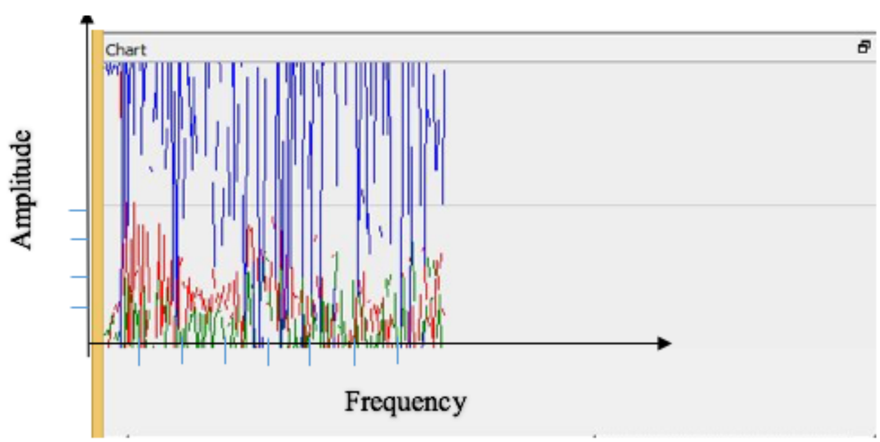


Figure 15. Plot display after attaching vibration motors to the finger randomly.

Another experiment was conducted by attaching two vibration motors on the left side of the finger and the other two on the right side of the finger. The result is shown in Figure 16. Investigating the highest amplitude value of the suppression signal on the y-axis in comparison to input signal (original vibration), we notice a reduction in amplitude that is close to 40%. This amount of reduction is the best result that was obtained in this experiment.

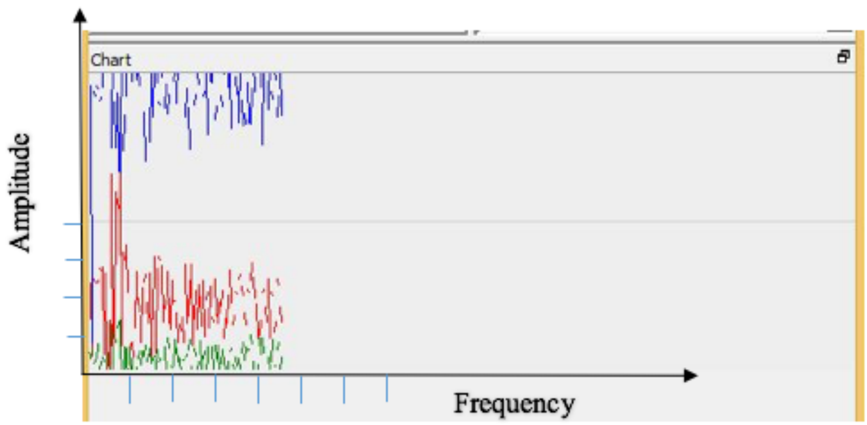


Figure 16. Plot display using two motors on each side of the finger.

When this figure is compared to Figure 13, we can see the improvement in the reduction of frequency on the X-axis (blue) and the vibration on Y-axis (green). Next, two motors were attached on the top of the finger, and the other two were attached with a 45 degree angle to the bottom of the finger. This configuration led to the signals shown in Figure 17. Notice this result is very similar to the result of Figure 15, with the exception of a little suppression achieved in the X-axis.

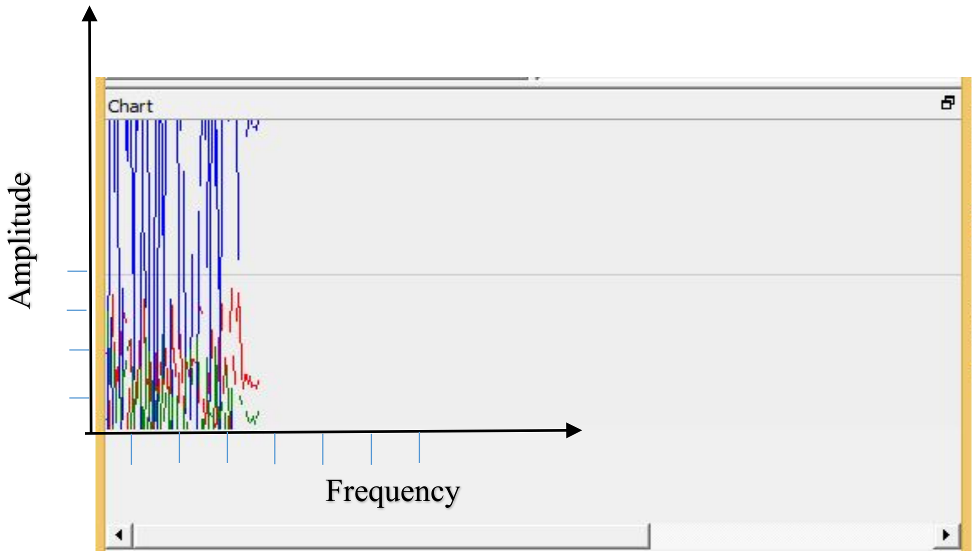


Figure 17. Plot display using four vibration motors, two on the top and two with a 45 degree angle on the bottom of the finger.

Finally, five vibration motors were arranged on the left side of the finger. The resulting signal is shown in Figure 18. As shown in the Figur, there was no improvement in the suppression of the tremor using this configuration.

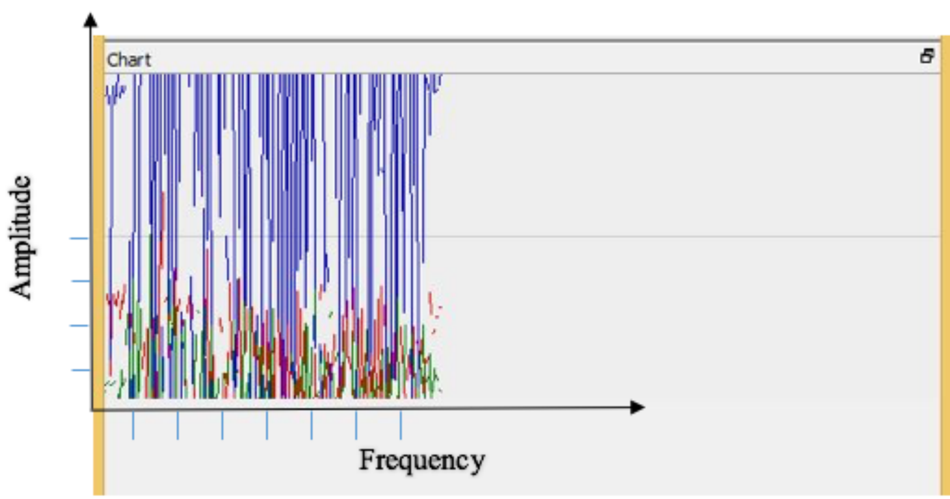


Figure 18. Plot display after attaching five motors to the left side of the finger.

Project Cost of the System

The proposed device is cheap, with the costs specified as follows: glove: $5, Arduino unit: $9, MEMS sensor: $4, power supply unit: $2.5, vibration motors: $0.5 x 5 units = $2.5, 3VDC motor: $2, 9V battery: $3, wires, glue, sponge, and Velcro $10, total = $38.

Conclusion

In this thesis, we proposed a hand tremor suppression system. The system is designed to be built-in a glove so that it can be used for several tasks instead of one limited task such as in hand tremor spoons or pens. This device is a low-cost, about $40, and can be afforded by many hand tremor patients. Furthermore, it is portable, light, and can be used anywhere and at any time. It is composed of light electronic components instead of heavy mechanical components consistent with other tremor suppression products. The arrangement of vibration motors on the fingers played an important role in the amount of the tremor suppression. The best suppression was achieved by placing two motors on both sides of the middle finger. With this arrangement, the shafts of the motors were in the X direction and the vibrations were created in the Y direction which allowed the sensors to perform at the best sensors' technical specifications. Finally, with further improvements, this system can lead to a prototype that is capable of helping tremor patients perform normal daily life activities.

Recommendations For Future Research

This prototype can be further modified to become smaller and more accurate with better tremor supersession. TheArduino-Uno3 module is based on the ATMEGA microcontroller (3 X 0.8 cm), which is relatively large compared to other versions available from the same manufacturer such as the Arduino-Mini. It is not only smaller (0.8 x 0.8 cm), but also cheaper (less than $2). Also, instead of using a separate accelerometer/gyro sensor, it would be a better idea to integrate the MPU6050 sensor with the Arduino-Mini in one single board. Another suggestion for improvements can be to explore replacing the motors by MEMS magnetic actuators. The capability to integrate all of these devices in a small board should result in a very small and a good hand tremor suppression system.

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Appendix A

Arduino MEMS Interfacing Code

Arduino MEMS Interfacing Code

```
#include<Wire.h>
const int MPU_addr=0x68;  // I2C address of the MPU-6050
int16_t AcX,AcY,AcZ,Tmp,GyX,GyY,GyZ;
void setup(){
   Wire.begin();
   Wire.beginTransmission(MPU_addr);
   Wire.write(0x6B);  // PWR_MGMT_1 register
   Wire.write(0);     // set to zero (wakes up the MPU-6050)
   Wire.endTransmission(true);
   Serial.begin(57600);
}
void loop(){
   Wire.beginTransmission(MPU_addr);
   Wire.write(0x3B);  // starting with register 0x3B (ACCEL_XOUT_H)
   Wire.endTransmission(false);
   Wire.requestFrom(MPU_addr,14,true);  // request a total of 14 registers
   AcX=Wire.read()<<8|Wire.read();  // 0x3B (ACCEL_XOUT_H) & 0x3C
   (ACCEL_XOUT_L)
   AcY=Wire.read()<<8|Wire.read();  // 0x3D (ACCEL_YOUT_H) & 0x3E
   (ACCEL_YOUT_L)
   AcZ=Wire.read()<<8|Wire.read();  // 0x3F (ACCEL_ZOUT_H) & 0x40
   (ACCEL_ZOUT_L)
   GyX=Wire.read()<<8|Wire.read();  // 0x43 (GYRO_XOUT_H) & 0x44
   (GYRO_XOUT_L)
   GyY=Wire.read()<<8|Wire.read();  // 0x45 (GYRO_YOUT_H) & 0x46
   (GYRO_YOUT_L)
   GyZ=Wire.read()<<8|Wire.read();  // 0x47 (GYRO_ZOUT_H) & 0x48
   (GYRO_ZOUT_L)
   //Serial.print("AcX = ");
    Serial.print(AcX);
    Serial.print(", ");
    //Serial.print(" | AcY = ");
     Serial.print(AcY);
     Serial.print(", ");
    //Serial.print(" | AcZ = ");
     Serial.print(AcZ);
     Serial.print(", ");
     //Serial.print(" | GyX = ");
    Serial.print(GyX);
    Serial.print(", ");
    //Serial.print(" | GyY = ");
     Serial.print(GyY);
     Serial.print(", ");
     Serial.print(GyZ);
     Serial.println("");
     delay(333);
}
```