Theoretical research and simulation on active control of assistive devices in Parkinson's disease

Cristina-Florentina Zamfirescu, Cristina Mohora, Adrian Olaru, Dana Tilina

Abstract— Due to the increase in the number of people affected by Parkinson's disease worldwide, the continuous development of new assistive devices must be accessible, ergonomic and easy to use as possible to facilitate daily activities, leading to the improvement the quality of patient's life. This work will be presented the methods of reducing Parkinson's disease as well as some of the assistive devices currently available on the market. Following the research of the current state, possible future improvements of these types of equipment will be proposed.

***Index Terms*—Active control, assistive equipment, Parkinson's disease, tremor, tremor treatments.**

INTRODUCTION

Recent studies have shown a significant increase in market requirements for the use of rehabilitation equipment and devices in recent years. This significant increase is due to several factors such as: the increase in the frequency of degenerative diseases, such as Parkinson's, Alzheimer's, circulatory diseases (arthritis), accidents, an increasing number of patients requiring rehabilitation therapy as well as the increase in life expectancy. An important factor that determines the development of the production of assistive equipment is the increase in life expectancy and the requirements of the elderly population and beyond [1].

The need for daily assistive devices for the disabled population around the globe is growing rapidly. The first classification of assistive equipment (Fig.1), includes equipment for ensuring mobility, devices for ensuring daily activities, equipment for supporting the body, and equipment for rehabilitation through exercises [1].

The estimates up to the year 2025 presented in figure 1, highlight the increase in the need for assistive equipment during the forecast period, due to the increase in the number of people with disabilities and the elderly. Neurological disorders are now the leading cause of disability globally, and the fastest-growing neurological disorder in the world is Parkinson's disease (PD), a slowly progressive disorder that affects movement, muscle control, and balance [1].

Parkinson's disease (PD) is characterized by several symptoms (bradykinesia, resting tremor, postural instability, and stiffness during walking) that occur due to the degeneration of dopamine-producing neurons.

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The neurotransmitter dopamine is responsible for body movement.

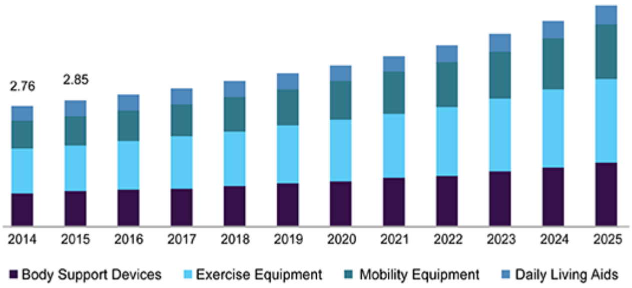


Fig. 1. Statistics on market demand

METHODS OF REDUCING THE EVOLUTION OF PARKINSON'S DISEASE

Understanding the mechanism and the operating principle underlying the process of decreasing the tremor in the hand or in the upper limb, its biomechanics as well as understanding the manifestation and evolution of Parkinson's disease in the body are extremely important, representing the key factors in developing more and more complex assistive devices. At the moment there are three possibilities for attenuating tremors in people with Parkinson's, namely alleviating tremors through medication and therapy, surgery, and orthoses [2].

A. Attenuation of tremor by medication

Although Parkinson's disease cannot be completely cured, taking the specific medication recommended by the neurologist helps control the symptoms of the disease and prevents its rapid evolution, especially for people in the early stages of the disease [2].

B. Attenuation of tremor by surgery

B.1. Focused ultrasound thalamotomy

This noninvasive surgery involves the use of focused sound waves that pass through the skin and skull. Heat is generated to destroy brain tissue in a specific area of the thalamus to stop the tremors.

The surgeon uses magnetic resonance imaging to target the correct area of the brain and make sure the sound waves are generating the exact amount of heat needed for the procedure.

This method creates a lesion that can lead to certain changes in brain function. However, most complications go away on their own or are mild enough that they do not interfere with the quality of life [4].

B.2. Deep brain stimulation

It is the most common type of surgery for essential tremor. Doctors insert a long, thin electrical probe into the part of the brain that causes tremor, in the thalamus.

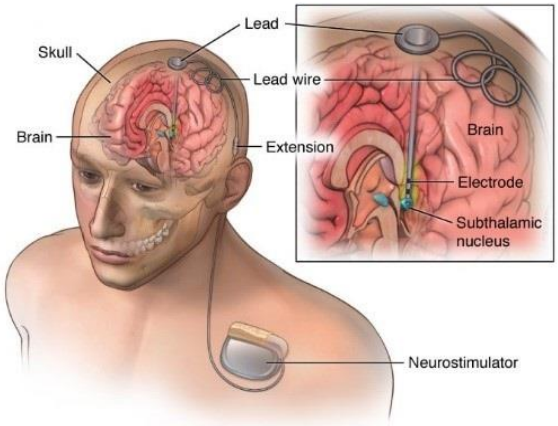


Fig. 2. Deep brain stimulation

A wire from the probe connects to a pacemaker-like device (neurostimulator) implanted in the chest of the person with Parkinson's. This device delivers painless electrical impulses to interrupt signals from the thalamus which causes the tremor [3].

C. Attenuation of tremor by wearing orthoses

This method represents an alternative noninvasive treatment of symptoms by mechanically suppressing the oscillating movement. It is necessary to identify the biomechanical processes of tremor in the upper limb and the forces generated, frequency, and intensity of tremor, especially during activities of daily living. These forces are important parameters for designing a suppression system. Such an orthosis must be ergonomic and generate an adequate counterforce to suppress involuntary movement.

Orthoses are classified according to the type of vibration suppression as follows: passive, semi-active, and active. Semi-active and passive technologies suppress involuntary movements, while active technologies continuously generate a force different from that generated by the human body or by gravity and which acts by dampening the tremor of the wearer's limb in real-time.

Passive suppression is achieved with assistive devices that are associated with elastic coefficients and damping constants. A passive system made of a spring damper has a low drag force at low values and a high drag at high speeds. Slow and deliberate movements can be made, while fast movements create a greater reaction force.

Semi-active orthoses work like passive orthoses, having adjustable characteristics, regulated by a controller. An active orthosis reacts to sensory information due to the actuator in its component. Therefore, after determining the amplitude of the tremor, an equal force is generated, directed in the opposite direction, thus dampening the involuntary movement. Ergonomic design is influenced by weight, thermal and sensory skin comfort, degree-of-freedom restrictions, and resisting forces for voluntary movements.

Currently, the results of studies in the literature show that most of the orthoses used for tremor suppression are active with a prevalence of 47%, followed by semi-active ones with a prevalence of 31%, and passive ones with a prevalence of 21% [4], [5], [6].

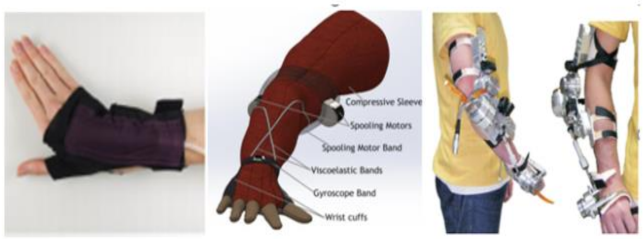


Fig. 3. Classification of orthoses according to the type of suppression: a) passive, b) semi-active, c) active

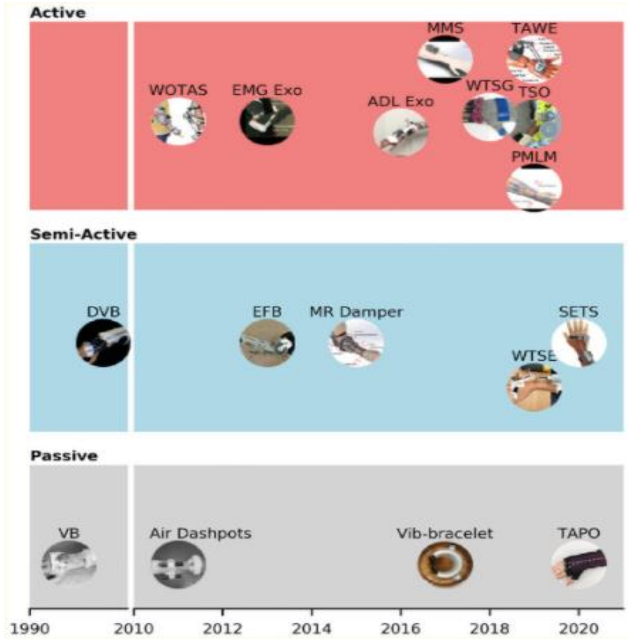


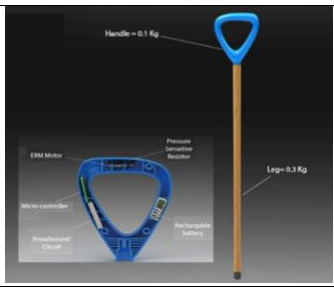
Fig. 4. The evolution over time of active, semi-active, and passive orthoses

Active orthoses are also the heaviest, with an average weight of 571 ± 477 g, followed by semi-active orthoses with 486 ± 395 g and passive orthoses with 191 ± 137 g. Most orthoses support only one degree of freedom (DOF) 54.5 %. Two-degree-of-freedom and three-DOF orthoses account for 33% and 18%, respectively. The mean tremor suppression efficiency using wearable orthoses is 83±13% [7].

Active orthoses are the most effective, with an average effectiveness of 83 ± 8%, followed by semi-active ones of 77 ± 19%, and later by passive orthoses with an effectiveness of 75 ± 12%. When tested in the laboratory, the effectiveness is 95 ± 5%, this value falling to 86 ± 8 when evaluating subjects affected by tremors.

Among the active devices, the orthoses with three degrees of freedom present in Fig. 4. include the WOTAS orthosis (Wearable Orthosis for Tremor Assessment and Suppression) and the Wearable Tremor Suppression Glove (WTSG). Whereas the WOTAS provides suppression of tremor at the elbow, forearm, and wrist, the WTSG orthosis was developed to attenuate the tremor at the wrist, fingers, and joints. Semi-active mechanisms mainly rely on Magneto Rheological (MR) fluid to generate the damping force. When exposed to a magnetic field, the viscosity of the MR fluid can be modulated by the magnetic force field. MR fluid has recently received an increased level of interest in the field of wearable exoskeletons due to its high power-to-weight ratio [7].

TABLE I: DAILY LIVING AIDS

Name	Device	Description
Eating device		- self-stabilizing spoon that compensates for hand tremors, - contains a controller and two motors built into the handle that acts as a detection mechanism for the direction of the tremor moving the utensil accessory in the opposite direction, - it weighs about 100g and has a rechargeable battery - it is only useful for people with mild to moderate tremors, not intended for people with severe tremors [8], [9]
Adapted mug		- is intended for people with difficulties caused by tremors, pain, muscle weakness, and limited dexterity, - the rotating handle allows the cup to remain in a vertical, constant position and tilt slightly without the patient having to bend their wrist or raise their elbow, - the rotating handle rotates easily 360° thanks to the two ball bearings present inside a low-friction mechanism in the handle - the cups are designed to be more stable if there is a tremor or poor coordination [10]
Adapted plates	a) b) 	- a) the plate features a higher protective metal rim that prevents users from pushing food off the sides of the plate and helps the user to remove food onto the utensil, thus keeping the food on the plate [11] - b) presents a side edge that gradually increases, functioning as an additional hand to push the food onto the utensils, - the base contains an anti-slip fastening material, which prevents the plate from sliding during tremors if the patient has the other hand on the plate [12], [13]
Sandwich holder		- easy to use, comfortable and low price; - plastic support handle and hard textile material; - rubber band for tightening; - resistance up to 52˚C for cleaning, - component materials: PLA, PLGA, rubber [14]
Walker		- it is robust and can be used both indoors and outdoors, - projects a red laser in the path of the patient when he has an episode of "freezing", - the laser sends the visual message to the brain and it passes it on to the lower limbs to move, thus restoring normal walking, - additional arm support design allows the user to walk upright with better posture, - features an elegant, lightweight frame, designed in a way to provides maximum stability and support, - it has a reverse manual braking system, so the patient must squeeze the lever slightly for the roller to go. It will stop immediately after the system is released. - supports a weight up to 375 kg [15]
Walking stick		- the cane works using haptic vibrations, the handle of the cane is equipped with a device that through vibration causes an impulse to the patient to continue movement during periods of tremors - it incorporates a recording sensor (on a stick) of the time and duration of the freezing episode based on their walking patterns, - this database will help doctors and health professionals to better understand the disease and its implications for their patients, - it is equipped with a battery with 5-day autonomy, - each product has a lifespan of five years[16]
Shoe-mounted laser		- Path Finder is a laser device attached to a rubber strap that can be easily attached to the shoe - the laser projects a colored line when the foot touches the ground and turns off when the foot is in motion - the green line serves as a visual cue for the wearer stimulating him to step with the other foot and take a step forward, thus the wearer continues to walk normally - helps eliminate periods of blockage, improves walking speed and stride length - no batteries are required, can be easily charged with a charging cable. [17], [18]

III. ASSISTIVE DEVICES WITH ACTIVE CONTROL

The disease affects about 50 percent more men than women. Most people with Parkinson's first develop the disease at about age 60, about 5 to 10 percent of people with Parkinson's have "early-onset" disease, which begins before the age of 50 [19].

Although biomechanical loading using active orthoses has demonstrated superior suppression efficacies, significant challenges remain (i.e., compact configuration, lightweight, aesthetic, and soft structure) [7].

In Parkinson's disease, the tremor often starts in the hand and may spread to a part of the body such as an arm or leg. People with tremors often have difficulty carrying out activities of daily living, such as eating, writing, and personal care, which leads to a limitation of independence. Among the assistive devices with active control useful to people in daily activities are:

A. Self-stabilizing spoon with active control

This is a noninvasive, assistive, and rechargeable device that includes a support bar, a rechargeable battery, and many attachments such as a soup spoon, everyday spoon, fork, and an inertial measurement unit (IMU) placed in the handle that acts as a tremor detection mechanism (Active Cancellation Of Tremor Technology). It also includes a Force Sensing Resistor (FSR) that changes resistance when a force or pressure is applied. FSR detects the direction of shaking and moves the utensils in the opposite direction. Because the spoon is portable and quite light, it can be used in restaurants, at social events, as well as at home. The rechargeable battery can work for about 3 hours.

The system contains an Arduino Nano board based on an ATmega 328 microchip equipped with fourteen digital and eight analog pins, six of which are PWM enabled; an MPU-6050 IMU unit that combines both a 3-axis gyro and 3-axis accelerometer on a silicon die and an integrated digital motion processor that processes complex 6-axis motion fusion algorithms and a Micro 9g servo motor small and powerful FS90 servo to balance and stabilize.

This motor has only three pins, where: one pin is for input voltage, another pin is for signals and the last one is for electrical ground. The operating voltage range for this motor is 4.8V-6V giving a good torque output of 1.5 kg cm as more torque can be obtained if the voltage is higher. It also contains a 9V battery for power, some connecting wires, and a breadboard [19].

This system involves the development of a wireless wearable system that applies electrical stimulation to peripheral nerves, with real-time adjustments of stimulation parameters based on data from an embedded three-axis accelerometer.

Using a three-axis accelerometer, the system quantifies tremor characteristics (frequency and severity) and activates electrical stimulation of peripheral nerves to modulate/attenuate tremor movements.

External signal processing detects the current tremor status, applies stimulation based on the current tremor status, and ultimately maximizes the effectiveness of tremor suppression by providing real-time optimization of stimulation parameters [19], [20].

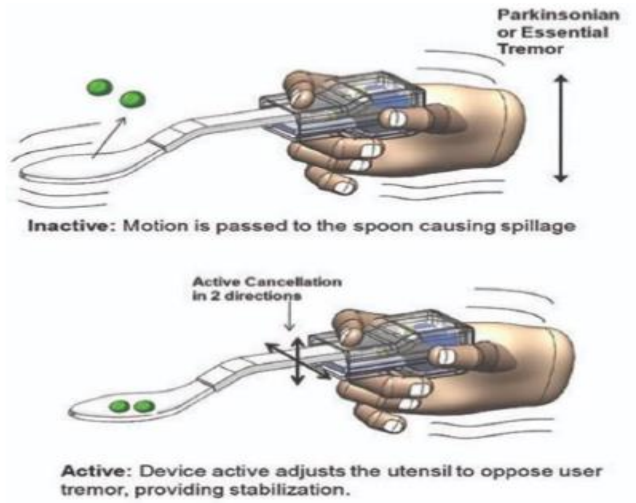


Fig 5: Principle of working

B. Wrist system with active control

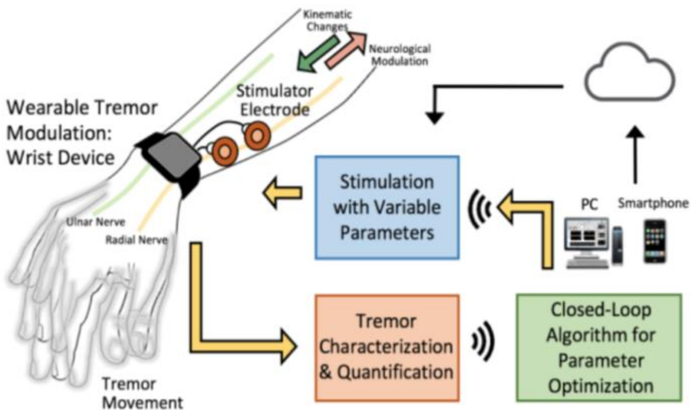


Fig 6: Overview of the Wearable Tremor Modulation System

The system is composed of four components: (1) a wireless wrist device consisting of a sensor interface and a constant voltage stimulator, (2) a wireless transceiver, (3) a pair of surface electrodes on the base of gel, and (4) a graphical user interface with a signal processing algorithm. The wrist device incorporates a three-axis motion sensor, a microcontroller, a wireless transceiver (2.4GHz radio frequency), a custom device, constant voltage mode stimulation circuitry, and a rechargeable lithium-ion battery of 3.7 V. The battery is charged by a standard lithium-ion linear battery charger connected to a 5 V mini-USB adapter. A full charge takes about three hours [20].

Peripheral nerve stimulation is generated by a voltage-mode stimulator. A voltage-mode device was used to avoid inducing skin burns if the resistance between the surface electrode and the skin was abnormally high. Two electronic switches are used to generate biphasic stimuli, which are alternately turned on and off. Stimuli are applied as short trains of stimulation. The stimulation amplitude is regulated by a variable resistor controlled by the MCU via a serial peripheral interface [20].

IV. LABVIEW SIMULATION OF ASSISTIVE DEVICES

Modelling and simulation activities are the most important in the design of the mechatronic devises, because with so different component: electronic, mechanic is difficult to choose the best of them.

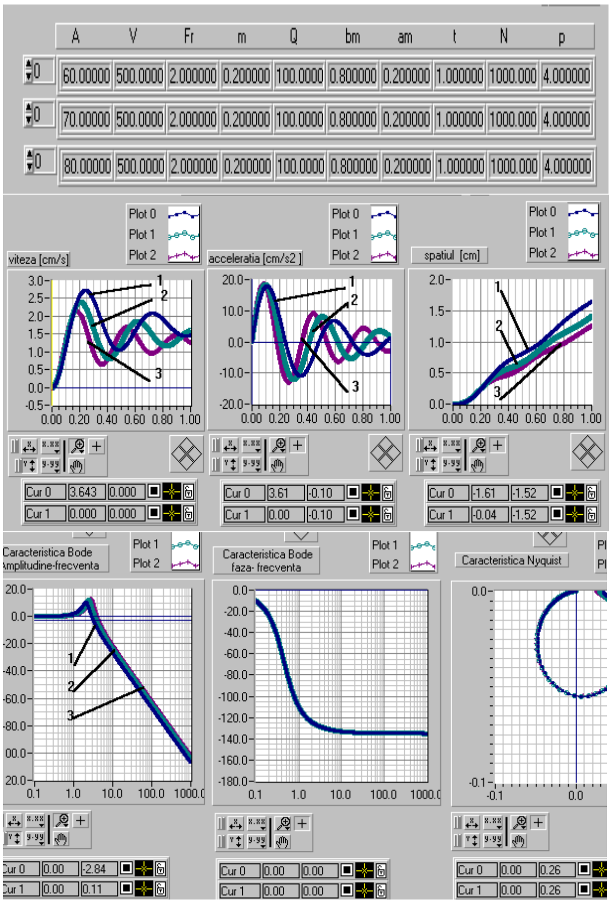


Fig.7. Front panel with some real and frequency characteristics when was changed active aria ***A*** of one pneumatic assistive device.

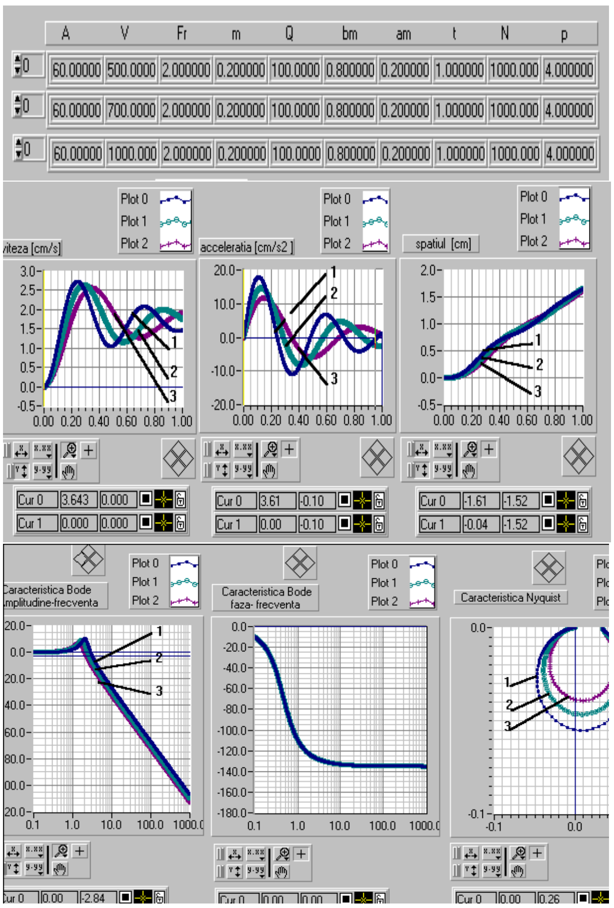


Fig.8. Front panel with some real and frequency characteristics when was changed active volume ***V*** of one pneumatic assistive device.

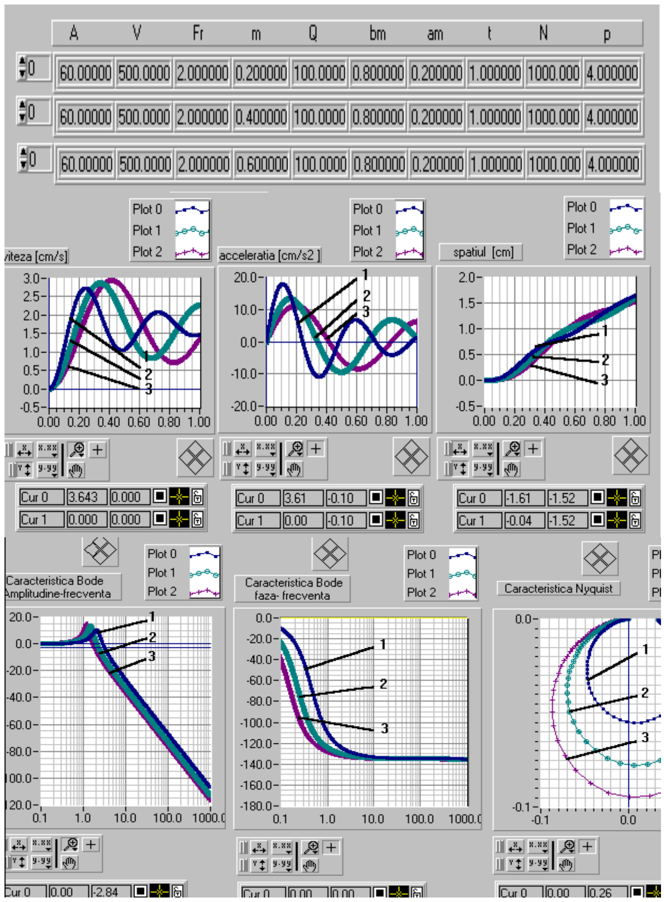


Fig.9. Front panel with some real and frequency characteristics when was changed active mass ***m*** of one pneumatic assistive device.

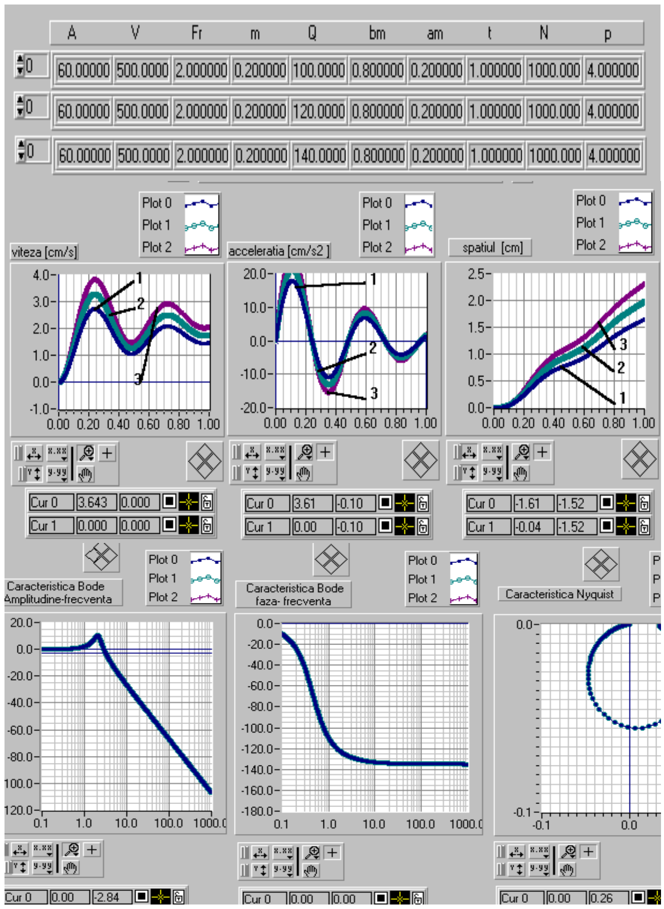


Fig.10. Front panel with some real and frequency characteristics when was changed active flow ***Q*** of one pneumatic assistive device.

Based on the analysis of figs.7-10, the following conclusions can be drawn: - the increase of the active area $\boldsymbol{A}$, determines the increase of the critical frequency, the increase of the chamber volume of the pneumatic motor $\boldsymbol{V}$, determines the increase of the response time $\boldsymbol{t}_{\mathrm{r}}$, the increase of the reduced mass at the rod of the pneumatic motor $\boldsymbol{m}$, determines the increase of the response time $\boldsymbol{t}_{\mathrm{r}}$ and of the critical frequency $\boldsymbol{f}_{\mathrm{c}}$, the increase of the supply air flow of the pneumatic motor $\boldsymbol{Q}$, determines the decrease of the response time $\boldsymbol{t}_{\mathrm{r}}$ and the increase of the maximum acceleration $\boldsymbol{a}_{\mathrm{max}}$.

Thus, the response time $\boldsymbol{t}_{\mathrm{r}}$ is mainly influenced by the active area $\boldsymbol{A}$ and the air flow rate $\boldsymbol{Q}$, the maximum acceleration is mainly influenced by the air flow rate $\boldsymbol{Q}$, by the active area $\boldsymbol{A}$, and by the gradient of force losses proportional to the speed $\boldsymbol{b}_{\mathrm{m}}$, the resonance frequency $\boldsymbol{f}_{\mathrm{r}}$ is influenced by the active area $\boldsymbol{A}$ and by the supply pressure $\boldsymbol{p}$, the critical frequency $\boldsymbol{f}_{\mathrm{c}}$ is influenced by the active area $\boldsymbol{A}$. By applying the exposed methodology and the highlighted program, it will be possible to optimize the dynamic behavior of the component elements of the servo systems from the design phase, ensuring at the same time that the performance falls within the requirements of the design theme.

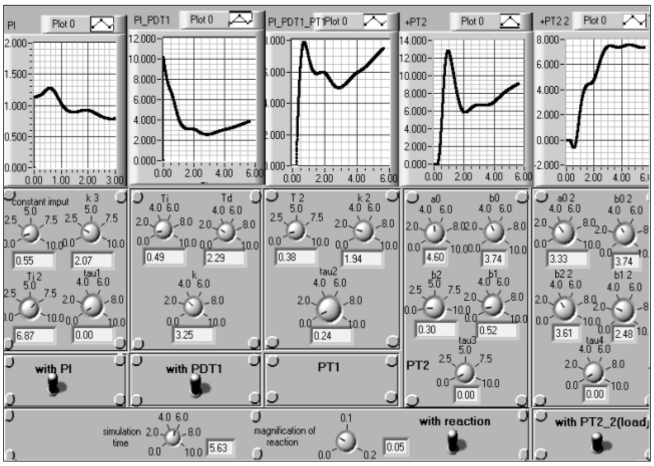


Fig.11. Front panel with some real and characteristics for simulation for one assistive devise that contents the transfer functions proportional integrator PI, proportional derivative with inertia of the first order PDT1, proportional with inertia of the first order PT1 and two components proportional with inertia of the second order PT2

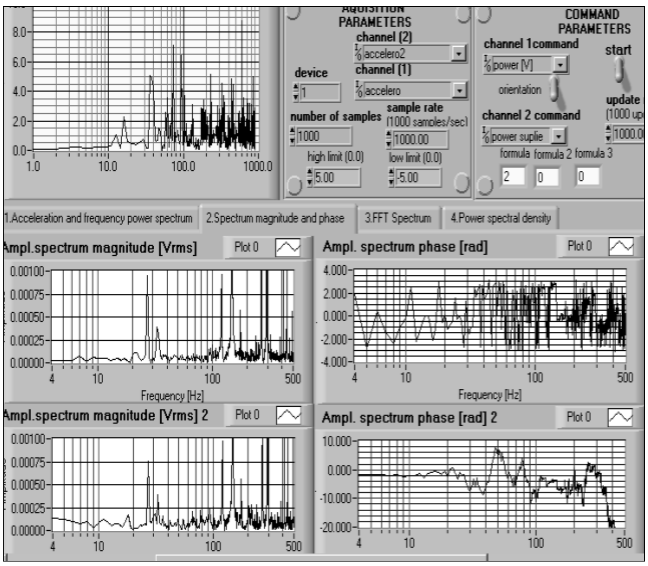


Fig.12. The front panel of the virtual LabView instrument for the data acquisition.

The simulation with the transfer functions fig.11, offers the possibility to obtain the optimal choice of the servo actuation structure and the parameters of each component. With this virtual LabView instrument we can, by using the buttons, to change some of the parameters of components and show what is the influences with/without reaction, with/without load and for different input data. Data acquisition, fig.12 are the most important way to adjust the parameters of the assistive devices, to choose the best parameters of all mechatronic parts and also to choose the best Fourier spectrum to reduce or to move the frequencies of the person with Parkinson in the high domain where isn't so dangerous.

V.CONCLUSION

In conclusion, the continuous increase in the number of people with disabilities requires the research and development of new devices or systems as personalized as possible to their needs. The continuous development and improvement of assistive devices helps to increase the quality of life of people with disabilities by facilitating their easier adaptation to environmental conditions. Their integration into society will lead to the reduction of discrepancies between them and people without disabilities, also helping to grow the economy.

We will focus both on active orthosis consists of a multichannel stimulator that provides support to activate several electrodes, placed on the forearm and upper arm above the flexor and extensor muscle points, that enable the selective muscle activation via distributed, asynchronous electrical stimulation. The inertial sensors deliver real-time estimation of tremulous movements to a host computer, which provides control over the stimulation of muscles. This system delivers out-of-phase stimulation by sending electrical current pulses to the flexor and extensor muscles, triggering the depolarization of motor neurons that counteracts the tremorgenic activity.

We will also study semi-active orthoses utilizing magnetorheological fluids as a strategy to provide tremor suppression. MR fluids consist of magnetizable, microscopic particles dispersed in oil or water. Upon encountering a magnetic field, these particles experience attractive force, and the viscosity of the MR fluids increases, opposing the existing flow. This rheological property has been exploited in tremor suppression orthoses by varying magnetic field intensities to tune the resistance force for tremor suppression.

More recently, the MR damper-based soft exoskeleton for the tremor suppression (SETS) system was proposed to suppress tremor in the wrist. Unlike previously designed semi-active orthoses, the SETS system equips a controllable flexible semi-active actuator that dynamically adapts to the motions of the wrist joint, providing tremor suppression in the wrist flexion/extension, abduction/adduction, rotation. This device also integrates passive suppression with two hyper-elastic blades, which suppress tremor in the wrist supination/pronation. The SETS system demonstrates potential clinical utility with its compatibility with the human wrist, real-time tunability based on tremor frequency, and lightweight design [2].

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Cristina Zamfirescu did the market research and wrote the paper, Adrian Olaru did the simulations in LabView, and the analysis of the obtained data, Cristina Mohora and Dana Tilina conducted the research, proofread the paper and contributed to the elaboration of the paper; all authors had approved the final version.

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