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A Review of Techniques Used to Suppress Tremor

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Abstract

The most frequent movement disorder is Tremor, which has an increased incidence and prevalence in people over 65 who have Parkinson's disease or essential tremors. Although not life-threatening, it prevents patients from performing their daily activities. An overview of different types of tremors and their treatment in medical and surgical views are discussed in this paper with a review of the stimulation nerves and muscles technique. Then a look at tremor detection and measurement methods are considered with a review of the medical devices' mechanism of action that is placed as a substitute treatment for patients that have a low response to medications and surgical treatment to provide effective and safe tremor suppression.

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Keywords: Hand Tremor; Tremor Suppression; Parkinson's Disease; Essential Tremor; Electrical Stimulation Technique.

1. Introduction

A tremor is an oscillatory involuntary and roughly sinusoidal movement with rhythm at a specific frequency of a body part that is projected to muscles as a result of persistent oscillations in the neural system. It is considered a common movement disorder that causes considerable functional impairment because it is resulting from overcompensating the musculoskeletal systems' feedback regulation mechanism [1]. Prevalence of pathological tremors among the elderly ranges from 2% to over 10% (65 years or older) [2]. The majority of tremors affect the hands and can impact the legs, head, and face, where tremors in the hands are a serious problem because they make it difficult for patients to do activities of daily living (ADL) including writing, eating, and drinking because of the involuntary vibration of their hands, which can create social anxiety and depression [3]. The natural movement mechanisms must be defined to understand the different types of tremors, where the movement of people can be divided into intentional and nonintentional movements. Intentional movement refers to desired motions such as picking up a glass of water. In contrast, nonintentional motion refers to movements that are involuntary, such as the little vibrations in the hand fist while attempting to keep it tight. Generally, classifying tremor levels based on frequency falls within the range of 4 to 18 Hz [1]. Tremors can be classified according to whether they happen at rest, the action, or with a particular posture of a patient [4]. Essential and Parkinson's tremors are the most common types in the world [5]. In addition, there are many different types of tremors, each with its unique set of causes and symptoms [6].
The contribution of this paper can be summarized as follows:

- First, a classification for the types of tremors is presented
- Second, different methods to treat tremors are discussed including medical, surgical, electrical, and other types.
- Third, comparing the performance of these different types to identify the gap in the previous research.

2. Classification of Tremor

Tremors are divided into several groups as required by the clinical assessment, which significantly impacts medical diagnosis and treatment. The classification is based on certain tremors' natural frequency and amplitude or by its root cause based on the tremor's reaction when the muscle is relaxed or contracted and whether it occurs at rest, during the motion, or in a specific posture (Table 1). The hand position is considered one of the most accepted classifications for tremors.

2.1. Parkinson's Disease (PD)

It is a type of neurodegenerative disorder that impact many older people. It can also be described as an oscillatory movement that has a reasonably steady frequency (from 3.5 to 11.5 Hz) but varies in amplitude over time, which is involuntary and rhythmic [12].

Nomenclature

ADL	Activities Of Daily Living	PIP	Proximal Interphalangeal
ANN	Artificial Neural Network	PwPD	Patients With Parkinson’s Disease
CAD	Computer-Aided Design	RSAA	Rotational Semi-Active Actuator
CZI	Caudal Zona Incerta	SETS	Soft Exoskeleton For Tremor Suppression
DBS	Deep Brain Stimulation	SRS	Stereotactic Radiosurgery
EMG	Electromyography	STN	Subthalamic Nucleus
EPS	Electrical Potential Sensors	TAPO	The Task Of Adjustable Passive Orthosis
ET	Essential Tremor	TENS	Transcutaneous Electrical Nerve Stimulation
FES	Functional Electrical Stimulation	TETRAS	The Essential Tremor Rating Assessment Scale
GPI	Globus Pallidus Internal	TSO	Tremor Suppression Orthosis
IMU	Inertia Measurement Unit	UPDRS	Unified Parkinson's Disease Rating Scale
MCP	Metacarpophalangeal	VIM	Ventral Intermediate Nucleus
MR	Magnetorheological	WEETS	Wearable Elbow Exoskeleton For Tremor Suppression
MRgFUS	Magnetic Resonance-Guided Focused Ultrasound	WTSE	Wrist Tremor Suppression Exoskeleton
NCC	Non-Contact Capacitive	WTSG	Wearable Tremor Suppression Glove
PD	Parkinson Disease		

This type is more frequent in elderly people with almost seven to ten million people affected by this disease worldwide. Wherein both emerging and developed countries, the total number is increasing annually and it is expected to be twice within the next 15 years [13]. PD is brought on by the dying of dopamine-producing nerve cells in the brain that is used to facilitate communication between nerve cells [14], therefore a lack of motor control results in a poor feedback system. In addition, other factors that may cause PD such as age, gender, and exposure to specific toxins [14]. PD symptoms show trembling in one or both hands at rest, which are distributed frequently and asymmetrically [15,16]. In addition to the above, facial expressions are diminished in the earlier stages of the injury, and change in handwriting, instability, and a decrease in performing movements [17]. As a result, patients experience troubling conditions such as fatigue, mood swings, sleep disturbances, and swallowing problems [14]. Parkinsonian tremor fluctuates around the mean in the time domain. In addition, it has multiple harmonics in the frequency domain especially the second and the third harmonics [18]. The unified Parkinson's disease rating scale (UPDRS) has four sections, where a patient conducts the first two sections, and the expert conducts the last two. where a questionnaire with 50 multiple-choice questions about the disease's motor and non-motor indications [19].

2.2. Essential Tremor (ET)

It is a common pathological tremor in adults and occurs because of a neurological disorder when the cerebellothalamocortical network's central oscillations travel to spinal motor neurons that induce the hostile muscles in the hand and forearm causing pathological tremble in the middle frequency (from 3 to 4 Hz) and high-frequency (from 10 to 12Hz) compared to other tremors [20]. ET is considered one of the action tremor types since it happens during movement [21]. Therefore patient experiences difficulties carrying out daily activities [3] and psychological strain, which extends and affects others around them [22]. To evaluate tremor is used the essential tremor rating assessment scale (TETRAS)[23], which is graded from 0 to 4 points based on the tested person's performance during the conduction of daily activities, such as writing or reading [23].

2.3. Characteristics Differing Between Parkinson's Disease (PD) and Essential Tremor (ET)

Even though ET and PD are very different in many ways, many people confused them because of the variety of causes and similarity of symptoms (Table 2), especially in the early stages of the disease [24].

Table 1. Summarizes the main categories of tremors

Categories	Definition	Frequency	Types of tremors associated with it	Effects
Rest Tremor	It is a rhythmic tremor that ensues when the body parts are completely at rest against gravity while the affected limb continues shaking [7]. However, stops shaking when the patient intentionally moves it, and also during the limbs are in severe repose, such as when sleeping, they vanish.	3 – 7 Hz	Parkinson’s disease, supranuclear palsy, multiple-systems atrophy, and Drug-induced tremor [8].	It often occurs in the hands and forearms and also affects the fingers, leg, jaw, and eyelids [9].
Postural tremor	It occurs when muscles voluntarily contract for the patient and attempts bodily part to be maintained at a certain posture against gravity, and during movement may continue or increase [10].	5 - 9 Hz	Essential tremor, Wilson's disease, physiologic tremor, withdrawal from alcohol or drugs, drug-induced tremor, and psychogenic tremor [8].	It can be seen in the legs or outstretched arms.
Action tremor	it occurs when activated the target muscle or muscle group changes the position intentionally of the affected part for example when the patient is requested to place his index finger on his face [11].	5 – 12 Hz	Rubral tremor, cerebellar lesion, psychogenic tremor.	It affects on hands and fingers.

Table 2. Compares differences between the main types of tremors in many aspects

Aspects	Parkinsonian Tremor	Essential Tremor
Definition	The most prevalent neurodegenerative conditions.	A disorder of the nervous system.
Genetic	Occurs by damage to neurons in the brain and rarely a family history.	Genetics plays a significant role in occurring many of cases ET in the family.
Frequency& Amplitude	A reasonably steady frequency, High amplitude and varies in time.	The frequency is higher and faster, The Amplitude is more variable.
Age of injury disease	Usually occurs between the ages of 55 and 65.	It can happen at any age but is most prevalent in middle age.
Case of occurring	Occurs at resting and postural; rarely kinetic.	Occurs during movement and Postural; resting is less common.
Consequences	Causes problems in movement, posture, and unsteady gait.	It does not cause any other health problems.
Affected areas of the body	It starts in the hands and then extends to the legs, and other body regions such as the jaw and it has no effect on the voice or the head.	It affects the hands, rarely the legs and it can also affect the head and voice.
Clinical traits	The rigidity of the muscles, the difficulty of the person to get up from a seated position, balance problems when walking, and some daily activities are accomplished slower.	It starts gradually, increases with stress, and excessive fatigue, and gets worse as movement increases.
Effect on the body sides	It is usually asymmetrical where that begins on one side of the body and moves to the opposite side.	(Bilateral; symmetrical) Initially affects both sides of the body.
Treatment	Treatment with levodopa usually improves the situation.	The medication used is propranolol.

3. Medication Treatment

Recommended use of levodopa the first-line therapy for all motor symptoms of PD [16] and has an immediate effect and is effective for minor tremors. In contrast, many ET does not respond to levodopa because it is substandard and only treats the symptoms and therefore does not make a meaningful improvement in their quality of life [25]. In addition, It has some negative effects, including long-term efficacy decrease, and drug dependency [26].

"Propranolol" and "primidone" are the two treatments available to reduce the intensity of essential tremors in the upper limb [27]. However, propranolol medication does not improve head or voice tremors [28, 29]. According to the study, Patients using primidone had fewer voice tremors, but it is not always effective to head tremors [30]. Adverse effects of the use of Propranolol include bradycardia and bronchospasm [27]. Also on initiation of treatment with primidone, early adverse effects including dizziness, fatigue, and malaise occurred in 23 to 32% of patients [27]. Nonetheless, roughly half of the patients eventually discontinued the use of either medication. Where limited efficacy and intolerable side effects are the most likely causes of discontinuation [27]. Also recommend topiramate, alprazolam, atenolol, gabapentin, and sotalol as second-line therapy [31], which is clinically helpful at greater doses [27].

4. Surgical Procedure

Considered deep brain stimulation, Gamma knife, magnetic resonance-guided focused ultrasound (MRgFUS), stereotactic radiosurgery (SRS), and thalamotomy from surgical treatments for tremors and more efficacious than pharmacotherapy [25][32].

Deep brain stimulation (DBS) is a surgical treatment most popular to date for patients with advanced PD or medically refractory ET by providing permanent tremor control. DBS can be performed by drilling a hole in the front of the skull and then inserting the electrodes microelectrode and macro electrode recordings can help identify specific targets in the brain, intracranial electrodes are eventually coupled to a pulse generator that has been implanted [33]. DBS efficacy is believed to be caused by electric stimulation of the ventral intermediate nucleus (VIM), the subthalamic nucleus(STN), the globus pallidus internal (GPI), and the pedunculopontine nucleus, which disrupts thalamic neurons' synchronous firing [34][35][36], and efficacy has been proven using interleaving stimulation [37] and closed-loop techniques [38, 39].

When DBS targets the subthalamic nucleus (STN), so the strength of the electrical stimulation and the position of the stimulating electrode will define the effects of STN-DBS on motor and nonmotor signs [40]. Therefore it can impact autonomic symptoms in PD, cardiovascular, pulmonary, gastrointestinal, and thermoregulatory [41]. The studies demonstrate, that some patients report improvements in limb tremor severity and everyday activities [33]. Both unilateral and bilateral ventral intermediate nucleus (VIM) implantation can help with head tremors, While voice tremors have shown mixed improvement in studies [33]. Alternatives to "ventral intermediate nucleus (VIM) is implantation in the caudal zona incerta (CZI). In a study of 15 patients with essential tremors who had bilateral CZI DBS, action tremor, proximal tremor, and activities of daily life all improved significantly [42].

MRI-guided high-intensity focused ultrasound is a surgical procedure less invasive than DBS, which allows for skull penetration without heating the bone [33]. However, the utilization of surgical treatments for tremors remains low because of high surgical costs [43], patient preference, access to the care required [44], practitioner preference [45], and additional perceptions of surgical risk [45, 46].

5. Electrical Stimulation Technique

In this section, several techniques that depend on electrical stimulation to control tremors are presented. These systems have been classified based on the type of stimulation into:

5.1. Stimulate Sensory Nerves

In 1985, an investigation of the use of transcutaneous electrical nerve stimulation (TENS) in treating movement disorders [47]. TENS aims to stimulate large myelinated peripheral sensor fibers A-beta in a selective manner, such that thalamic circuits receives sensory data from A-beta fibers that are involved in tremor generation [48]. Cala ONE was the first wearable transcutaneous device that is a non-invasive electric nerve stimulator [49]. Cala-Trio is a newer version that has the potential to relieve symptoms of hand tremors in patients who are not candidates for surgery or who are not responding to medication [47], by placing two functional electrodes on the wrist anterior surface and a counter electrode on the rear surface to stimulate intermittently ventral intermediate nucleus (VIM) and the radial and median nerves which are involved in the essential tremor via the peripheral sensor nerves. Skin irritations (redness, itching, or swelling), pain, or burns were reported by 18% of patients [50], these side effects were alleviated by applying topical ointment, a reduction in stimulation level, and the discontinuation of therapy [50]. Contraindications have been identified to the use of Cala Trio, the most important of which is the presence of implanted electrical medical devices in the body [47].

5.2. Muscles Activation

The activation of motor neurons by functional electrical stimulation (FES) causes muscular contraction, it is a distinction from TENS. The approaches followed using FES to control tremor is the asynchronous and co-contraction way [51]. The MOTIMOVE system is asynchronously stimulating, it uses with patients having ET, PD, and hemiplegia [52]. Where comprises inertial sensors and a multichannel stimulator that enables selected activations of muscles via out-of-phase electric stimulation by electrodes mounted on the upper arm above the flexor and extensor muscle sites and forearm as shown in Fig. 1, causing motor neurons to depolarization, which reduces tremors [47]. According to a MOTIMOVE pilot research, asynchronous stimulation will not be effective with all tremor patients.

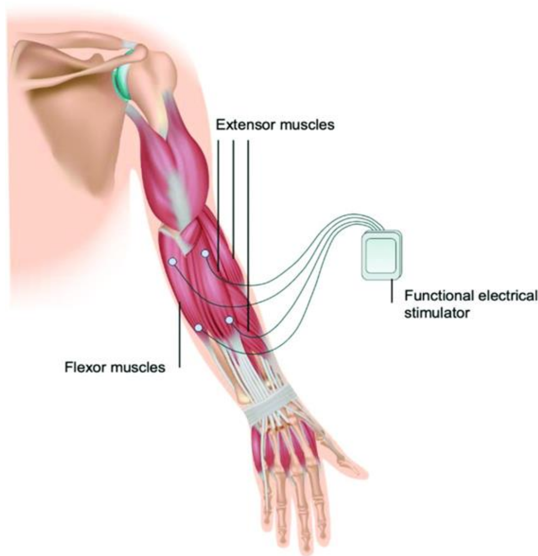

Fig. 1. MOTIMOVE functional electrical stimulation system [47]

Both neurorobotics and the tremor's glove prototypes have been tested on ET and PD patients and have a similar design to the MOTIMOVE. They have electrodes for muscle stimulation, inertial sensors, and a controller and use co-contraction stimulation that increases limb stiffness by applying mechanical loading to a couple of hostile muscles by continuous transcutaneous stimulation, subsequently filtering out the mechanical manifestations of tremorgenic activity [47]. The TREMOR neurorobotics activate the forearm muscles and decrease tremors by 52 % in 6 patients. On the other hand, the musculus abductor pollicis brevis and the first and second dorsal interossei muscles of the hand are stimulated by the Tremor's glove and can cause numbness and a burning feeling in the hand [53]. A reduction in tremor frequency and magnitude have been shown in a study of 14 patients with PD [54]. However, FES causes muscle fatigue in treated patients. It is forbidden to use FES in the case of the presence implanted electrical device, malignancy, osteomyelitis, thrombosis/ hemorrhage, or epilepsy.

6. Measurement of Hand Tremors

Different types of sensors and techniques have been used to identify the type, magnitude, and frequency of the tremor's occurrence such as laser displacement sensors [55]. An inertia measurement unit (IMU) is a movement sensor that has to be connected to the body of the patient to grasp the motion and assess the tremor. Therefore, it restricts the patient's motions and necessitates special approaches for precise limb alignment. Severity scales are commonly used in clinical settings to assess PD symptoms [56]. Accelerometers, gyroscopes, magnetometers, and electromyography have been employed in several investigations to understand motor signs and discriminate between healthy and PD groups by analyzing the frequency features [57][58]. Skin irritation is a side effect of these sensors and skin preparation is important to avoid this effect [59]. Therefore, non-contact capacitive (NCC) sensors [56] for evaluating biopotentials in an alternative way using dielectric properties are achieved by electrical potential sensors (EPS). Essential tremors can be detected and treated properly with frequent diagnostics [60]. AWEAR bracelet uses a 3D accelerometer and gyroscope to collect the information needed for diagnosing PD patients' that have a solid tremor or bradykinesia [61]. Detecting PD can automatically be achieved using an artificial neural network (ANN) utilizing electromyography (EMG) and recurrent ANN classifier [55]. TreCap is a custom-built wearable with innovative software that captures and evaluates real-time tremors symptoms [62]. In the lab and the field, wrist-worn accelerometers were used to identify PD tremors. Furthermore, several systems were tested to see if they could evaluate the ratio of tremors over a long duration of time [63].

7. Techniques of Medical Devices

The medical technics for tremor treatment above mentioned have varying degrees of effectiveness, several drawbacks, and often are associated with side effects. Therefore, many researchers are interested in less intrusive alternatives in the body human that do not have any negative effects. There are many devices for tremor suppression in the upper limbs classed according to the actuation method to active, passive, or semi-active.

7.1. Active Suppression

It is worked by creating an active force that counteracts involuntary motions while enabling voluntary motions.
To see if a voluntary speed-controlled tremor suppression strategy is feasible, a prototype was developed called the tremor suppression orthosis (TSO) for elbow tremors, where voluntary torque for users was employed to steer orthosis and activated with a DC motor. A force transducer records the forces between the mechanical suppressor and the patient then filtered to extract the voluntary motion and transformed into a velocity signal passed to the closed-loop controller with an internal velocity that ensured tracking the voluntary motion with little resistance while rejecting the tremor [64]. On the other hand, a tremor in the fingers has received less attention than wrist and elbow tremors. As a result, has created a wearable glove for tremor suppression in the wrist, index finger joint, and thumb without limiting voluntary movement. The glove has three DC motors and five IMUs to evaluate and manage the joints' motion at the same time yet independently and a cable-based transmission system to send forces from motors to the joints. It was tested on a patient with PD during three tasks and showed encouraging results [65]. A wearable tremor suppression glove (WTSG) prototype has been created to eliminate tremors mechanically without altering voluntary mobility in a flexion-extension way for the index finger metacarpophalangeal joint, wrist, and thumb joint [66]. It has an actuation, sensor glove, IMU as shown in Fig. 2, a cable-enabled power transfer system, and brushless DC motors positioned on the arm to control cables attached to anchor points for movement while involving enough force to suppress the tremor. Two validation experiments with positive results were conducted using recorded data from Parkinson's patients [66].

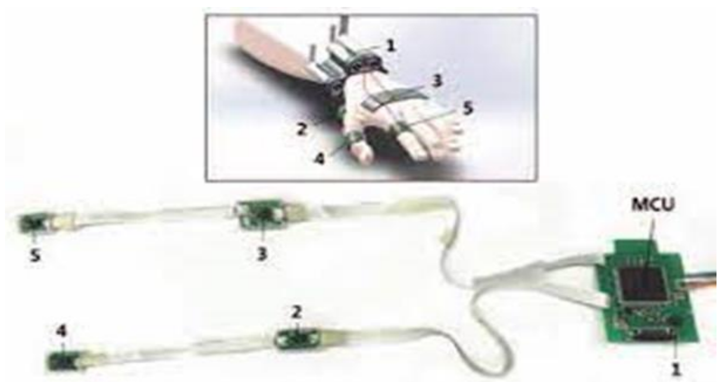

Fig. 2. Configuration and location of the IMUs and the microcontroller [66]

7.2. Semi-Active Suppression

It uses energy absorption or dissipation to prevent involuntary motions and can have its damping volume changed by an active controller.
Magnetorheological (MR) fluid is a material consisting of magnetized tiny particles scattered in oil or water in which, it experiences an attraction force when applying a magnetic field with an increase in the viscosity in opposition to the existing flow. This feature was used to tailor the resistance force for tremor elimination by changing the magnetic field intensity [67].
The wrist tremor suppression exoskeleton (WTSE) system has been designed utilizing the semi-active controller to exhibit the advantage of being lightweight, portable, good controllability, and uses extremely little energy as shown in Fig. 3. It is based on MR fluid damper that generates real-time variable damping force controllable damping force based on the collected tremors information from the IMU. Three experiments have been applied and the results have shown that the WTSE was able to suppress the wrist tremor significantly [68]. To optimize the dimensions of the mechanical components, design for flexion/extension a wearable elbow exoskeleton for tremor suppression (WEETS) with lightweight, comfortable wearability, and compact design. It uses a rotational semi-active actuator (RSAA) controllable and a magnetorheological fluid to control the system and IMU to measure tremor that is placed on the back of the forearm. Experiments have shown a reduction in elbow tremor from where angular velocity and acceleration by 61.55% and 61.68% respectively [69]. Also, designed a soft exoskeleton for tremor suppression (SETS) [70]. Incorporates a controlled flexible semi-active actuator that combines cylinder-piston and elastic fluidic dampers utilizing MR fluid that responds to the motions of the wrist joint dynamically. The test results showed that it could reduce 61.39% and 56.22% in terms of speed and degree of acceleration, respectively, Demonstrating the functional system's apparent mechanical efficiency [70].

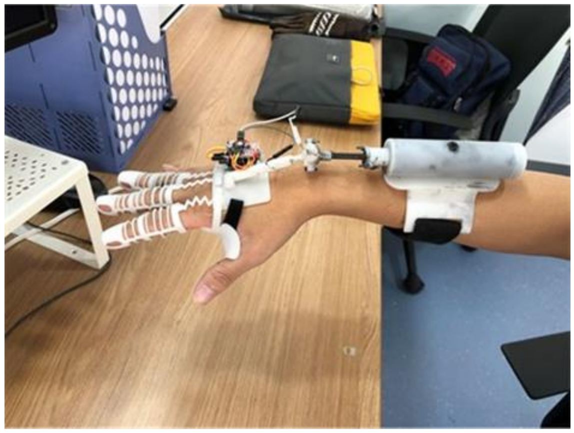

Fig. 3. The prototype of the WTSE [68]

7.3. Passive Suppression

It is based on the use of energy-passive absorption or dissipation without compromising normal manual reflexes.

Vib-bracelet has been designed according to dynamic vibration absorption tenets to absorb and attenuate the tremor passively considering its frequency. The prototype has been tested on the forearm and the results have shown efficient attenuation of tremors at 85% in the extent of 4-6 Hz [71]. Another approach, the concept has been devised for the task of adjustable passive orthosis (TAPO). The textile glove has a soft, lightweight, and air-filled texture that inflates or deflates easily for a specific task by an electrical pump or hand and is placed on the back of the wrist, while inflating, air pressure rises and generates an opposite force to the compression created by bending, therefore suppressing the involuntary motions. The efficacy was determined by analyzing suppression in patients with PD, shown to reduce tremor power in three of six tasks including pouring, drinking, and drawing a spiral by (74-82)% [72]. As a technique for minimizing tremor which emerges in the initial stages of the illness. a wearable passive device that uses magnetic actuators to lessen hand and arm vibrations developed. It is inexpensive, lightweight, and has no restrictions on hand movement [73]. The developed wearable forearm bracelet that is used by patients with Parkinson's disease (PwPD), considers a hand as the primary mass-spring-damper system when designing biodynamics and uses dual passive vibration absorbers in a parallel configuration due to having an efficiency that is higher than the series. When a tremor hand, the device starts to feel an inertia force causing the absorber mass to oscillate. Simultaneously, connected to the absorber mass are springs that compress and extend, absorbing the tremor energy and friction damping dissipating the energy absorbed as shown in Fig. 4. The device performance was assessed by contrasting the typical pattern drawn while wearing a device and without it, where the temporal response has been sinusoidal and rhythmic at various frequencies [74].

A particle damper is a sort of passive vibration control device that controls vibrations by dissipating energy and exchanging momentum generated by particle collisions [75]. To apply this technique, a particle-damping mechanical paradigm has been designed with low cost, resilience, and reliability to suppress tremors and has a large damping frequency band, and is insensitive to severe temperatures. Numerical simulations and experimental research demonstrated that increasing particle mass improves damper [75]. More recently, Propose a passive vibration control model for an essential tremor-affected human arm. The coupled system, which is a model of the arm connected to a non-linear absorber, is addressed using time-multiple scale techniques, which enable the identification of both quick and slow system dynamics. The nonlinear absorber's properties can be tuned using these dynamics as design tools. The proposed absorber may be seen to be capable of controlling (mathematically) diverging arm responses [76].

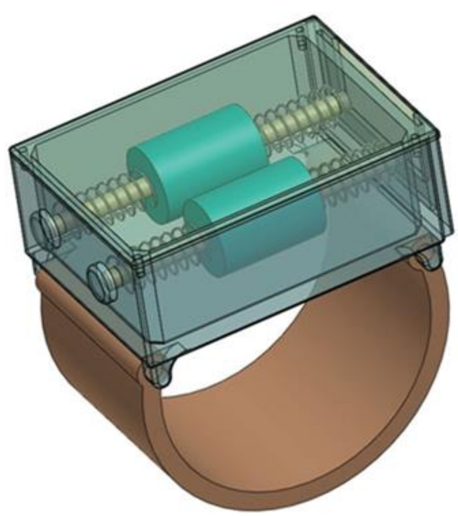

Fig. 4**.** Proposed design of vibration absorber[74]

8. Other Devices

Using a pneumatic mechanism for designing a wearable handcuff. The accelerometer sensor provides a signal that activates the pneumatic circuit by two separate valves that enable inflation and deflation of the handcuff and supply the required air to present a resisting power in a revolving, linear movement to suppress tremors in the upper arm. The performance was assessed, and one patient with ET had a 30 % reduction in tremors, therefore showing that this approach had limited efficacy [77].

The computer-aided design (CAD) and simulation with MATLAB of a device such as a spoon and a smartphone pen that helps patients with tremors in their daily life have been performed [78]. Assuming vertical and horizontal shaking, used two motors with the two orthogonal axes and PID controller to adverse the tremor action. A wearable vibrometer was used to measure the tremor data and then it was filtered with Butterworth high-pass filter [78]. A new technique includes the design and implementation of a soft glove using a jamming layer for tremor suppression of the proximal interphalangeal (PIP) of the finger (front and rear) and metacarpophalangeal (MCP) joints that the jamming material is positioned to cover them. The glove creates resistance to the tremor and hides it in the vertical plane. Arduino Mega 2560 microcontroller for movement of the artificial hand and data from 15 patients were used to perform a preliminary evaluation of the glove, results reveal that the palmar side component can reduce tremor amplitude [79]. Another study proposed a wearable system that used the feedback linearization technique to quantify the control input for kinetic energy used to balance the condition of the system. When wearing the design, a human hand with one degree of freedom at the wrist and a gyroscope-based anti-tremor device attached to the back of the hand become. The system's mathematical dynamics were simulated to verify the efficiency of the technique. It has been shown to have an impact on tremor suppression by looking at the gyroscope's settings and orientation [80]. Clarification of all previous technical in terms of the system used and accuracy of tremor suppression in (Table 3).

Table 3. Shows the systems used and the percentage of tremor reduction for each device

Research name	Actuation method	Model type	System used	Evaluation Method	Tremor reduction rate
" Controlling a motorized orthosis to follow elbow volitional movement: tests with individuals with pathological tremor " [64]	Active	Elbow	DC motor & LabVIEW	Tremor Patient (Simulation)	94.4%
" Design and Preliminary Performance Assessment of a Wearable Tremor Suppression Glove" [65]	Active	Index, thumb finger, and wrist	DC motors & MATLAB	Tremor Patient	73.1%, 80.7%, and 85.5% in resting, 70.2%, 79.5%, and 81% in postural, and 60.0%, 58.7%, and 65.0% in kinetic tremor
" Development of a Wearable Tremor Suppression Glove " [66]	Active	Wrist and hand	DC motors & IMU & LabVIEW	Tremor Dataset	85.0% ± 8.1%
"A Novel Exoskeleton System Based on Magnetorheological Fluid for Tremor Suppression of Wrist Joints " [68]	Semi-Active	Wrist	Magnetorheological fluid damper & IMU & Stereo lithography appearance	Healthy Subject	Acceleration 60.39% and angular velocity 55.07%
"A wearable elbow exoskeleton for tremor suppression equipped with rotational semi-active actuator " [69]	Semi-Active	Elbow	Rotational semi-active actuator & magnetorheological fluid	Healthy Subject	angular velocity 61.55% and acceleration 61.68%
" A Soft Exoskeleton for Tremor Suppression Equipped with Flexible Semiactive Actuator " [70]	Semi-Active	Wrist	Semi-active actuator & magnetorheological fluid	Healthy Subject	Acceleration 61.39% and angular velocity 56.22%
" Vib-bracelet: a passive absorber for attenuating forearm tremor " [71]	Passive	Forearm	A dynamic vibration absorber & IMU	Tremor Patient (Simulation)	85%
" Design of a lightweight passive orthosis for tremor suppression " [72]	Passive	Wrist	Air-filled structure	Tremor Patient	74 to 82%
" Design and fabrication of a novel passive hand tremor attenuator " [73]	Passive	Hand and arm	Magnetic actuators	Healthy Subject	Not available
" Hand tremor suppression device for patients suffering from Parkinson's disease " [74]	Passive	Wrist	Passive vibration absorbers & MATLAB	Healthy Subject	57.25%
" Analytical and experimental studies on particle damper used for tremor suppression " [75].	Passive	Hand	Particle damper	Tremor Dataset	Not available

" Nonlinear passive tremor control of the human arm, " [76].	Passive	Upper limb	Non-linear absorber & time-multiple scale	Not available	Not available
"Sensor-based portable tremor suppression device for stroke patients " [77].	Other technology	Upper arm	Pneumatic mechanism & accelerometer sensor	Tremor Patient	30 %
" Design of a noninvasive and smart hand tremor attenuation system with active control: a simulation study " [78]	Other technology	Hand	CAD software (SolidWorks) & MATLAB	Tremor Dataset	During eating 75% and following a spiral pattern 65%
" A Novel Soft Glove for Hand Tremor Suppression: Evaluation of Layer Jamming Actuator Placement " [79]	Other technology	Hand	Jamming layer &. Arduino Mega 2560	Tremor Dataset	78.32% and 38.23%
" Developing an Assisting Device to Reduce the Vibration on the Hands of Elders " [80]	Other technology	hand	Feedback linearization technique & gyroscopic system & MATLAB	Tremor Dataset	92.6%

9. Conclusions

Although not life-threatening, tremor produced by a neuromuscular problem in the elderly around the world has a significant impact on everyday activities. Tremors are treated with either pharmacotherapies, surgery, or electrical Stimulation which has shown limited effectiveness Due to the pathophysiology of tremors and the risks and side effects of using them. In this paper, we look at numerous wearable technologies that have been offered as potential solutions for attenuating and providing safe and effective tremor suppression, as well as assisting patients doing everyday tasks who do not respond well to drugs or surgery. Tremor suppression devices have been demonstrated to be effective in suppressing tremors in the upper limbs in studies. Nonetheless, many devices are heavy and based on preliminary data, therefore, future research and developments are needed to adding of suppressing tremor devices to the patient's present treatments and comprehend the efficacy, safety, and acceptability of these devices among patients, before their clinical practice.

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Reference

[1] K. P. Bhatia et al., "Consensus Statement on the classification of tremors. from the task force on tremor of the International Parkinson and Movement Disorder Society," Mov. Disord., vol. 33, no. 1, pp. 75–87, 2018.
[2] G. Herrnstadt, M. J. McKeown, and C. Menon, "Controlling a motorized orthosis to follow elbow volitional movement: Tests with individuals with pathological tremor," J. Neuroeng. Rehabil., vol. 16, no. 1, pp. 1–14, 2019, doi: 10.1186/s12984-019-0484-1.
[3] H. Chen et al., "Genetic analysis of LRRK1 and LRRK2 variants in essential tremor patients," Genet. Test. Mol. Biomarkers, vol. 22, no. 6, pp. 398–402, 2018.
[4] S. Abramavičius, M. Venslauskas, A. Vaitkus, V. Gudžiūnas, O. Laucius, and E. Stankevičius, "Local vibrational therapy for essential tremor reduction: a clinical study," Medicina (B. Aires)., vol. 56, no. 10, p. 552, 2020.
[5] A. M. Bougea, P. Zikos, I. Spanou, and E. Efthymiopoulou, "Clock-Drawing Tasks as Predictive Measurements for Disease Classification Among Patients With Parkinson's Disease and Essential Tremor," Cureus, vol. 13, no. 2, 2021.
[6] S. Kakei, M. Manto, H. Tanaka, and H. Mitoma, "Pathophysiology of cerebellar tremor: The forward model-related tremor and the inferior olive oscillation-related tremor," Front. Neurol., vol. 12, p. 694653, 2021.
[7] J. K. Wong et al., "STN versus GPi deep brain stimulation for action and rest tremor in Parkinson's disease," Front. Hum. Neurosci., vol. 14, p. 578615, 2020.
[8] J. Cook, M. Umar, F. Khalili, and A. Taebi, "Body Acoustics for the Non-Invasive Diagnosis of Medical Conditions," Bioengineering, vol. 9, no. 4, p. 149, 2022.
[9] M. Muthuraman et al., "Deep brain stimulation and L-DOPA therapy: concepts of action and clinical applications in Parkinson's disease," Front. Neurol., vol. 9, p. 711, 2018.
[10] Y. Lin, B. W.-K. Ling, N. Xu, R. W.-K. Lam, and C. Y.-F. Ho, "Effectiveness analysis of bio-electronic stimulation therapy to Parkinson's diseases via joint singular spectrum analysis and discrete fourier transform approach," Biomed. Signal Process. Control, vol. 62, p. 102131, 2020.
[11] P. F. Crawford III and E. E. Zimmerman, "Tremor: sorting through the differential diagnosis," Am. Fam. Physician, vol. 97, no. 3, pp. 180–186, 2018.
[12] S. J. Chia, E.-K. Tan, and Y.-X. Chao, "Historical perspective: Models of Parkinson's disease," Int. J. Mol. Sci., vol. 21, no. 7, p. 2464, 2020.
[13] A. Rossi, K. Berger, H. Chen, D. Leslie, R. B. Mailman, and X. Huang, "Projection of the prevalence of Parkinson's disease in the coming decades: Revisited," Mov. Disord., vol. 33, no. 1, pp. 156–159, 2018.
[14] V. Skaramagkas, G. Andrikopoulos, Z. Kefalopoulou, and P. Polychronopoulos, "A Study on the Essential and Parkinson's Arm Tremor Classification," Signals, vol. 2, no. 2, pp. 201–224, 2021.

[15] E. R. Dorsey et al., “Global, regional, and national burden of Parkinson’s disease, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016,” Lancet Neurol., vol. 17, no. 11, pp. 939–953, 2018.
[16] S. H. Fox et al., “International Parkinson and movement disorder society evidence-based medicine review: update on treatments for the motor symptoms of Parkinson’s disease,” Mov. Disord., vol. 33, no. 8, pp. 1248–1266, 2018.
[17] G. Paparella et al., “Clinical and kinematic features of valproate-induced tremor and differences with essential tremor,” The Cerebellum, vol. 20, no. 3, pp. 374–383, 2021.
[18] Y. Zhou, M. E. Jenkins, M. D. Naish, and A. L. Trejos, “Characterization of parkinsonian hand tremor and validation of a high-order tremor estimator,” IEEE Trans. Neural Syst. Rehabil. Eng., vol. 26, no. 9, pp. 1823–1834, 2018.
[19] B. Bluett et al., “Effect of urate-elevating inosine on early Parkinson disease progression: the SURE-PD3 randomized clinical trial,” JAMA, vol. 326, no. 10, pp. 926–939, 2021.
[20] G. Puttaraksa et al., “Voluntary and tremorogenic inputs to motor neuron pools of agonist/antagonist muscles in essential tremor patients,” J. Neurophysiol., vol. 122, no. 5, pp. 2043–2053, 2019.
[21] A. Yi, A. Zahedi, and D. Zhang, “Design and validation of a novel wrist tremor suppression exoskeleton system based on magnetorheological fluid,” in IEEE International Conference on Rehabilitation Robotics (ICORR), 2019, pp. 24–28.
[22] H. Dowd et al., “Prospective longitudinal study of gait and balance in a cohort of elderly essential tremor patients,” Front. Neurol., vol. 11, p. 581703, 2020.
[23] M. Seier, A. Hiller, J. Quinn, C. Murchison, M. Brodsky, and S. Anderson, “Alternating thalamic deep brain stimulation for essential tremor: a trial to reduce habituation,” Mov. Disord. Clin. Pract., vol. 5, no. 6, pp. 620–626, 2018.
[24] O. Brotons Rufes, “Technical characterization of a handwriting analysis pressure sensor for biometrics application,” 2020.
[25] J. J. Ferreira et al., “MDS evidence-based review of treatments for essential tremor,” Mov. Disord., vol. 34, no. 7, pp. 950–958, 2019.
[26] N. Sarkar and Z. K. Zheng, “Design and validation of a tremor stabilizing handle for patients with parkinson disease and essential tremor,” in International Conference on Human-Computer Interaction, 2019, pp. 274–283.
[27] D. Haubenberger and M. Hallett, “Essential tremor,” N. Engl. J. Med., vol. 378, no. 19, pp. 1802–1810, 2018.
[28] W. G. Ondo, “Current and emerging treatments of essential tremor,” Neurol. Clin., vol. 38, no. 2, pp. 309–323, 2020.
[29] G. Paparella et al., “Differential effects of propranolol on head and upper limb tremor in patients with essential tremor and dystonia,” J. Neurol., vol. 265, no. 11, pp. 2695–2703, 2018.
[30] F. Hopfner and G. Deuschl, “Managing essential tremor,” Neurotherapeutics, vol. 17, no. 4, pp. 1603–1621, 2020.
[31] T. A. Zesiewicz et al., “Practice Parameter: Therapies for essential tremor [RETIRED]: Report of the Quality Standards Subcommittee of the American Academy of Neurology,” Neurology, vol. 64, no. 12, pp. 2008–2020, 2005.
[32] R. J. Elble, L. Shih, and J. W. Cozzens, “Surgical treatments for essential tremor,” Expert Rev. Neurother., vol. 18, no. 4, pp. 303–321, 2018.
[33] V. Shanker, “Essential tremor: diagnosis and management,” bmj, vol. 366, 2019.
[34] K. S. Chen and R. Chen, “Invasive and noninvasive brain stimulation in Parkinson’s disease: clinical effects and future perspectives,” Clin. Pharmacol. Ther., vol. 106, no. 4, pp. 763–775, 2019.
[35] A. Farokhniaee and C. C. McIntyre, “Theoretical principles of deep brain stimulation induced synaptic suppression,” Brain Stimul., vol. 12, no. 6, pp. 1402–1409, 2019.
[36] Z. Mao et al., “Comparison of efficacy of deep brain stimulation of different targets in Parkinson’s disease: a network meta-analysis,” Front. Aging Neurosci., vol. 11, p. 23, 2019.
[37] D. S. Kern et al., “Interleaving stimulation in Parkinson’s disease, tremor, and dystonia,” Stereotact. Funct. Neurosurg., vol. 96, no. 6, pp. 379–391, 2018.
[38] A. Velisar et al., “Dual threshold neural closed loop deep brain stimulation in Parkinson disease patients,” Brain Stimul., vol. 12, no. 4, pp. 868–876, 2019.
[39] G. Weerasinghe, B. Duchet, H. Cagnan, P. Brown, C. Bick, and R. Bogacz, “Predicting the effects of deep brain stimulation using a reduced coupled oscillator model,” PLoS Comput. Biol., vol. 15, no. 8, p. e1006575, 2019.
[40] G. Bellini, L. A. Best, U. Brechany, R. Mills, and N. Pavese, “Clinical impact of deep brain stimulation on the autonomic system in patients with Parkinson’s disease,” Mov. Disord. Clin. Pract., vol. 7, no. 4, pp. 373–382, 2020.
[41] S. Kurcova et al., “Bilateral subthalamic deep brain stimulation initial impact on nonmotor and motor symptoms in Parkinson’s disease: an open prospective single institution study,” Medicine (Baltimore)., vol. 97, no. 5, 2018.
[42] B. Al-Fatly, S. Ewert, D. Kübler, D. Kroneberg, A. Horn, and A. A. Kühn, “Connectivity profile of thalamic deep brain stimulation to effectively treat essential tremor,” Brain, vol. 142, no. 10, pp. 3086–3098, 2019.
[43] C. Li et al., “Cost-Effectiveness of Magnetic Resonance-Guided Focused Ultrasound for Essential Tremor,” Mov. Disord., vol. 34, no. 5, pp. 735–743, 2019.
[44] H. Walters and B. B. Shah, “Focused ultrasound and other lesioning therapies in movement disorders,” Curr. Neurol. Neurosci. Rep., vol. 19, no. 9, pp. 1–7, 2019.
[45] A. M. Lozano et al., “Deep brain stimulation: current challenges and future directions,” Nat. Rev. Neurol., vol. 15, no. 3, pp. 148–160, 2019.
[46] A. W. Shukla, W. Deeb, B. Patel, and A. Ramirez-Zamora, “Is deep brain stimulation therapy underutilized for movement disorders?,” Expert Rev. Neurother., vol. 18, no. 12, pp. 899–901, 2018.
[47] J. Mo and R. Priefer, “Medical devices for tremor suppression: current status and future directions,” Biosensors, vol. 11, no. 4, p. 99, 2021.
[48] K. Garcia, J. K. Wray, and S. Kumar, “Spinal Cord Stimulation, StatPearls.” StatPearls Publishing: Treasure Island, FL, USA, 2020.
[49] H. H. S. Food and Drug Administration, “Medical Devices; Neurological Devices; Classification of the External Upper Limb Tremor Stimulator. Final order,” Fed. Regist., vol. 83, no. 201, pp. 52315–52316, 2018.
[50] S. H. Isaacson et al., “Prospective home-use study on non-invasive neuromodulation therapy for essential tremor,” Tremor and Other Hyperkinetic Movements, vol. 10, 2020.
[51] J. Kim, T. Wichmann, O. T. Inan, and S. P. DeWeerth, “Analyzing the Effects of Parameters for Tremor Modulation via Phase-Locked Electrical Stimulation on a Peripheral Nerve,” J. Pers. Med., vol. 12, no. 1, p. 76, 2022.
[52] D. B. Popović and L. Popović Maneski, “The instrumented shoe insole for rule-based control of gait in persons with hemiplegia,”

EasyChair Prepr., p. 1345, 2019.
[53] A. Pascual-Valdunciel et al., "Peripheral electrical stimulation to reduce pathological tremor: a review," J. Neuroeng. Rehabil., vol. 18, no. 1, pp. 1–19, 2021.
[54] J.-H. Heo, H.-M. Jeon, E.-B. Choi, D.-Y. Kwon, and G.-M. Eom, "Effect of sensory electrical stimulation on resting tremors in patients with Parkinson's disease and SWEDDs," J. Mech. Med. Biol., vol. 19, no. 07, p. 1940033, 2019.
[55] D. Lukšys, G. Jonaitis, and J. Griškevičius, "Quantitative analysis of parkinsonian tremor in a clinical setting using inertial measurement units," Park. Dis., vol. 2018, 2018.
[56] F. H. M. Oliveira, A. G. Rabelo, L. M. D. Luiz, A. A. Pereira, M. F. Vieira, and A. O. Andrade, "On the Use of Non-Contact Capacitive Sensors for the Assessment of Postural Hand Tremor of Individuals with Parkinson's Disease," in 2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), 2019, pp. 6591–6594.
[57] D. Phan, M. Horne, P. N. Pathirana, and P. Farzanehfar, "Measurement of axial rigidity and postural instability using wearable sensors," Sensors, vol. 18, no. 2, p. 495, 2018.
[58] M. Delrobaei, S. Memar, M. Pieterman, T. W. Stratton, K. McIsaac, and M. Jog, "Towards remote monitoring of Parkinson's disease tremor using wearable motion capture systems," J. Neurol. Sci., vol. 384, pp. 38–45, 2018.
[59] A. Angelucci et al., "Smart textiles and sensorized garments for physiological monitoring: A review of available solutions and techniques," Sensors, vol. 21, no. 3, p. 814, 2021.
[60] N. Ferenčík, M. Jaščur, M. Bundzel, and I. Zolotová, "Measurement of hand tremors," in 2018 IEEE 16th World Symposium on Applied Machine Intelligence and Informatics (SAMI), 2018, pp. 109–112.
[61] A. Channa, R.-C. Ifrim, D. Popescu, and N. Popescu, "A-WEAR Bracelet for detection of hand tremor and bradykinesia in parkinson's patients," Sensors, vol. 21, no. 3, p. 981, 2021.
[62] R. P. Bremm, A. Werle, C. Auer, F. Hertel, J. Gonçalves, and K. P. Koch, "TreCap: A wearable device to measure and assess tremor data of visually guided hand movements in real time," arXiv Prepr. arXiv2108.01736, 2021.
[63] R. San-Segundo et al., "Parkinson's disease tremor detection in the wild using wearable accelerometers," Sensors, vol. 20, no. 20, p. 5817, 2020.
[64] G. Herrnstadt, M. J. McKeown, and C. Menon, "Controlling a motorized orthosis to follow elbow volitional movement: tests with individuals with pathological tremor," J. Neuroeng. Rehabil., vol. 16, no. 1, pp. 1–14, 2019.
[65] Y. Zhou, A. Ibrahim, K. G. Hardy, M. E. Jenkins, M. D. Naish, and A. L. Trejos, "Design and Preliminary Performance Assessment of a Wearable Tremor Suppression Glove," IEEE Trans. Biomed. Eng., vol. 68, no. 9, pp. 2846–2857, 2021.
[66] Y. Zhou, M. E. Jenkins, M. D. Naish, and A. L. Trejos, "Development of a wearable tremor suppression glove," in 2018 7th IEEE International Conference on Biomedical Robotics and Biomechatronics (Biorob), 2018, pp. 640–645.
[67] N. P. Fromme, M. Camenzind, R. Riener, and R. M. Rossi, "Need for mechanically and ergonomically enhanced tremor-suppression orthoses for the upper limb: A systematic review," J. Neuroeng. Rehabil., vol. 16, no. 1, pp. 1–15, 2019, doi: 10.1186/s12984-019-0543-7.
[68] A. Yi, A. Zahedi, Y. Wang, U.-X. Tan, and D. Zhang, "A novel exoskeleton system based on magnetorheological fluid for tremor suppression of wrist joints," in 2019 IEEE 16th International Conference on Rehabilitation Robotics (ICORR), 2019, pp. 1115–1120.
[69] A. Zahedi, Y. Wang, U. Martinez-Hernandez, and D. Zhang, "A wearable elbow exoskeleton for tremor suppression equipped with rotational semi-active actuator," Mech. Syst. Signal Process., vol. 157, p. 107674, 2021.
[70] A. Zahedi, B. Zhang, A. Yi, and D. Zhang, "A soft exoskeleton for tremor suppression equipped with flexible semiactive actuator," Soft Robot., vol. 8, no. 4, pp. 432–447, 2021.
[71] E. Buki, R. Katz, M. Zacksenhouse, and I. Schlesinger, "Vib-bracelet: a passive absorber for attenuating forearm tremor," Med. Biol. Eng. Comput., vol. 56, no. 5, pp. 923–930, 2018.
[72] N. P. Fromme, M. Camenzind, R. Riener, and R. M. Rossi, "Design of a lightweight passive orthosis for tremor suppression," J. Neuroeng. Rehabil., vol. 17, no. 1, pp. 1–15, 2020.
[73] M. Masoumi, S. Kmanzi, H. Wang, and H. Mohammadi, "Design and fabrication of a novel passive hand tremor attenuator," J. Med. Eng. Technol., vol. 45, no. 8, pp. 597–605, 2021.
[74] M. S. Faizan and M. Muzammil, "Hand tremor suppression device for patients suffering from Parkinson's disease," J. Med. Eng. Technol., vol. 44, no. 4, pp. 190–197, 2020.
[75] Z. Lu and Z. Huang, "Analytical and experimental studies on particle damper used for tremor suppression," J. Vib. Control, vol. 27, no. 23–24, pp. 2887–2897, 2021.
[76] A. T. Savadkoohi, C.-H. Lamarque, and C. Goossaert, "Nonlinear passive tremor control of human arm," Mech. Syst. Signal Process., vol. 146, p. 107041, 2021.
[77] A. Kalaiarasi and L. A. Kumar, "Sensor based portable tremor suppression device for stroke patients," Acupunct. Electrother. Res., vol. 43, no. 1, pp. 29–37, 2018.
[78] M. Abbasi, A. Afsharfard, R. Arasteh, and J. Safaie, "Design of a noninvasive and smart hand tremor attenuation system with active control: a simulation study," Med. Biol. Eng. Comput., vol. 56, no. 7, pp. 1315–1324, 2018.
[79] W. V. I. Awantha, A. T. Wanasinghe, A. G. P. Kavindya, A. L. Kulasekera, and D. S. Chathuranga, "A novel soft glove for hand tremor suppression: Evaluation of layer jamming actuator placement," in 2020 3rd IEEE International Conference on Soft Robotics (RoboSoft), 2020, pp. 440–445.
[80] H. Phan Van and H. Q. T. Ngo, "Developing an Assisting Device to Reduce the Vibration on the Hands of Elders," Appl. Sci., vol. 11, no. 11, p. 5026, 2021.