Original Article

Design and Fabrication of a Device for Reducing Hand Tremor in Parkinson Patients during Eating

Fereshteh Talaei[1], Seyed Mohammad Kargar[2]

[1]Department of Electrical Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran, [2]Smart Microgrid Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran

Abstract

Background: In this paper, the method of designing a noninvasive device for eliminating hand tremors in Parkinson's patients is presented. The designed device measures the tremors of the patient's hand and implements the tremor control accordingly. Since Parkinson's disease reduces patients' abilities to perform daily activities, this device is designed as an electronic spoon. The inertial measurement units are used to measure hand tremors. **Method:** The signals got from motion sensors are passed through Butterworth's second order low pass filters to attenuate signals amplitude at frequencies higher than the human hand's natural frequency. The signals are sent to a proposed Proportional Integral (PI) fuzzy controller as a set point signal, and appropriate control signals are applied to two actuators installed orthogonal. Besides motion sensors, a microcontroller is installed inside the spoon handle that implements a PI fuzzy controller and provides control signals for two high speed servo motors installed perpendicularly. **Results:** As such, the spoon can minimize the tremor effect. In this system, no damper or mass is added to the hand, and the patients are not required to wear an orthosis. The contribution of this paper is twofold. First, we use sensor data fusion to increase measurement accuracy. In this paper, we use accelerometer and gyroscope sensors. Second, we proposed a robust PI fuzzy controller to compensate for the uncertainties and reduce the tremor. **Conclusion:** The test results show that the hand tremor of Parkinson's patients during eating is reduced up to 75% using this method.

Keywords: *Filter, noninvasive tool, Parkinson's disease, proportional-integral fuzzy controller, tremor*

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Introduction

Parkinson's disease is a condition of the central nervous system in adults that features gradually progressive muscle stiffness, tremor, and loss of motion abilities. This disorder occurs when specific brain parts lose their ability to produce dopamine (a neurotransmitter in the brain). Parkinson is among the neurological disorders that usually happen after the age of 60. Out of every 100 people over 60 years, a person is diagnosed with Parkinson.[1] However, this disease is also observed among younger people, who constitute 5% to 10% of patients.[1] Hand tremors are usually categorized into resting and action tremors. Resting tremor occurs when the patient's hands do not move voluntarily. The frequency of this tremor is usually between 3 and 6 hertz.[2]

On the other hand, action tremor is prevalent among patients with essential tremor and occurs when they make a voluntary movement. The frequency of this tremor is usually between 5 and 12 hertz.[2] A significant problem of Parkinson's patients is their inability to eat since the spoon or piece of food cannot reach the mouth due to hand tremors and may spill. These tremors are often embarrassing and eventually limit the patient's social presence.

Medication is often used to control and manage various tremors, but patients' medication responses are different. Medicine might also cause side effects such as blurred vision, dizziness, fatigue, and muscular paralysis.[3] Brain surgery is another method of controlling tremors, but it is an invasive method and is often recommended when an insufficient response to medication is observed. Nowadays, many researchers have interested in less invasive treatment options that do not cause any side effects. The recent technologies involve

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Address for correspondence:
Dr. Seyed Mohamad Kargar, Smart Microgrid Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran.
E-mail: kargar@pel.iaun.ac.ir

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stabilizers that keep the devices stable despite the shaking of the user's hand. Hence, researchers have decided to use this technology and various control methods to design practical devices to eliminate hand tremors in Parkinson's patients. As such, they assist patients in performing daily functions.

For example, an electromechanical spoon is made that uses piezoelectric devices and suppresses tremors.[2] David Case *et al*. used small-scale Magnetorheological Dampers to excite the orthosis that suppresses upper limb tremor.[3] An adaptive algorithm is designed to eliminate involuntary movement from the raw signal recorded in real-time.[4] Faizan and Muzammil have created a wrist brace that adapts to the hand tremor frequency mechanically, using mass and spring, and absorbs the tremor.[5] A light wearable orthosis is designed in which a structure filled with constant air volume is placed behind the wrist and swells with the wrist's bending, increasing the air pressure and suppressing involuntary motion.[6] A glass-shaped robotic device is made that is used to drink beverages.[7] A device is built to communicate with the system to adjust the desired angle using a Force Sensor Resistor.[8] Arnal *et al*. have designed a robotic system installed behind the patient's arm via magnetic bonding and damps the patient's hand tremor.[9] Actuators have been designed that suppress tremors using a Proportional-Integral (PI) control algorithm along with Active Force Control.[10] Kostikis *et al*. have used the accelerometer and gyroscope sensors of a smartphone.[11] A pen is made to improve Parkinson patients' handwriting, in which a Linear Voice Coil Actuator is used as the anti-tremor device.[12] A smart glove is designed with a rotating brass disc. The brass disc attempts to resist the input forces and creates a gyroscopic effect in the patient's hand tremor.[13] Chen Liu *et al*. have used a closed-loop fuzzy control method based on parameter estimation.[14] Veluvolu *et al*. designed a double adaptive band-limited multiple Fourier linear combiner to estimate modulation signals with multiple frequency components and filter.[15] A dynamic hand tremor absorber is designed by Rahnavard *et al*. using the H_2 optimization method.[16] Zhou *et al*. conducted a study of tremors in the hand's fingers and wrist as a reference for designing tremor suppression devices.[17] Finally, viscous dampers implemented in some portable devices are used to control hand tremors.[18]

In this study, we design a noninvasive device to suppress hand tremors in Parkinson's patients during eating. This device can not only be useful in the life of millions of Parkinson's patients in the world, Still, it may also significantly reduce treatment costs and, in situations where there is no definitive cure for the disease, provide temporary relief for these patients so that they can return to their everyday lives. This device is an electronic spoon in which a filter is implemented using a microcontroller to eliminate destructive noise because of the patient's hand tremor. Since the filter type and the parameter tuning affect the tremor signal, the filter is selected and designed to eliminate the noise impact more carefully than in previous studies. Then, using a PI fuzzy controller, an appropriate control signal is prepared and applied to two actuators that have been installed orthogonal on each other.

As no damper or mass is added to the hand, the device does not cause muscle fatigue or limitation in the range of voluntary movement. The proposed device is not limited to a specific location, unlike fixed systems designed to reduce tremors. Besides, this system actively controls the hand movement, and the filters assist the device only to affect hand tremors and have less impact on the voluntary motion, which can be influenced by vibration absorption systems in passive systems.

After the initial design, the device was fabricated in the laboratory, and actual hand tremor data were used to test it. The prototype is shown in Figure 1. It must be mentioned that eliminating hand tremors is useful for Parkinson's patients and many applications, such as critical surgeries, videography, photography, sports, and physiotherapy.

The present paper is divided into five sections. A literature review is presented in section one. In section two, the general design of the research is explained in detail. In the third section, the filter design method to process the tremor signal is described. The controller is designed in section four, and the results of implementing this method are discussed in the fifth section. Finally, the research is concluded in section six.

Methods

The designed system is a smart device that distinguishes voluntary movements from involuntary hand tremors and suppresses them. The schematic of this device is shown in Figure 2. The spoon comprises a light handle, tremor sensor, angle sensor, controller, and two small motors. For ease of use, the spoon tip rotation must be prevented; in other words, the spoon tip should only move linearly. The first motor is connected to the handle and moves left and right, and the second motor is installed on the first motor shaft orthogonally and moves up and down. Thus, the system has two degrees of freedom (DOFs); i.e., it can suppress tremors in two directions. An angle sensor has also been installed on each motor's shaft and specifies the motor

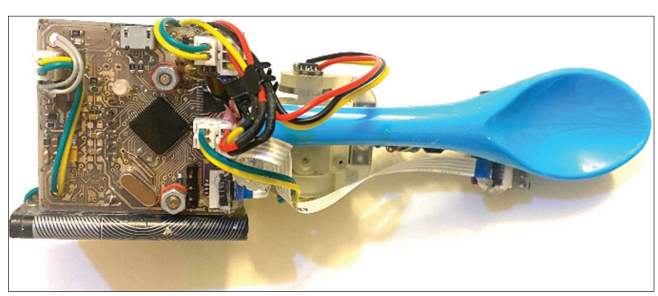

Figure 1: Hand tremor reducer spoon for Parkinson patients

position after the control command through the magnet's rotation attached to the motors. The motor's weight is <20 g, and the total weight of the mechanism is about 120 g. Tremor sensors have been installed on the spoon's handle and bowl to compare and determine the error signal between the hand tremor signal and the signal received from the spoon tip. We have also used a rechargeable battery in the spoon handle to supply the energy required by this device, and external energy sources charge it. Previous studies show that hand tremors in Parkinson's patients usually occur with a frequency of 3–6 hertz.[2] In more severe cases, this frequency range can increase to 5–12 hertz.[2] Moreover, the average hand tremor amplitude in Parkinson's patients is 1.4 cm, and the proposed mechanism should cover the mentioned range.[2] Figure 3 shows a block diagram of the functioning of the proposed device. As seen, we have used the Inertial Measurement Unit (IMU) technology to measure hand tremor and convert it to electrical signals. This technology refers to a stationary positioning unit or inertia-based positioning system that includes electronic sensors with Micro Electro Mechanical System structure and 9 DOFs. The electronic sensor comprises the accelerometer, gyroscope, and magnetometer sensors installed in the device to be in full contact with the patient's hand. Hence, its motion is equivalent to that of the patient's hand. An accelerometer is a sensor that measures the sum of dynamic (moving object) and static (gravitational) accelerations. In this sensor, a piezoelectric element is used to convert the acceleration into a suitable electrical signal. In this research, the accelerometer's measurement range is ± 2 g, and the bandwidth of its measurement frequency is set to 64 Hz. However, according to the sensor catalog, the data sampling rate is halved by passing through the sensor's internal filter

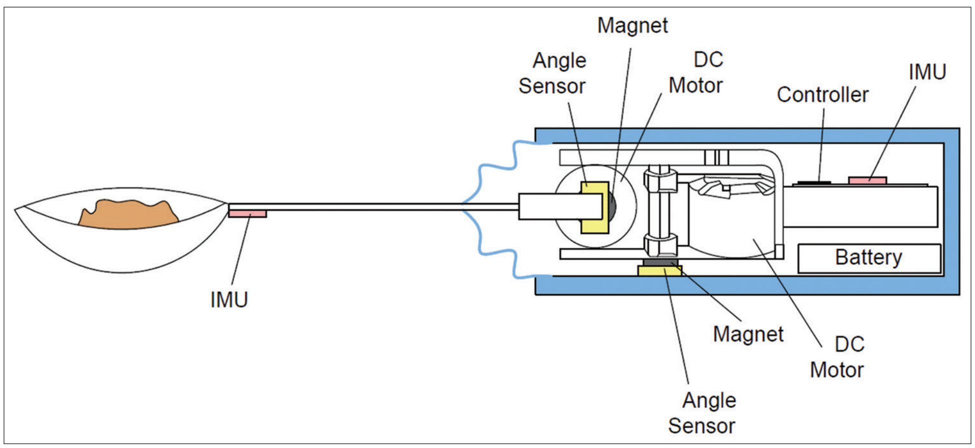

Figure 2: Schematic of the designed spoon

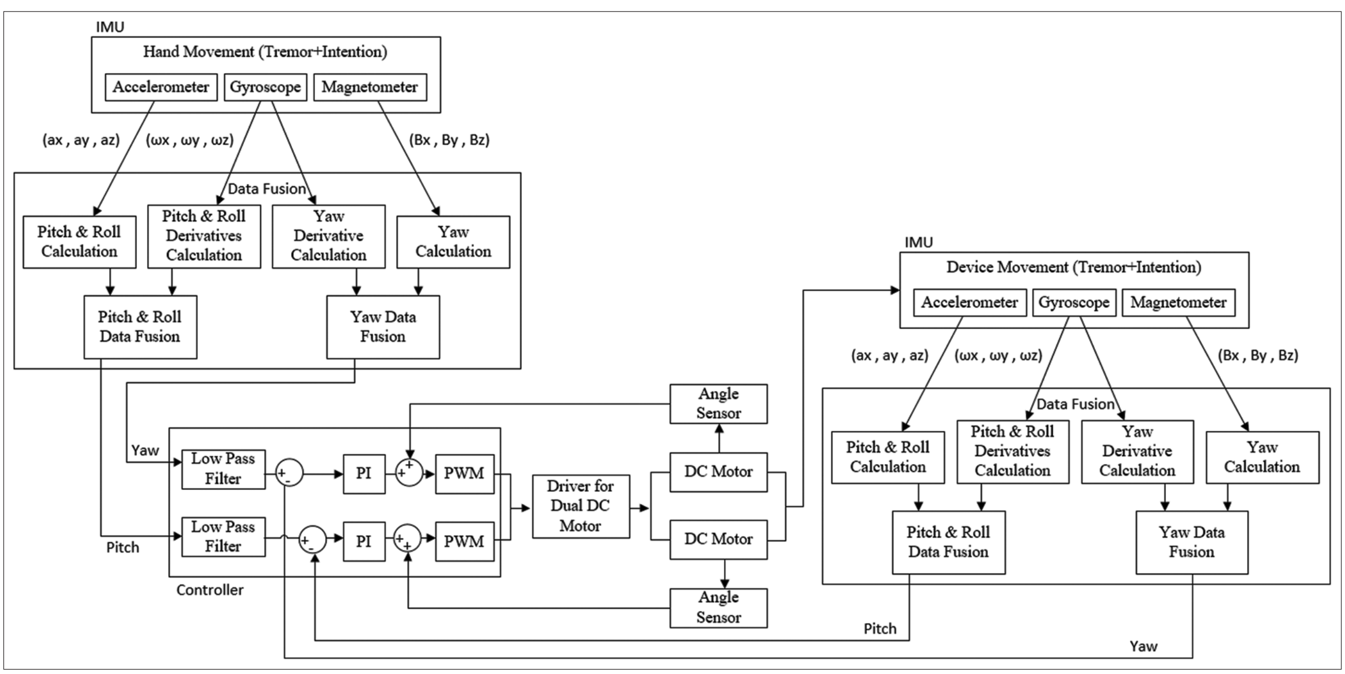

Figure 3: Block diagram of the designed spoon

and becomes once per 15.6 ms. The gyroscope measures the angular velocity of the hand motion. The gyroscope's primary duty is to create a reference coordinate system so that the accelerometer can measure the hand movement's acceleration along this coordinate system's axes.

In this research, the gyroscope's measurement range and its measurement frequency bandwidth are set to 125°/sec and 100 Hz, respectively. According to the sensor catalog, its measurement frequency bandwidth reaches 32 Hz by passing through the internal filter; thus, the data will be sampled once per 15.6 ms. The magnetometer is a sensor that can provide information about the angle of the patient's hand by measuring the magnetic field. The bandwidth of the measurement frequency of the magnetometer is set to 30 Hz.

As seen, the IMU sensors' sampling rate is less than once per 33 ms on average. Thus, the sampling frequency is at least 30 Hz, which is appropriate for recording tremors with a frequency of 6 Hz or less. The data received from the sensors are transmitted to the controller via an Inter-Integrated Circuit (I2C) interface. As mentioned previously, the signal received from the measurement sensors contains data relating to the vibrational motion of the patient's hand and the spoon tip. Getting the spoon tip and hand's angular position is possible using either the accelerometer or the gyroscope sensors. However, both sensors have a significant drawback that makes it impossible to use their data separately. The accelerometer measures all the forces exerted on an object; hence, it measures many forces other than the Earth's gravitational force. Any small force exerted on the object can cause an error in the measurement by the sensor. Thus, the accelerometer data are valid only in the long term; hence, a low-pass filter must be used in their output.

On the other hand, the gyroscope data integration is performed approximately from a finite sum of numbers. Hence, the gyroscope is valid in the short-term and suffers a drift in the long term; therefore, it will have a small deviation when it returns to its initial state. To reduce the measurement error of the vibrational motion, we use sensor data fusion. Data fusion is a process where information and various data of an actual object or an action are merged to increase measurement accuracy. The following relationships are used for this purpose:[19]

$$R_x = \frac{R_x^{ACC} + R_x^{Gyro} * w^{Gyro}}{1 + w^{Gyro}} \quad (1)$$

$$R_y = \frac{R_y^{ACC} + R_y^{Gyro} * w^{Gyro}}{1 + w^{Gyro}} \quad (2)$$

$$R_z = \frac{R_z^{ACC} + R_z^{Gyro} * w^{Gyro}}{1 + w^{Gyro}} \quad (3)$$

Where R_x^{ACC}, R_y^{ACC} and R_z^{ACC} are the acceleration read by the accelerometer along the x, y, and z axes, respectively. R_x^{GYro}, R_y^{GYro}, and R_z^{GYro} are the angular velocity read by the gyroscope along the x, y, and z axes, respectively. w^{GYro} is the weighting coefficient and shows the extent to which we can trust the gyroscope compared to the accelerometer. This value can be selected experimentally, and values between 5 and 20 usually lead to excellent results.

The hand rotation angle along the pitch and yaw axes is obtained by processing the gyroscope and accelerometer output. A nine-axes IMU module is installed on the device tip to provide the controller with accurate motion data as a feedback signal. As shown in Figure 4, the device under study is connected to a computer via universal serial bus, and the signals measured from the actual patient's hand tremor can be observed using the STM Studio software.

The signal measured from the patient's hand tremor is passed through a low-pass filter after processing, so its unfavorable frequencies are attenuated, and the voluntary movement signal is separated from the tremor signal. Two DC motors are used in this design to execute the control commands. The controller determines the motion's speed and range for the DC motors and transmits a Pulse Width Modulation (PWM) signal to the motor driver. In general, DC motors do not have a linear RPM-PWM relationship. The reasons for this include the friction in the shaft, ElectroMotive Force, and the effect of external factors such as the resistive torque due to fluctuating loads or voltages. However, most of the time, the motor is needed to work with the same speed or torque despite the operating conditions or the loads required to carry it. Hence, the nonlinear correction function is necessary to provide the desired output under any condition discussed in the controller design section. In this paper, angle sensors are used for the motors to measure each motor's shaft angle. These sensors provide the controller with the rotation data of the motors. The motor's position is checked using these sensors after applying control commands. By receiving the motion data of the spoon tip and comparing it with the tremor motion of the patient's hand, the controller applies the appropriate command to the motors. Eventually, the

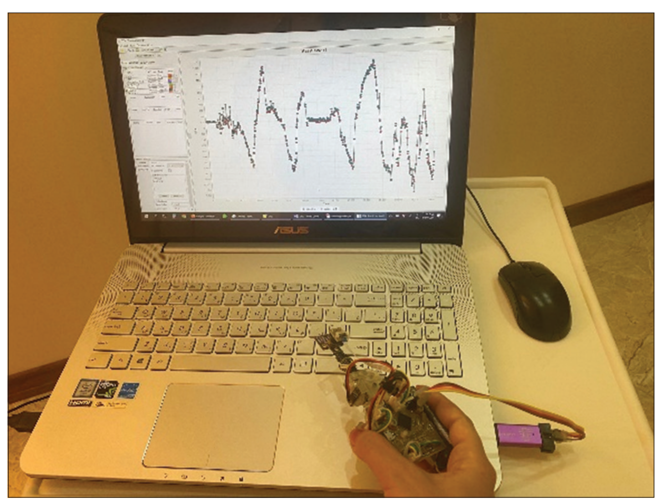

Figure 4: Connection of the device to a computer through a USB port

rotation of the motors' shafts to the left and right and up and down suppresses the spoon tip's involuntary motions.

Filter design

Unlike hand tremors, voluntary hand motion must not be affected by the system; In other words, the device tip must follow the voluntary hand motion.

Amplitude, frequency, and phase are three important vibrational motion features and can be processed according to the control aim. Limiting the signal amplitude at specific frequencies and reducing the range of angular changes in the patient's hand motion create the desired conditions to eliminate involuntary tremors. The measured signal from the patient's hand tremor is processed using a filter to reach this goal. The human hand's natural motion frequency is <3 Hz,[2] so we have designed a low-pass filter that the output signal of which has a smaller amplitude than the corresponding input signal at frequencies higher than 3 Hz and the frequency of which is larger than the natural motion frequency of a healthy hand is separated. It must be mentioned that the most crucial reason for the computational delay, which practically deteriorates the performance of the system, is the filters. Because of this fault, high-order low-pass filters should not be used. In this research, the Butterworth second-order low-pass filter, a filter with Infinite Impulse Response, is considered. The advantage of the Butterworth filter is its smooth and ripple-free frequency response. It is obtained as follows:

$$G(\omega) = \frac{1}{\sqrt{1+\omega^{2N}}} \quad (4)$$

Where ω and N are the angular frequency in radian per second, and the filter order, respectively. The minimum order of the filter for obtaining the desired characteristics is determined as follows:

$$N \geq \frac{log_{10}\left(\frac{\delta_s^{-2}-1}{\delta_p^{-2}-1}\right)}{2\ log_{10}\left(\frac{\Omega_s}{\Omega_p}\right)} \quad (5)$$

Where Ω_p, δ_p, Ω_s and δ_s, are the passband frequency, gain deviation in the passband, stop-band frequency and gain deviation in the stop-band, respectively. The Butterworth transform function poles are obtained from the following formula, where k is the pole number.

$$S_R = -\sin\frac{(2k-1)\pi}{2N} + j\cos\frac{(2k-1)\pi}{2N} \quad (6)$$

$k = 1.2\ldots n$

By substituting the poles, the formula is rewritten as follows:

$$G(s) = \begin{cases} \dfrac{\Omega_c^N}{\prod_{k=1}^{N/2}(s^2 + b_k.\Omega_c.s + \Omega_c^2)} & if\ N\ even \\ \dfrac{\Omega_c^N}{(s+\Omega_c)\prod_{k=1}^{N-1/2}(s^2 + b_k.\Omega_c.s + \Omega_c^2)} & if\ N\ odd \end{cases} \quad (7)$$

Where

$$b_k = 2\ sin\frac{(2k-1)\pi}{2N}$$

In the above relationships, Ω_c and N are the cutoff frequency and filter order, respectively. Healthy people's eating time is the time to carry the spoon from the plate to the mouth and is between 1s and 3s for various people. Therefore, in this study, the eating frequency is considered to be between 0.33 Hz and 1 Hz, i.e., the hand motion to bring the spoon to the mouth occurs less than once per second.

As mentioned earlier, the Butterworth filter is of the second-order and Low-pass type, with a bandwidth of about 1 Hz in practice and a cut-off frequency of about 6 Hz. Therefore, this filter attenuates hand movements at frequencies above 1 Hz and eliminates frequencies above 6 Hz.

By placing N = 2 and Ω_c = 6 in relation (7), transfer function of the designed filter, obtained as follows:

$$G(s) = \frac{39.48}{S^2 + 8.886\ S + 39.48} \quad (8)$$

The transfer function obtained for the filter was implemented in software and in C language in the microcontroller

Controller design

The classical PI controller is used in the controller's design. The PI controller is useful for steady-state error-free control, and its algorithm is:

$$u(t) = k_p e(t) + k_I \int_0^t e(t)\,dt \quad (9)$$

Where u(t) is the controller output, k_p is the proportional gain, k_I is the integral gain, and e(t) is the error signal. The constant controller gains cause poor performance under certain conditions. Hence, in this research, the fuzzy logic approach is used to determine the controller gains adaptively. The reason for choosing fuzzy logic is its capability in designing a robust controller and good performance under the uncertainties and inaccuracies, such as noise, tremor, and other system parameters changes. A general fuzzy logic controller comprises four parts: A fuzzifier, which is to receive the input from the sensors and fuzzify them for further processing. Membership functions, which are used to map the variables to fuzzy sets. A knowledge basis, where the rules are formed using linguistic variables. Fuzzy measurements are used by the inference engine to evaluate the rules stored in the fuzzy rules set and determine the fuzzy output. Finally, the fuzzified output is converted to a single value. This conversion is called defuzzification. The defuzzified values represent actions that must be taken to control the process.

In this paper, the fuzzy logic controller has two inputs: The angle error and the angle error change. The difference between the spoon tip's current angular position, with the reference value or setpoint, which is the desired angular position, is defined as the angle error. The difference in errors at the instants t and t-1 is defined as the angle error change. The controller's defuzzification is performed based on the centroid method, i.e., the closer the input data to the center of the membership function, the larger its membership ratio. We concentrate on using Mamdani inference, which is one of the most successful techniques in applied fuzzy logic. Figure 5 displays the block diagram of the fuzzy controller for determining the k_p gain.

First, the membership functions and linguistic variables are determined to get the desired dynamics. The most well-known membership functions in practical applications are triangular, trapezoidal, and Gaussian functions. Figure 6 shows the schematic of a triangular membership function $\mu_f(x)$.

The performance formula of the triangular membership function is:

$$\mu_f(x) = \begin{cases} 0 \quad x < a \\ \dfrac{x-a}{m-a} \quad a \le x < m \\ \dfrac{b-x}{b-m} \quad m \le x \le b \\ 0 \quad x > c \end{cases} \tag{10}$$

The fuzzy logic inputs have seven linguistic variables named Negative Big, Negative Medium, Negative Small, Zero, positive big (PB), positive medium (PM), and positive small. The output of the fuzzy logic controller has the same linguistic variables. Figure 7 displays the membership functions' performance and linguistic variables of the two inputs and one output of the fuzzy controller for determining the k_p gain.

Membership functions are determined by analyzing real data from practical experiments. Choosing a very large or very small scale for the input/output operational region causes this region to reach saturation or convert to a narrow state. Therefore, choosing a suitable scale is an essential factor in designing fuzzy controllers because of its powerful effect on stability and reducing fluctuations. In this research, the input/output operational region's scale in the spoon's upward and downward motion (along the z-axis) is considered as (–30 + 30), which results in the best performance of the system in practical experiments. After defining the membership functions, we define applicable rules according to the actual system performance. In the PI controller, the response amplitude increases by increasing k_p, and the output amplitude decreases with a decrease in k_p, which is defined as a rule for a fuzzy structure. By changing the k_i gain in the PI controller structure, the steady-state system's fluctuations, and errors can be changed. These rules and similar ones can be expressed via the if-then rule. Tables 1 and 2 show the fuzzy controller rules for determining the gains k_p, and k_i, respectively.[20]

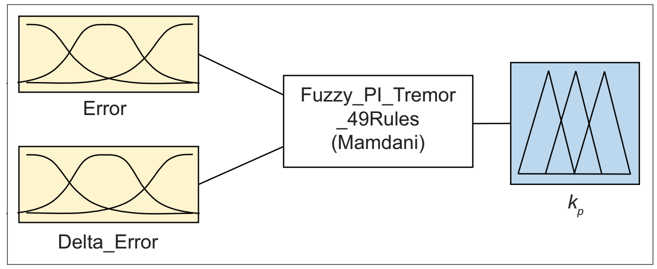

Figure 5: Block diagram of the fuzzy controller

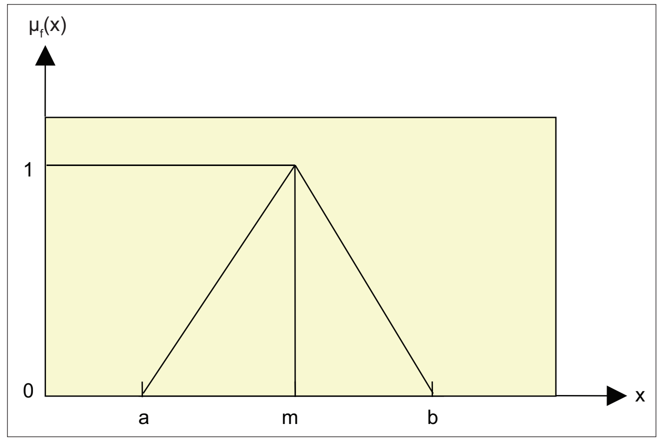

Figure 6: Schematic of the triangular membership function

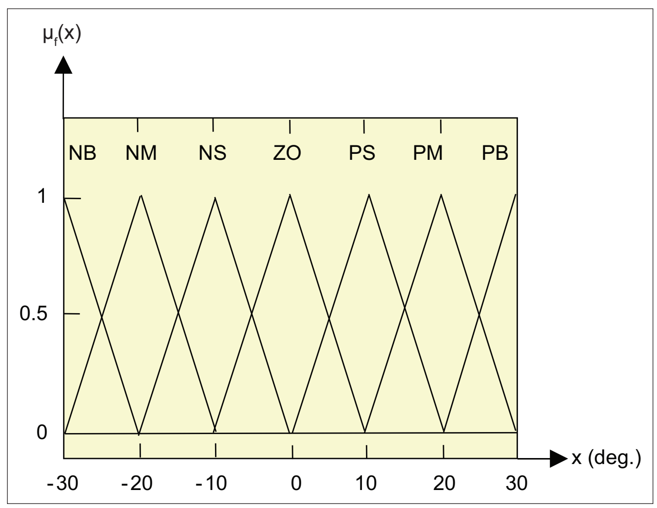

Figure 7: Membership functions of the first input (error) and second input (changes in error) for k_p and the output (the gain k_p)

Assume the error and error changes membership functions are PM and PB, respectively. Hence, the fuzzy rules are derived according to the intervals defined in Table 1, as follows:

$$if\ Error \in PM\ and\ Delta_{Error} \in PB\ then\ k_p \in PB \tag{11}$$

Figure 8 shows the fuzzy rules that determine the output value for the k_p coefficient and presented in Table 1, is shown in the three-dimensional surface:

Then, at each instant, the fuzzy controller's output, k'_p, and k'_I, are added as an adaptive term to the value of the PI

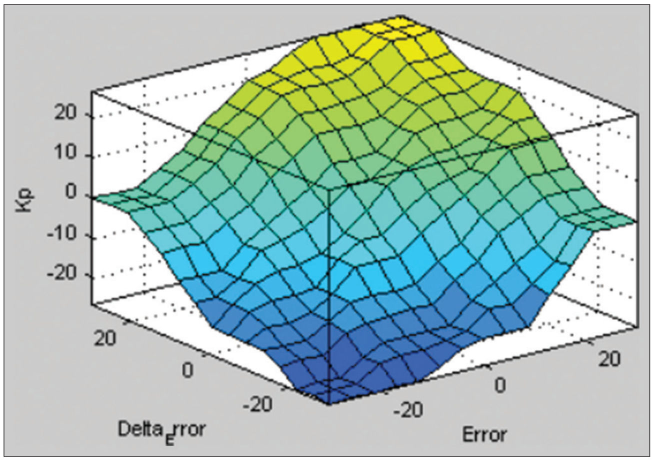

Figure 8: The fuzzy rules governing the fuzzy controller related to the spoon model for the gain k_p

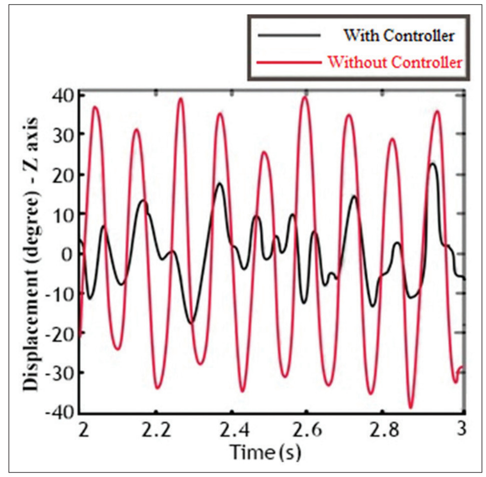

Figure 9: Comparison of the vibration amplitude of the spoon upward and downward with and without the controller

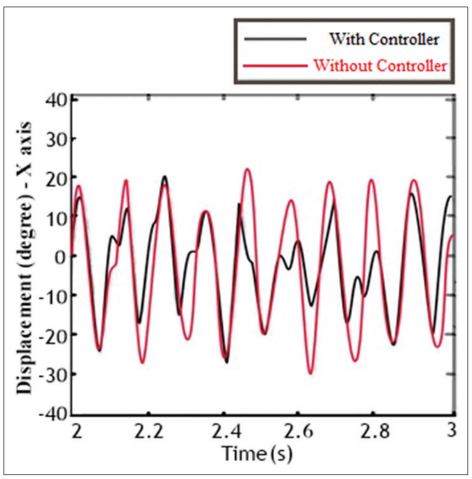

Figure 10: Comparison of the vibration amplitude of the spoon Tip to the left and right with and without the controller

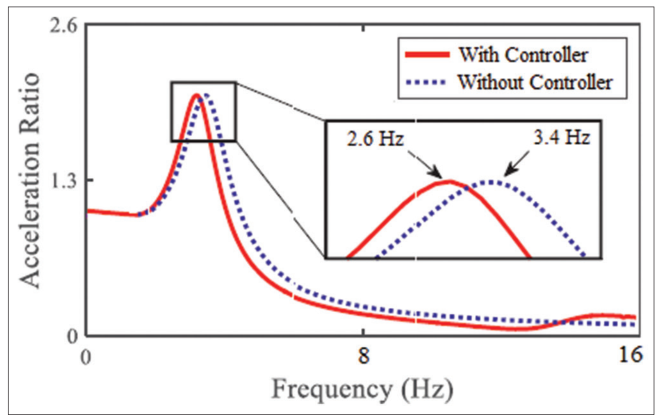

Figure 11: Comparison of the vibration frequency of the spoon tip with and without the controller

controller coefficients, $\tilde{k}_p$, and $\tilde{k}_I$, and the final coefficients k_p and k_I are obtained.

$$k_p = \widetilde{k_p} + k'_p \quad (12)$$

$$k_i = \widetilde{k_i} + k'_i \quad (13)$$

In the above relationships, $\tilde{k}_p$ and $\tilde{k}_I$ is the constant proportional and integral gain respectively, k'_p and $\tilde{k}_I$ and are the fuzzy adaptive proportional and integral gain, respectively.

Finally, the control input is determined by the PI controller based on the new coefficients and is applied to the servo motors as a PWM signal. A microcontroller with ARM architecture is used to implement the controller, which uses a minimal and highly optimized set of instructions.

System implementation results

In this section, the system implementation results are examined. The effect of eliminating involuntary tremors in the patient's hand is shown in Figures 9-11. In these

Table 1: The fuzzy controller rules for the gain k_p

e	ec						
	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NM	NM	NS	ZO	ZO
NM	NB	NB	NM	NS	NS	ZO	ZO
NS	NB	NM	NS	NS	ZO	PS	PS
ZO	NM	NM	NS	ZO	PS	PM	PM
PS	NM	NS	ZO	PS	PS	PM	PB
PM	ZO	ZO	PS	PS	PM	PB	PB
PB	ZO	ZO	PS	PM	PM	PB	PB

Table 2: The fuzzy controller rules for the gain k_I

e	ec						
	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PS	PS	ZO	NS
NS	PM	PM	PM	PS	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NM	NM	NM	NB
PB	ZO	ZO	NM	NM	NM	NB	NB

Figures, the spoon's controlled motion using the fuzzy PI controller is compared to the patient's hand tremor.

As shown in Figure 9, the patient's hand tremor caused the spoon head to move up and down 40 degrees (along the Z-axis), which is reduced by about 75% by applying control using the smart spoon. Moreover, it is observed in Figure 10 that the patient's hand tremors displace the spoon tip by 20° to the left and right (along the X-axis), which is reduced by about 35% by applying control using the smart spoon. Figure 11 shows that the spoon tip's frequency is 3.4 Hz without the controller, which is reduced down to 2.6 Hz using the controller. In other words, the vibration frequency of the spoon tip is less than the hand tremor frequency in Parkinson's patients, which is between 3 Hz to 6 Hz.

Conclusion

In this study, a new noninvasive, light, and hand-held device that helps Parkinson's patients is presented. First, the hand tremor signal is measured using IMU technology, including three motion sensors: Accelerometer, gyroscope, and magnetometer. The data obtained from the motion sensors are fused to increase the data's accuracy and quality. The second-order Butterworth low-pass filter is designed to eliminate tremor signals from the voluntary motion signal so that the frequency of which is larger than the natural motion frequency of a healthy hand can be separated. The filter output signal shows that frequencies above 3 Hz are attenuated up to about 80%. This signal is used as a control reference, and a fuzzy PI controller is used to create the appropriate control signal via a microcontroller. The PI controller gains are determined via the Mamdani fuzzy technique to guarantee the system's proper performance in the presence of disturbances or undesirable conditions. The control signal obtained as PWM is used to control the motors in two directions. According to the prototype test results, this device can considerably reduce the hand tremor in Parkinson's patients along with two perpendicular directions. The results show that the tremor is reduced by 70% to 75% along the Z-axis (Moving up and down) and 30% to 35% along the X-axis (Moving right and left) by the proposed controller.

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None.

Conflicts of interest

There are no conflicts of interest.

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