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Self-Stabilizing spoon for Parkinson's patients and functionally challenged people

Abdulfattah Al ghariani [1], Yousef Abulahbas[2], Jamal Askri[3], Fatma Dren[4] and Nour Himeedah[5]
[1, 2,3,4,5] Electrical & Electronics Engineering, College of Engineering Technology-Janzour.
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Abstract
Parkinson's disease is a common neurodegenerative disorder that affects older people because of environmental or genetic factors. It is defined as a brain disorder that causes unattended or uncontrollable movements such as shaking, stiffness, and difficulties with balance and coordination [3]. There is no cure for disease so far, so the aim of this paper is to produce a stabilizing spoon that will help the patient eat by themselves without the need for help from others, which increases self-confidence.
The spoon remains fixed in its horizontal position no matter how strong the tremor is in the patient's hand. In recent years, stabilizing assistive devices have been in continuous development, but what makes this paper special is the low cost of the device.
This paper consists of a gyroscope and accelerometer, which they use to measure angles and acceleration, then send them back to the microcontrollers to ensure that the spoon is in the horizontal position.
All these measuring features are on one chip, as the one used in this paper, which called IMU (MPU6050); also, this paper consists of two servomotors, one for the movement in pitch angle and the other for the roll angle.
All components of the paper were selected to achieve one of the most important objectives of this paper, which is low cost.
Keywords: Arduino, Micro Servo Motor MG90, IMU (MPU6050), Stabilization, PID.

1. Introduction

In the proposed paper, self-stabilizing spoon to help people who have Parkinson's disease; as a common known neurodegenerative disorder that affects the elderly due to environmental or genetic factors. That causes unattended or uncontrollable movements such as tremors, stiffness, and difficulties with balance and coordination. There is no cure for the disease yet, so a spoon stabilization system will be tested that will help the patient eat alone without the need for the help of others, which will increase self-confidence as the spoon remains stable in its horizontal position.
This proposed aims to measurement features that are on a single chip as the one used in projects called the IMU (MPU6050), which consists of a gyroscope, and an accelerometer. It used to measure angles, acceleration and return them to the Arduino Nano (microcontrollers) to ensure the spoon in the horizontal position and including two servomotors, one for movement at the tilt angle and the other for the roll angle.

2. Objectives

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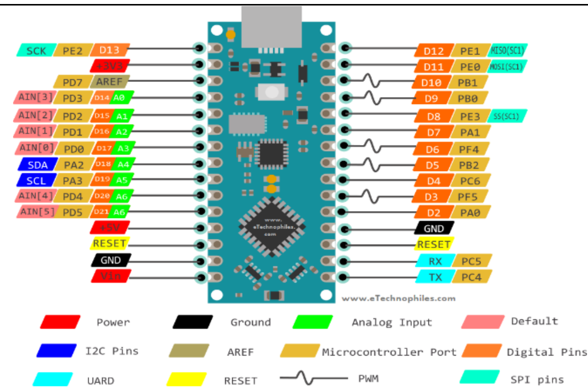
Designing a device for Parkinson's disease patients to eat independently, using a PID controller for turbulence response and minimizing overshoots, ensuring the device maintains its optimal state with minimal deviations.

3. Research Components and structure.

Table [1] Hardware components

Arduino Nano	
MPU-6050 Unit	
Servo Motor	
9V Battery	

3.1 Main control board (Arduino Nano)

The Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328 (Arduino Nano 3.x) which has 2 KB of SRAM and 1 KB of EEPROM. It can be powered via the Mini-B USB connection, 6-20V unregulated external power supply (pin 30), or 5V regulated external power supply (pin 27). The power source selected automatically to the highest voltage source. It has

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14 digital pins and can used as an input or output. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kΩ [4].

3.2 Inertial Measurement Unit MPU6050

The GY-521 module is a breakout board for the MPU-6050 MEMS (Micro electromechanical systems) that features a 3-axis gyroscope, a 3-axis accelerometer, a digital motion processor (DMP), and a temperature sensor. The digital motion processor used to process complex algorithms directly on the board. Usually, the DMP processes algorithms that turn the raw values from the sensors into stable position data. The sensor values retrieved by using the I2C serial data bus, which requires only two wires (SCL and SDA). If you plan to use full range of features or require reliable and stable position data [5].

3.3 Micro Servo Motor MG90

Micro Servo Motor MG90 is a tiny and lightweight server motor with high output power.
A **servomotor** is a type of motor that can rotate with great precision. Normally this type of motor consists of a control circuit that provides feedback on the current position of the motor shaft; this feedback allows the servomotors to rotate with great precision. If you want to rotate an object at some specific angles or distance, then you use a servomotor. It made up of a simple motor, which runs through a **servomechanism**. When motor powered by a DC power supply then it called DC servomotor, and if it is AC-powered motor then it called AC servomotor. A part from these major classifications, there are many other types of servomotors based on the type of gear arrangement and operating characteristics. A servomotor usually comes with a gear arrangement that allows us to get a very high torque servomotor in small and lightweight packages. Due to these features, they used in many applications like toy car, RC helicopters and planes, Robotics, etc. [1].

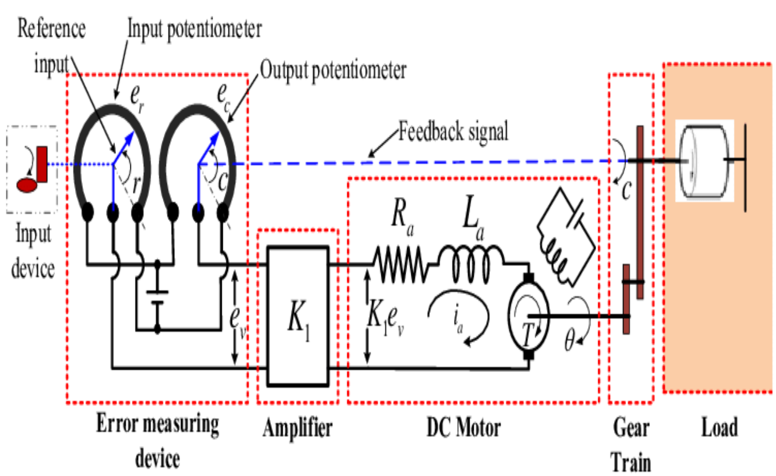

Fig. (1) Servomotor Structure

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3.4 Hardware Structure

Figure (2) shown hardware components for the research which contains control unit Arduino Nano, input and output modules. In addition, Figure (3) shown Electronic circuit.

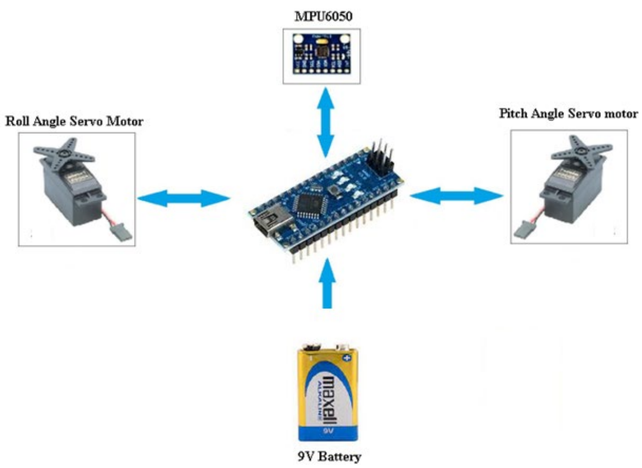


Fig. (2) Hardware Structure

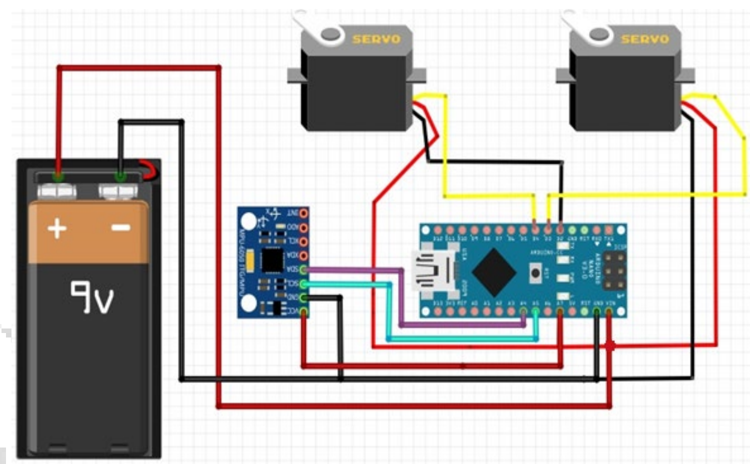


Fig. (3) Electronic circuit connection

3.5 Block diagram

Represent the Block diagram of the system as shown in figure (4) below.

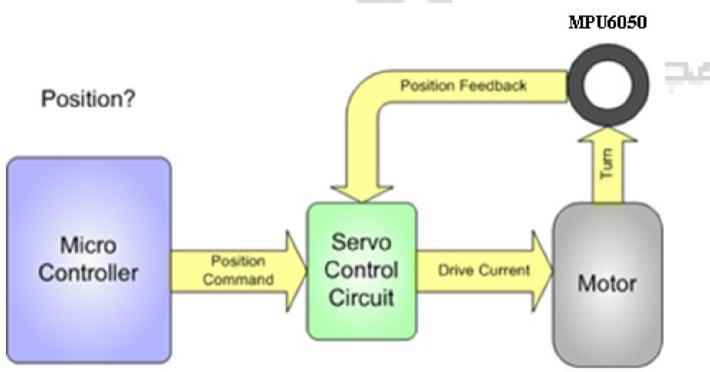


Fig. (4) Block diagram

4. PID Controller.

PID is an abbreviation for (Proportional + Integral + Differential) which is responsible for correcting the error caused by the difference between the required value and the measured value. The working theory of this type of controller depends on the actions of the proportional controller, the integrative controller and the differential controller, and this type combines the advantages of three types as shown in the following figure (5).

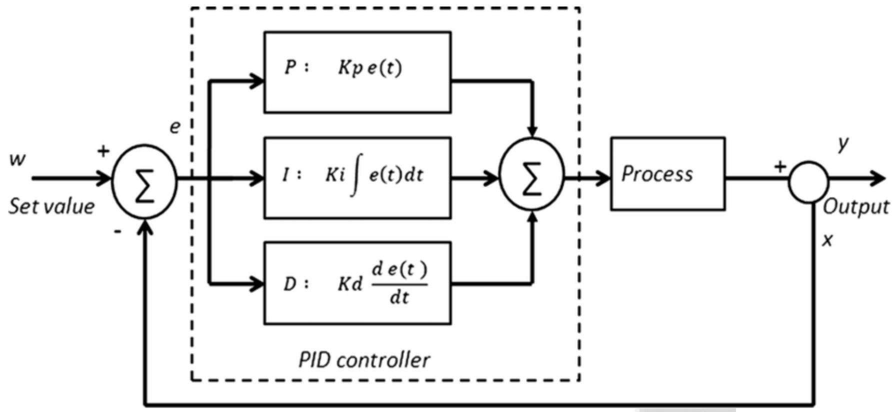


Fig. (5) Shown a control system using the PID-Controller

The basic work of this type of controller can explained by the following equations:

$$m(t) = K_P e(t) + K_I \int_0^t e(t)dt + K_D \frac{d}{dt} e(t) \qquad \longrightarrow \qquad (1)$$

Where m(t) is the output signal of the controller, e(t) is the input signal of the controller (error signal), it is noted that (Kp) is the proportional controller gain, (Ki) is the integrative controller gain, and (Kp) is the controller gain In order to find the transformation function of this controller, we perform the Laplace t transformation of the previous equation No.(2), assuming that all the initial values are equal to zero, resulting in [6]:

$$\frac{M(s)}{E(S)} = K_P + \frac{K_I}{s} + K_D S \qquad \longrightarrow \qquad (2)$$

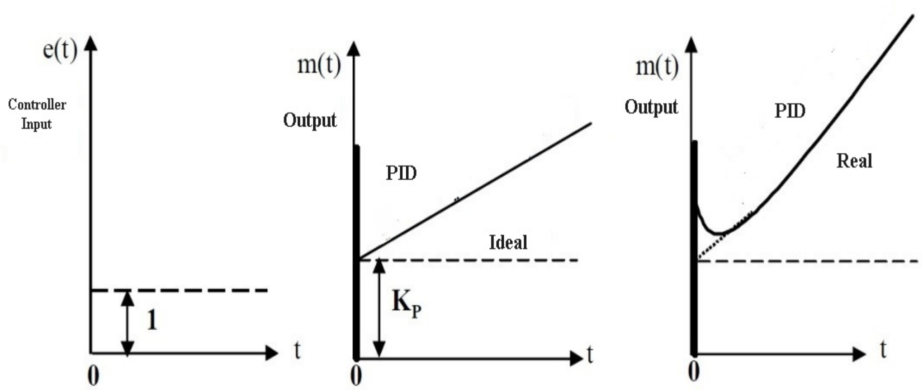


Fig. (6) shows the input and output signals of the PID controller in the case that the input signal is a step function whose value is equal to one (Step=1).

4.1 PID Tuning

Loop tuning is one of the most complex and dangerous control operations, especially direct tuning during operations, and the reason is that there is no fixed law governing the process. If we make a mistake in selecting the appropriate values for the tuning elements (the coefficients of the proportional, integrative, and differential amplifier) the process to be controlled can become unstable and possibly out of control. Instead of obtaining a stable value after a period, there may either be a longer time to obtain this stable value, or it may not stabilize and remain in a state of fluctuation and out of control completely. There are some well-known methods in the approximate tuning process, which usually done by the Manual Mode, the most famous of which are as shown in Table [2].

Table [2] Tuning methods:

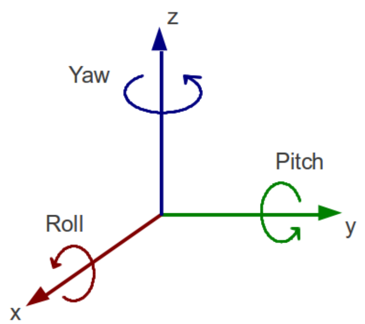
Method	Advantages	Disadvantages
Manual Tuning	Online method	Requires experienced person No math required
Ziegler-Nichols	Proven method. Online method	Process upset, some trial and error, very aggressive tuning. Used only for process control systems
Software tools	Consistent tuning online or offline method may include valve and sensor analysis allow simulation before downloading. Can support non-Steady State (NSS) Tuning.	Some cost and training involved
Cohen-Coon	Good process models	Offline method. Only good for first-order processes.

4.2 PID auto tuning

Auto tuning can eliminate much of the trial and error of a manual tuning approach, especially if you do not have a lot of loop tuning experience. Performing the Auto tuning procedure will get the Tuning Parameters close to their optimal values, but additional manual tuning may be required to get the Tuning Parameters to their optimal values.

5. Stabilization

Once the gyroscope and accelerometer values have converted to angular readings, they assessed to determine the movement received by the user towards the rear end of the spoon. As the accelerometer works in a cylindrical coordinate system, it is important to convert our values to the Cartesian system before applying them to the stabilization process. In the cylindrical system, the roll pitch and yaw calculated by the system considered while converting the values using the equations depicted below.



$$Change\ in\ X = tan^{-1}\left(\frac{accY}{accZ + abs(accX)}\right) \times 360 \times \frac{\pi}{2} \longrightarrow (3)$$

$$Change\ in\ Y = tan^{-1}\left(\frac{accX}{accZ + abs(accY)}\right) \times 360 \times \frac{\pi}{2} \longrightarrow (4)$$

Fig. (7) Movement Angles

Where ***accX***, ***accY*** and ***accZ*** are raw angular values obtained after conversion, from the accelerometer. Once we obtain our final angular readings, we can set our servo motor 'X' and 'Y' accordingly with the respective value + 90° (initial). This will calibrate exactly to its base position at any given instant. We can do this by the given formula [2].

Servo 'X' = 90° + Change in Angle on the X axis
Servo 'Y' = 90° + Change in Angle on the Y axis

6. Block Diagram of Movement Control System.

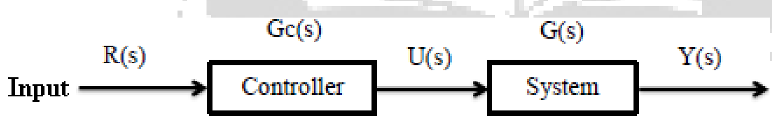


Fig. (8) Block diagram of movement system

7. Block Diagram of Stabilization Control System.

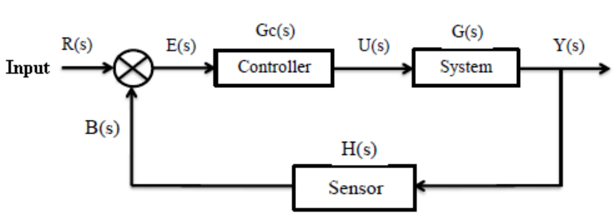


Fig. (9) Block diagram of Stabilizing system

8. Equations of Motion.

There is three equations of motion are fundamental to the derivation of the transfer function. The relationships between torque via current, voltage via angular displacement, and torque via system inertia are used. Torque is proportional to the armature current.

The constant of proportionality called the torque constant and given symbol (K_t). The time and frequency domain relationships given as equations

The back electromotive force (back-emf) V_b is a result of the rotor spinning at right angles in a magnetic field. It is proportional to the shaft velocity. The constant of proportionality called the back-emf constant and given the symbol (K_b). The time and frequency domain relationships given as equations in a table [3].

Torque can written as a relationship that depends on the load attached to the motor shaft. If the load inertial and damping behaviors reflected back to the shaft the result of equivalent inertia coefficient and viscous damping coefficient can used to model the mechanical system attached to the shaft. These equivalents combine the motor and load properties in a model with a single degree of freedom.

Table (3) Servo motor parameters:

• Torque and Current.	$T_m(t) = K_t * I_a(t)$ $T_m(s) = K_t * I_a(s)$
• Angular displacement and Voltage.	$V_b(t) = K_b * \frac{d\theta_m}{d_t}$ $V_b(s) = K_b * s\theta_m(s)$
• Torque, inertia and damping ratio. D_e . Damping ratio J_e . Inertia	$T_m = (J_e * S^2 + D_e * S) * \theta_m$ $G_\theta = \frac{1}{J_e * S^2 + D_e * S}$

9. Block Diagram of Servo Motor

Applying Ohm's law on the electric circuit in figure (10) we can get the current equation for the servo motor [1].

$$I_a = \frac{V_a - V_b}{R_a + s * L_a} = \left(\frac{1}{R_a + s * L_a}\right) * (V_a - V_b) = G_I * (V_a - V_b) \longrightarrow \quad (5)$$

Now we can draw the block diagram of servo motor current equation

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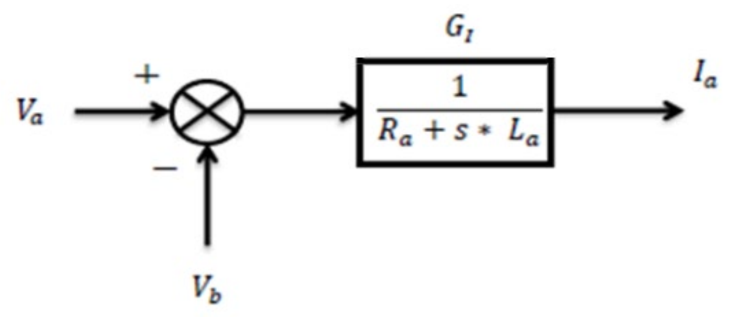

Fig. (11) block diagram of servo motor current equation

Now we can use movement equations in the block diagram to connect between equations

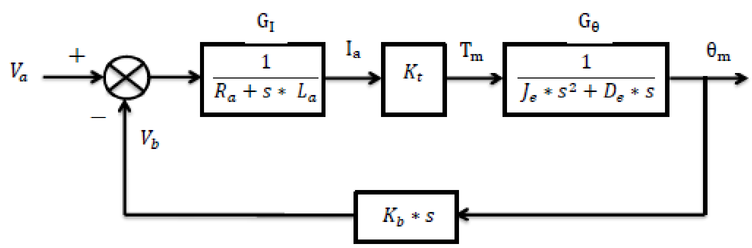

Fig. (12) Block diagram of servomotor

In addition, by simplifying the previous block diagram we get the following.

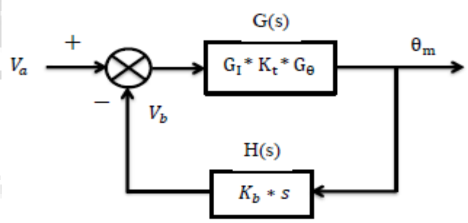

Fig. (13) Simplified servo motor block diagram

Since the transformation function of any system is

$$T(s) = \frac{G(s)}{1 + G(s) * H(s)} \longrightarrow \quad (6)$$

Therefore, the transfer of servomotor is.

$$T(s) = \frac{\theta_m}{V_a} = \frac{G}{1 + G * H} = \frac{G_I + K_t + G_\theta}{1 + (G_I + K_t + G_\theta) * (K_b + s)} \longrightarrow \quad (7)$$

$$\frac{\theta_m}{V_a} = \frac{G_I K_t G_\theta}{1 + (G_I K_t G_\theta)(K_b * s)} \longrightarrow \quad (8)$$

$$G_1 = \frac{1}{R_a + SL_a} \quad , \quad G_\theta = \frac{1}{J_\theta + S^2 + D_\theta * S} \longrightarrow \quad (9)$$

$$\frac{\theta_m}{V_a} = \frac{\frac{K_t}{(R_a+SL_a)(J_e+S^2+D_e*S)}}{1+\frac{K_t K_b\, s}{(R_a+SL_a)(J_e+S^2+D_e*S)}} \longrightarrow \quad (10)$$

$$\frac{\theta_m}{V_a} = \frac{K_t}{(R_a+SL_a)(J_e*S^2+D_e*S)+K_t K_b\, s} \longrightarrow \quad (11)$$

$$\frac{\theta_m}{V_a} = \frac{K_t}{R_a J_e S^2 + L_a J_e S^3 + R_a D_e S + L_a D_e S^2 + K_t K_b\, s} = \frac{K_t}{L_a J_e S^3 + (R_a J_e + L_a D_e)S^2 + (R_a D_e + K_t K_b)\, s} \longrightarrow \quad (12)$$

Table [4] Servo motor parameters

Parameter	**Label**	**Value**
R_a	Armature Resistance	1Ω
L_a	Armature inductance	0.5H
J	Motor Moment of inertia	0.0093kg/m^2
D	Motor Viscosity	0.008 N.m.s
K_b	Motor EMF to speed proportional constant	0.01v/rad/sec
K_t	Motor torque to current proportional constant	0.01N.m/amb

$$T(s) = \frac{\theta_m}{V_a} = \frac{0.01}{0.005S^3 + 0.06S^2 + 0.1S} \longrightarrow \quad (13)$$

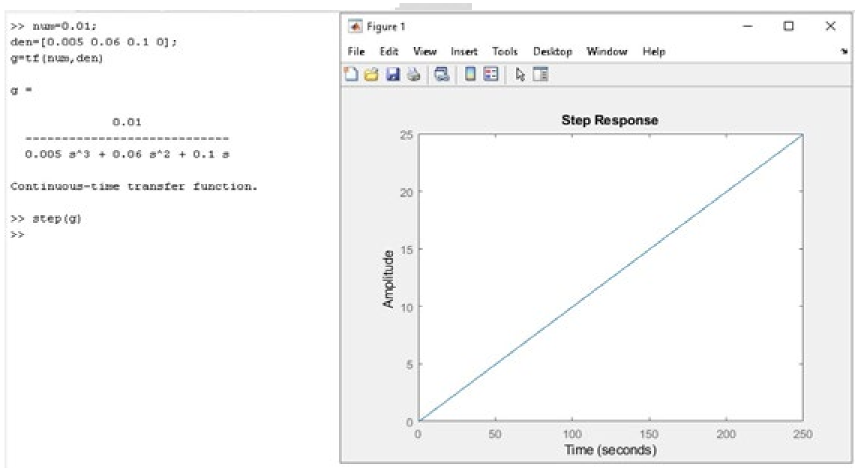

Fig. (14) Step Response without PID

It noted from the response of close loop servomotor without PID controller that there is a positive relationship between the motor voltage and the angle.

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Position control of servo systems is normally unstable when they are implemented in closed loop configuration so PID controller is used to improve the dynamic performance and reduce the steady state error of the systems.

The output of The PID controller (U (t)) given by:

$$U(t) = K_b e(t) + Ki\int e(t) + K_d \frac{d}{dt} e(t). \longrightarrow \quad (14)$$

Where K_p K_i K_d are proportional, Integral and derivative gains and

$e(t) = error = set\ point - output$

The PID output in Frequency domain can be represented as

$$\frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} + K_d S \longrightarrow \quad (15)$$

The closed loop Transfer Function is given by:

$$\frac{Y(s)}{U(s)} = \frac{G(s)}{1+G(s)H(s)} \quad H(s)=1 \longrightarrow \quad (16)$$

Table [5] Comparison of gain response of P, PI and PID controllers

Parameter	Speed of Response	Stability	Accuracy
Increasing K	Increase	Deteriorates	Improves
Increasing Ki	Decrease	Deteriorates	Improves
Increasing Kd	Increase	Improves	No Effect

Table [6] Effects on various O/P parameter of P, PI and PID controller to variation in Rise-Time

Parameter	P Controller	PI Controller	PID Controller
Rise time	Decrease	Decrease	Decrease
Overshoot	Increase	Increase	Decrease
Settling time	Small change	Increase	Decrease
Steady state error	Decrease	Significant change	No change
Stability	good	Worse	If Kd small better

- **PID auto Tuning using MATLAB simulation**
  The proportional controller tested alone, and we found that the rise time was very high which is undesirable as shown in figure (15).

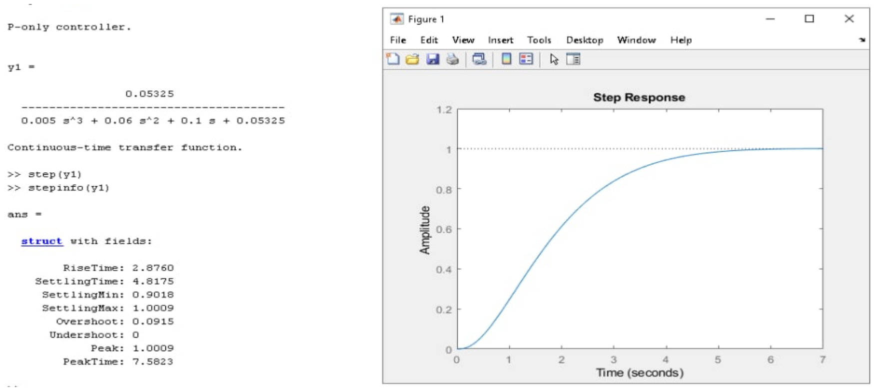

Fig. (15) P Controller response

Then the proportional integral controller was tested we found that the settling time and over shoot were very high which is also undesirable.

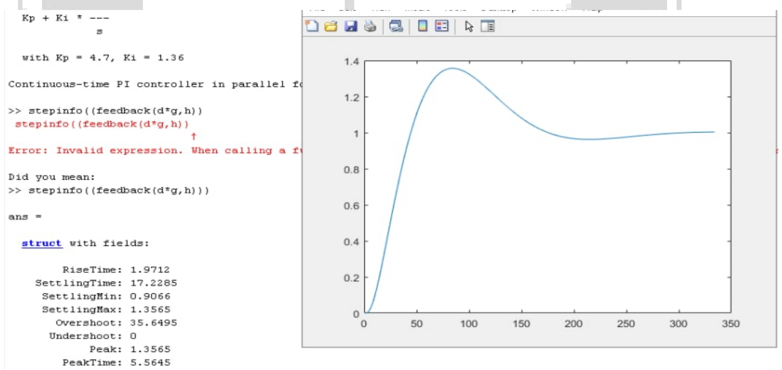

Fig. (16) PI Controller response

When we used PD controller, we found the system settling time and rise time were too high which is not suitable for our system as shown in figure (17a), then we auto tuned PID controller and the system response was acceptable as shown in figure (17b).

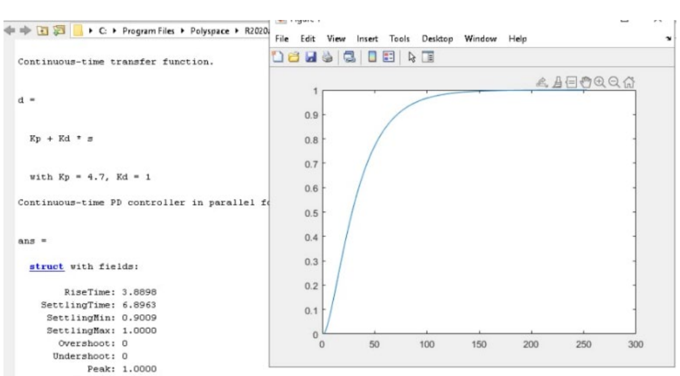

Fig. (17a) PD controller response

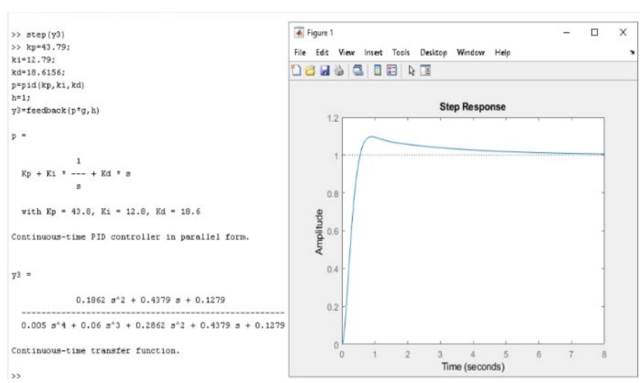

Fig. (17b) Step Response with auto tuned PID parameters

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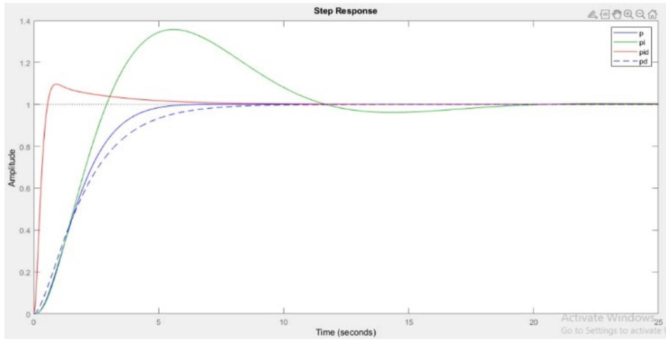

(18) Step Response for (P,PI,PD,PID)

Table [7] Auto tuned PID controller gains.

Discribtion	P	PI	PD	PID
Rise Time	2.87	1.97	3.88	0.8020
Over shoot	0.09	35.64	0	8.233
Settling time	4.81	17.22	6.89	7.46

Table [8] Auto tuned PID controller gains

K_p	K_i	K_d
43.79	**12.79**	**18.62**

The transfer function of closed circle DC-servo motor with auto tuned PID controller is:

$$\frac{U(s)}{Y(s)} = \frac{0.1862S^2 + 0.4379S + 0.1279}{0.005S^4 + 0.06S^3 + 0.2862S^2 + 0.4379S + 0.1279} \longrightarrow \quad (17)$$

According to the Nyquist Stability Criterion encirclement over (-1, 0) and no open-loop poles are in right half plan, so the closed-loop transfer function is stable

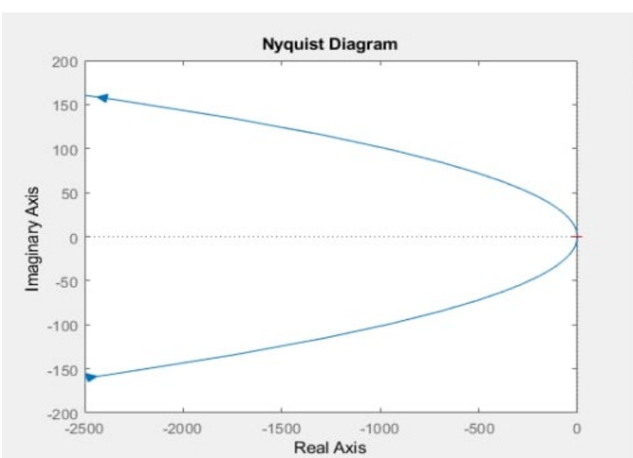

Fig. (19) Nyquist plot

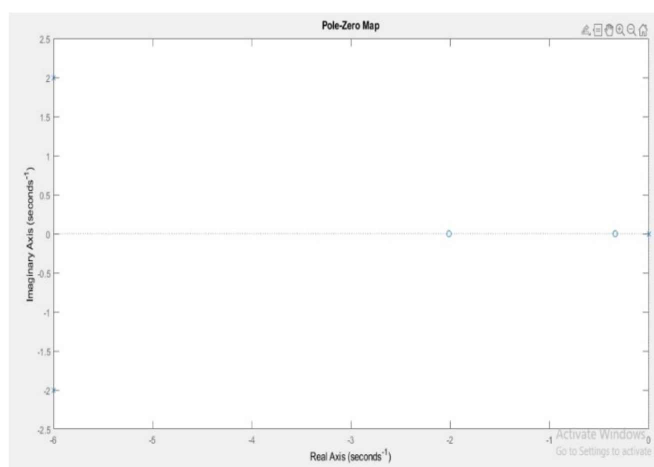

Fig. (20) Pols of open-loop transfer function

10. Model assembly

The beginning of the practical part in this project is to find the appropriate structure to install the electronic parts in it. At the beginning, we collected information about the materials that can be used, but we found that it can be made of various materials, but the weight of the material is primarily taken into account.

So we decided that the plastic is the best material to use in the frame Also the frame must be light weight, easy to handle and easy to hold.

In addition, the shape of the frame must have space to gather all the components of the project, so using a 3D printer to customize the frame will be perfect. Unfortunately, we do not have access to such resources so we tried to borrow a frame from any other ready device and modify it to accomplish the specification of this project as shown in figure (21a, 21b).

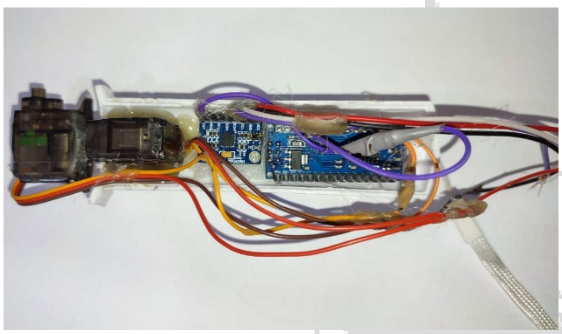

Fig. (21a) Project frame Modification

Fig. (21b) Final Project Shape

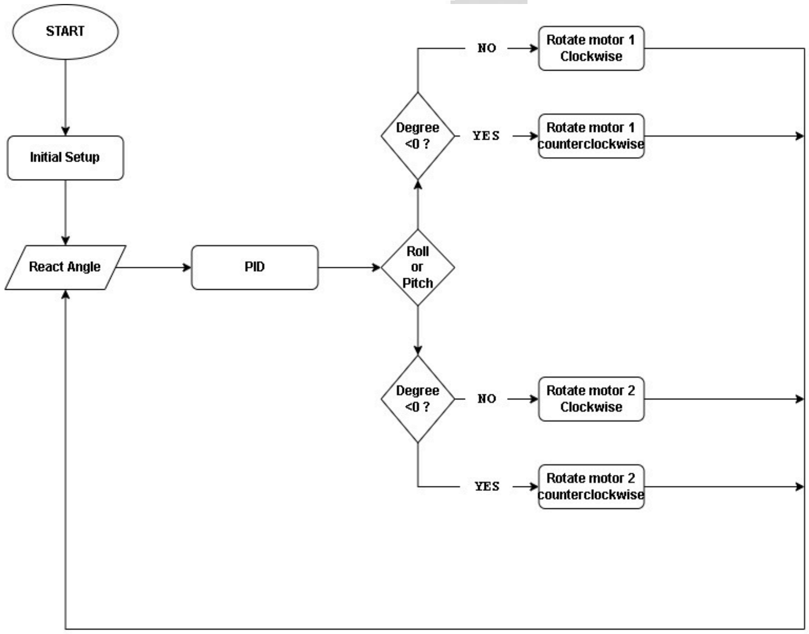

Fig. (22) Data flow diagram

We must know the control system, which shown in the figure (22) as well as the logical sequence of the control process flow, which is represented in the data flow diagram of operations shown in figure above.

11. Testing Stage

We was tested the model and observe its behavior reaction without using a control system, as well as after using the control system. In order to conduct practical experiments, we used a MATLAB program that displays the data as a graph directly on the screen so that we review its reaction to calculate the rise time and settling time. The figures below 23a and 23b explained behavior reaction system with and without control.

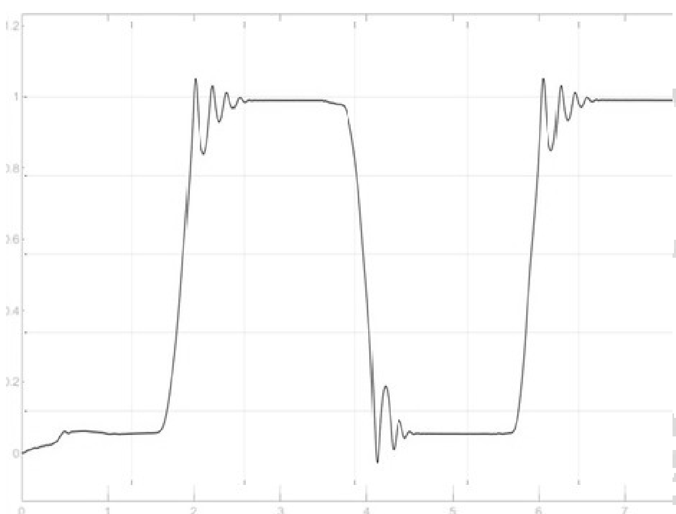

Fig. (23a) without control system

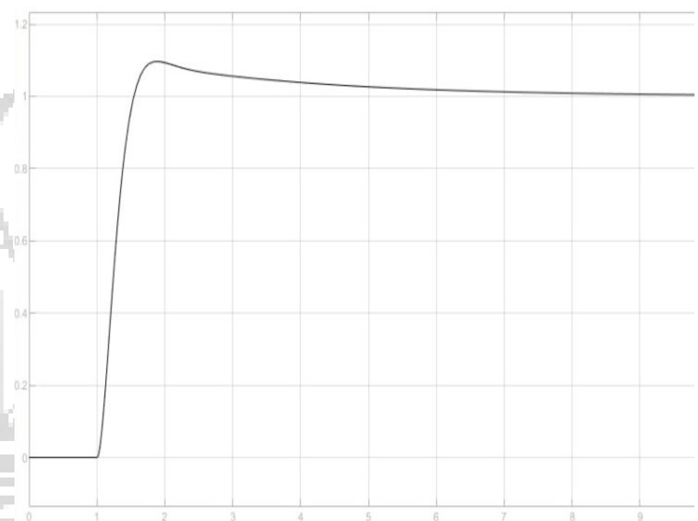

Fig. (23b) with control system

12. Conclusion

The studies concentrate on assisting those with neurological conditions, especially those with Parkinson's disease and essential tremors, with everyday activities, particularly when eating. A tool to steady a spoon or cutlery during trembling eating has been designed to increase independence and freedom. The gadget improves the existing products on the market because it is compact, inexpensive, and placed on a conventional spoon.

As a consequence, we were able to effectively create the mean gadget, which provided us with an excellent and approved reaction. Our study's key conclusions center on how crucial it is to use advanced methods like PID tuning in order to enhance our system. We illustrate the disparities in errors between the aforementioned figures (23a) and (23b) as well as how to minimize errors to obtain the best result.

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