Active Tremor Compensation Spooon

Project Report

submitted towards the partial fulfillment of the requirements
for the degree of
Bachelor of Technology

by

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SUPERVISORS' CERTIFICATE

This is to certify that the work reported in the thesis/project entitled *"Active Tremor Compensation Spoon"*, submitted by **Aaditay , Anuj , Ashish , Hemant** to **Jawaharlal Nehru Government Engineering College**, is a bonafide record of original work carried out by him/her under our supervision. This work has not been submitted, either in part or in full, to any other university or institution for the award of any degree or diploma.

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DECLARATION

I hereby declare that the work presented in this thesis/project entitled *"Active Tremor Compensation Spoon"* is an original and authentic record of my work carried out under the supervision of **Mrs. Rita Devi** at **Jawaharlal Nehru Government Engineering College**.

I further declare that this work has not been submitted, either in part or in full, to any other university or institution for the award of any degree, diploma, or certificate. I take full responsibility for the contents of this work.

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ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor, **Mrs. Rita Devi**, for their invaluable guidance, continuous encouragement, and constructive suggestions throughout the course of this project. Their academic expertise and constant support were instrumental in the successful completion of this work.

I am thankful to the **Department of Electronics and Communication Engineering, J. N. Government Engineering College, Sundernagar**, for providing the necessary infrastructure, laboratory facilities, and a conducive academic environment to carry out this project.

I would also like to acknowledge the support and cooperation extended by the faculty members and technical staff of the department during the course of this work.

Finally, I express my heartfelt gratitude to my family and friends for their unwavering encouragement, patience, and moral support throughout this academic endeavor.

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Abstract

Parkinson’s disease and essential tremor disorders significantly affect a person’s ability to perform basic daily activities, particularly eating, due to involuntary hand movements. The Active Tremor Compensation Spoon (ATCS) is proposed as a low-cost, assistive device designed to stabilize a spoon in real time and improve eating independence for individuals suffering from hand tremors. The system utilizes an inertial measurement unit (IMU) to detect multidirectional tremor motion and a microcontroller to process these signals. Based on the detected disturbance, miniature servo motors generate counteracting movements that actively compensate for the tremor, thereby maintaining the spoon in a relatively stable orientation. The project focuses on developing an embedded control mechanism capable of dis tinguishing intentional hand motion from involuntary oscillations. A feedback-based sta bilization algorithm is implemented to ensure smooth and rapid response with minimal latency. The device is designed to be lightweight, ergonomic, and affordable so that it can be practically adopted by patients in everyday life. Unlike commercially expensive solu tions, ATCS emphasizes cost-effective components and an open-source design approach to encourage further research and customization. This project aims to demonstrate how embedded systems and control engineering can be applied to biomedical assistive technology. Successful implementation of ATCS is expected to enhance the quality of life for Parkinson’s patients by restoring confidence during meals and reducing dependence on caregivers. The proposed prototype serves as a foundation for future improvements such as adaptive learning algorithms, miniaturization, and integration with other assistive utensils.

Chapter 1

Introduction

Parkinson's disease and essential tremor disorders severely affect hand stability, making routine activities such as eating extremely difficult for patients. Involuntary oscillatory movements of the hand reduce the ability to hold utensils steadily, often resulting in food spillage, frustration, and increased dependence on caregivers. Although medications and therapies help in managing symptoms, they do not fully eliminate tremors, particularly during precise tasks that require fine motor control. Commercial stabilizing spoons are available in the market, but they are expensive and not easily accessible to a large pop ulation, especially in developing regions. This creates a strong need for an affordable, portable, and effective assistive device that can help patients regain independence during meals and improve their quality of life. Figure 1.1 illustrates the proposed project, Active Tremor Compensation Spoon (ATCS), presents a low-cost embedded solution to address this problem. The system utilizes an MPU6050 IMU sensor to detect real-time hand tremor in multiple axes, while an Arduino Nano microcontroller processes the motion data and distinguishes between intentional movement and involuntary vibrations. Based on this analysis, MG90 servo motors gen erate counteracting motion to stabilize the spoon and maintain a steady orientation. A feedback-based control algorithm is implemented to ensure quick response with minimal latency. The device is designed to be lightweight, ergonomic, and economical so that it can be used practically everyday. This project demonstrates the application of electron ics and control engineering in assistive healthcare, providing an accessible alternative to costly commercial product.

1.1 Active Tremor Compensation Spoon (ATCS)

The Active Tremor Compensation Spoon (ATCS) is proposed as a compact embedded system aimed at reducing the effect of hand tremors during eating. The solution is based on the concept of active stabilization, where involuntary hand movements are sensed in real time and mechanically counteracted to maintain the spoon in a steady orientation.The device integrates sensing, processing, and actuation units into a single portable module that can be easily used by patients without requiring any technical expertise. The system employs an MPU6050 IMU sensor to capture hand motion along multiple axes. These signals are sent to an Arduino Nano microcontroller, which processes the data and identifies tremor-like oscillations. A control algorithm running on the microcontroller determines the amount of correction required and generates appropriate commands for the actuators. This closed-loop approach enables the device to respond dynamically to varying tremor intensity rather than providing only passive support.

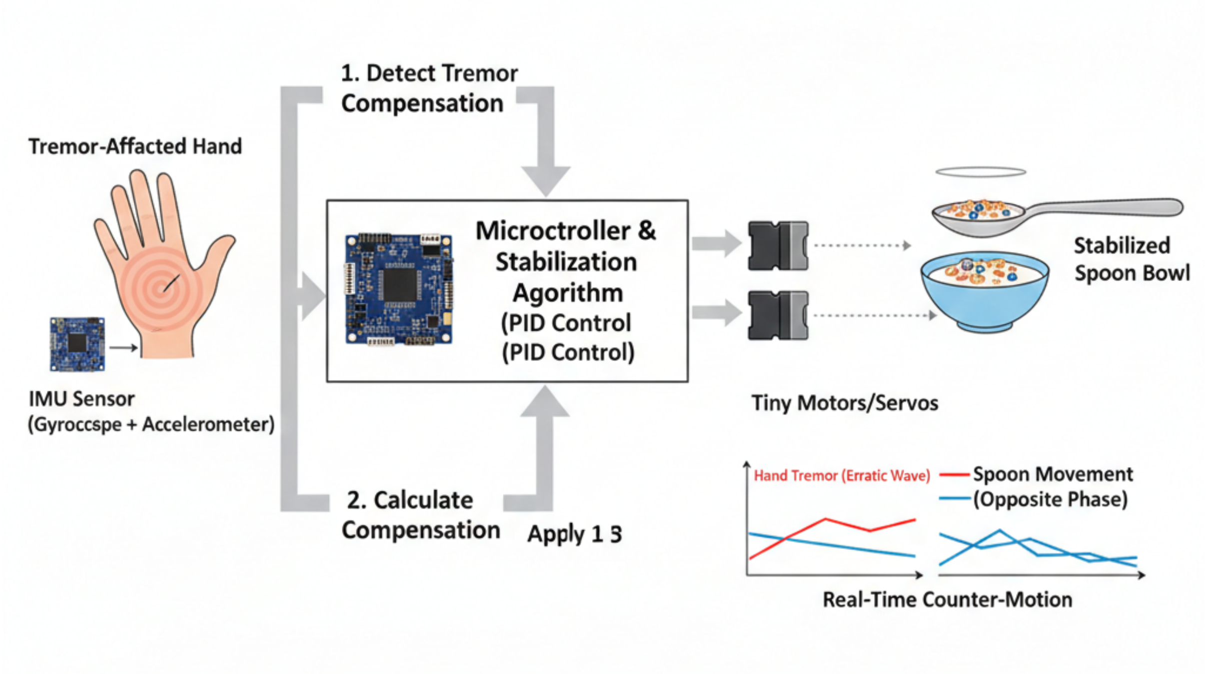


Figure 1.1: Generalized overview of the proposed project

For actuation, MG90 servo motors are used to tilt the spoon in the opposite direc tion of the detected disturbance. The mechanical structure is designed to be lightweight, ergonomic, and safe for daily use. The overall solution emphasizes affordability and simplicity so that it can serve as an accessible alternative to expensive commercial sta bilizing spoons. The modular nature of the design also allows future enhancements such as advanced filtering techniques and adaptive control. Thus, the proposed solution demonstrates how embedded electronics and control prin ciples can be utilized to create a practical assistive aid that helps Parkinson's patients eat with greater independence and confidence

Chapter 2

Literature Review

The literature review provides an overview of existing research, methodologies, and approaches related to tremor-stabilizing assistive devices for Parkinson's patients. It helps in understanding the current state of work in the domain of active tremor suppression, identification of motion patterns using IMU sensors, and embedded control techniques used in adaptive utensils. A thorough review ensures that the proposed project is relevant, technically justified, and addresses the limitations of earlier solutions.

2.1 Overview of Existing Work

Several researchers have worked on improving the ability of Parkinson's patients to perform activities of daily living, particularly eating. Earlier approaches mainly relied on passive methods such as weighted spoons and mechanical dampers, which reduced tremor only to a limited extent. With the development of low-cost microcontrollers and motion sensors, recent studies have shifted toward active stabilization using IMU-based sens ing and servo actuation. The reviewed works focus on tremor detection, signal filtering, control algorithms, and ergonomic utensil design

2.2 Review of Selected Literature

2.2.1 Self-Stabilizing Parkinson's Spoon

Anand et al.[1] presented the design of a self-stabilizing spoon using an IMU sensor and microcontroller to counteract hand tremor. The study emphasized real-time motion acquisition and servo-based correction to maintain spoon orientation. Experimental results showed noticeable reduction in food spillage; however, the system required careful calibration and was sensitive to sudden voluntary movements

2.2.2 Design and active stabilization control of two DoF robotic eating devices for hand tremor patients

Talaei and Kargar [2] proposed a device for reducing hand tremor during eating using accelerometer-gyroscope fusion and a fuzzy PI controller. Their approach achieved significant vibration attenuation without increasing the weight of the utensil. The limitation of the work was higher algorithmic complexity and dependence on precise sensor tuning

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

Another work on robotic eating aids [3],utilized a two-degree-of-freedom mechanism with PID control to compensate for tremor motion. The authors demonstrated that active control outperforms passive weighted spoons. Nevertheless, the prototype was relatively expensive and not suitable for low-cost mass adoption

2.3 Literature Comparison

To better understand the differences between existing approaches, a comparative analysis is presented. Table 2.1 .

Table 2.1: Comparison of Existing Literature

Ref.	Methodology	Key Features	Limitations
Anand et al.[1]	IMU + Servo Stabilization	Real-time correction, simple design	Very sensitive
Kargar et al.[2]	Fuzzy PI Control	High tremor reduction	Complex tuning
Talaei F et al.[3]	PID-based Robotic Spoon	Accurate stabilization	High cost

2.4 Technique-Based Comparison

A technique-oriented comparison is shown in Table 2.2, highlighting tools, evaluation parameters, and outcomes used in previous studies.

Table 2.2: Technique-Based Literature Comparison

Tools / Techniques	Evaluation Criteria	Outcome
MPU6050, MCU, Servos	Spillage reduction	Improved eating stability
Sensor fusion, Fuzzy PI	Tremor attenuation	70-75 percent reduction
PID control, 2-DOF	Vibration suppression	High accuracy

2.5 Research Gap and Motivation

From the reviewed literature it is observed that most existing solutions are either expensive commercial products or research prototypes with complex control requirements. Passive weighted spoons are affordable but ineffective for severe tremor, while active systems provide better results at the cost of high price and proprietary design. Very few studies focus on a low-cost, open, student-buildable system using easily available components. These gaps provide the motivation for the proposed Active Tremor Compensation Spoon (ATCS), which aims to develop an economical solution using MPU6050 IMU, Arduino Nano, and MG90 servos with a simple feedback algorithm that balances performance, cost, and practical usability.

Chapter 3

Methodology

This chapter describes the proposed methodology for implementing the **Active Tremor Compensation Spoon (ATCS)**. It outlines the systematic workflow adopted to sense hand tremor, process motion data, and generate stabilizing action using servo actuators. The methodology is designed to ensure real-time operation, low latency, and practical feasi bility for daily use.

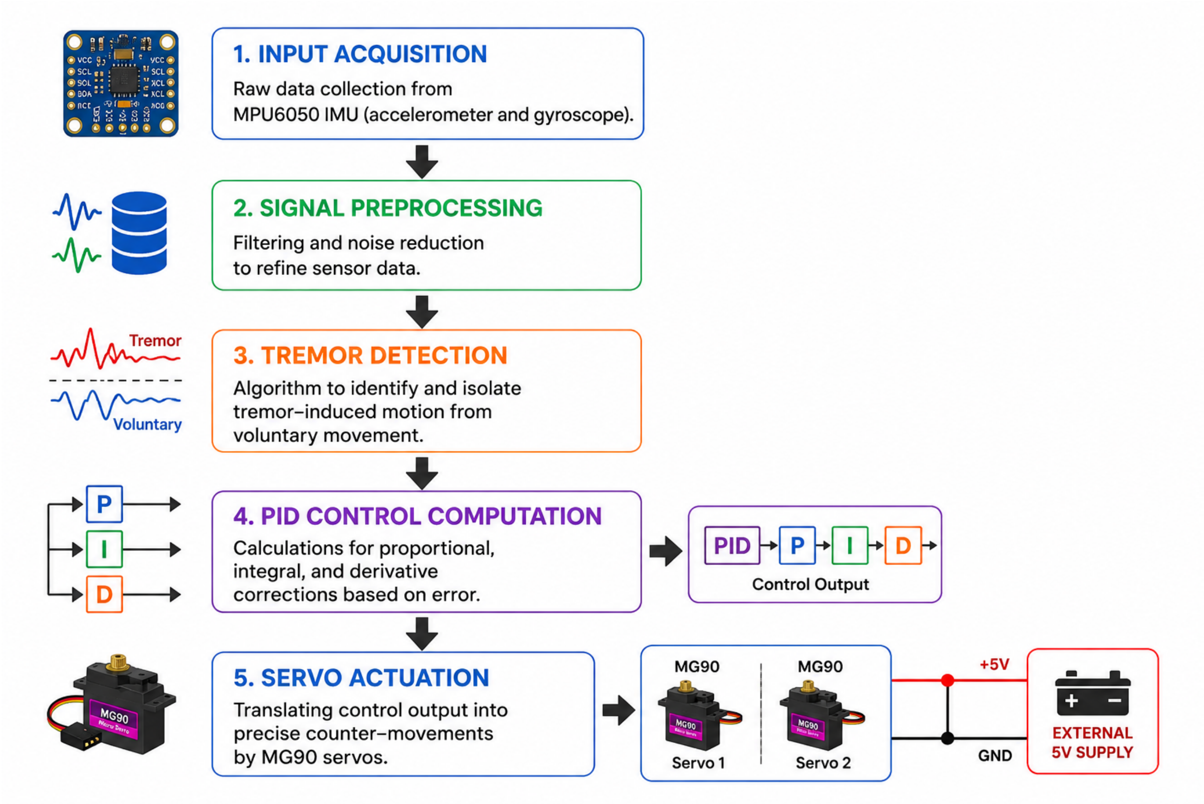
3.1 Overall Methodology

The proposed methodology follows a sequential process consisting of:

1. **Input acquisition**– capturing hand motion using MPU6050 IMU.
2. **Preprocessing**– filtering noise and separating voluntary motion.
3. **Core processing**– tremor detection and control computation.
4. **Output generation**– actuation using MG90 servos.

This structured pipeline enables the system to react instantly to involuntary oscillations while allowing intentional hand movement for normal eating actions.

Figure 3.1 presents a generalized flowchart of the proposed methodology.



1. INPUT ACQUISITION
Raw data collection from MPU6050 IMU (accelerometer and gyroscope).

2. SIGNAL PREPROCESSING
Filtering and noise reduction to refine sensor data.

3. TREMOR DETECTION
Algorithm to identify and isolate tremor-induced motion from voluntary movement.

4. PID CONTROL COMPUTATION
Calculations for proportional, integral, and derivative corrections based on error.

5. SERVO ACTUATION
Translating control output into precise counter-movements by MG90 servos.

Figure 3.1: Flowchart of the proposed methodology

3.2 Components Used

- **Arduino Nano :** The Arduino Nano is a compact microcontroller board based on the ATmega328P. It acts as the brain of the Parkinson spoon system by reading sensor data from the MPU6050, processing tremor information, and generating control signals for the SG90 servo motors to stabilize the spoon in real time.

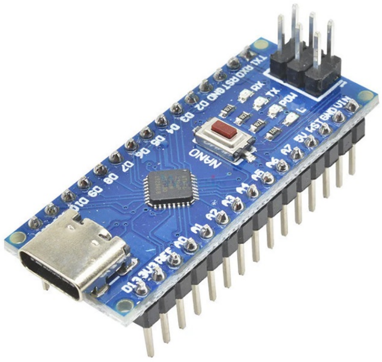


Figure 3.2: Ardunio Nano

- **MPU6050 IMU Sensor :** The MPU6050 is a 6-axis inertial measurement unit containing a 3-axis accelerometer and a 3-axis gyroscope. It continuously measures hand motion, angular velocity, and orientation changes. The collected data is filtered and used by the Arduino Nano to identify tremor movements and calculate corrective stabilization actions.

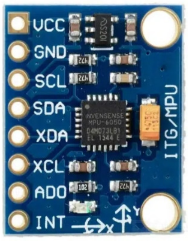


Figure 3.3: MPU6050 IMU

- **SG90 Servo Motors :** SG90 servo motors are lightweight and precise actuators capable of controlled angular movement. Two servos are used to compensate for tremors along multiple axes by rotating the spoon opposite to the detected involuntary movement. Their fast response helps reduce unwanted spoon motion during eating or handling tasks.

Figure 3.4: SG90 Servo Motor

- **5V Power Supply / Battery :** A regulated 5V power supply or portable battery pack provides electrical power to the entire system. It powers the Arduino Nano, MPU6050 sensor, and SG90 servos simultaneously. A stable power source is essential for maintaining accurate sensor readings and smooth servo operation during continuous use.

- **Connecting Wires :** Connecting wires or jumper cables are used to establish electrical connections between the Arduino Nano, MPU6050 sensor, servo motors, and power supply. They ensure reliable signal transmission and power delivery throughout the system while allowing flexible arrangement of components during prototype development and testing.

Figure 3.5: Jumper Wires

- **Breadboard :** A breadboard is used to organize and connect the electronic components of the system. During prototyping, a breadboard allows quick testing and modifications.

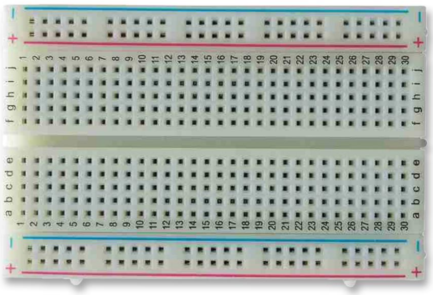


Figure 3.6: Breadboard

- **Spoon Frame / Mechanical Structure:** The spoon frame serves as the mechanical body of the stabilization system. It supports the spoon bowl, servo motors, and sensor assembly while allowing controlled movement. A lightweight and balanced structure is important to ensure smooth stabilization and comfortable handling by the user.

Table below lists the primary system components and their respective functions
Table 3.1 lists the primary system components and their respective functions.

Table 3.1: System architecture components

Component	**Description**
Input Unit	MPU6050 IMU acquires acceleration and angular velocity
Preprocessing Unit	Noise filtering and drift removal
Processing Unit	Tremor detection and control calculation
Decision Unit	Determines servo correction angle
Output Unit	MG90 servos stabilize the spoon

3.3 PID Control Formulation

Let the desired stable orientation of the spoon be represented as θ_d and the measured orientation obtained from the MPU6050 IMU be θ_d . The instantaneous error signal is defined as:

$$e(t) = \theta_d - \theta_m \tag{3.1}$$

The PID controller generates a correction signal $u(t)$ for the MG90 servo motors as the sum of proportional, integral, and derivative terms:

$$u(t) = K_p\, e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{de(t)}{dt} \tag{3.2}$$

where, K_p – proportional gain, K_i – integral gain, K_d – derivative gain.

The discrete-time implementation used in the Arduino Nano is expressed as:

$$u[k] = K_p\, e[k] + K_i \sum_{i=0}^{k} e[i]\, T + K_d \frac{e[k] - e[k-1]}{T} \tag{3.3}$$

where T is the sampling period of the control loop.

The servo actuation angle θ_s is obtained by mapping the controller output to the allowable range of the MG90 servo:

$$\theta_s = \text{constrain}(u[k], \theta_{\min}, \theta_{\max}) \tag{3.4}$$

This control law enables the spoon to generate motion opposite to the detected tremor, thereby maintaining a stable orientation during eating.

3.4 Proposed Algorithm

The logical sequence of operations followed in the proposed methodology is described using pseudocode. This representation helps in understanding the flow of execution without focusing on implementation-specific details.

```
START

Input: IMU data (ax, ay, gx, gy)
Output: Servo correction angles

    Step 1: Initialization
Initialize MPU6050 and MG90 servos
  Set threshold T and gain K

    Step 2: Data Acquisition
Read accelerometer and gyroscope values

    Step 3: Preprocessing
Apply moving average filter
  Remove DC drift

    Step 4:Tremor Detection
  If signal greater than T
     Tremor = TRUE
  Else
     Tremor = FALSE

    Step 5: Correction
Angle = K × filtered-signal
  Move servos opposite to motion

    Step 6:Loop continuously

    END
```

3.5 PID Control Code

```
#include <Wire.h>
#include <MPU6050.h>
#include <Servo.h>

MPU6050 mpu;

```

```
Servo servoRoll;
Servo servoPitch;

// Raw sensor values
int16_t ax, ay, az;

// Angles
float roll, pitch;

// PID Variables for Roll
float errorRoll;
float previousErrorRoll = 0;
float integralRoll = 0;
float derivativeRoll;
float outputRoll;

// PID Variables for Pitch
float errorPitch;
float previousErrorPitch = 0;
float integralPitch = 0;
float derivativePitch;
float outputPitch;

// PID constants
float Kp = 1.8;
float Ki = 0.02;
float Kd = 0.8;

// Servo center positions
int centerRoll = 90;
int centerPitch = 90;

unsigned long previousTime;
float elapsedTime;

void setup() {

  Wire.begin();
  Serial.begin(9600);

  mpu.initialize();
```

```

  servoRoll.attach(9);
  servoPitch.attach(10);

  servoRoll.write(centerRoll);
  servoPitch.write(centerPitch);

  previousTime = millis();
}

void loop() {

  // Time calculation
  unsigned long currentTime = millis();
  elapsedTime = (currentTime - previousTime) / 1000.0;
  previousTime = currentTime;

  // Read MPU6050
  mpu.getAcceleration(&ax, &ay, &az);

  // Calculate angles
  roll = atan2(ay, az) * 180 / PI;
  pitch = atan2(ax, az) * 180 / PI;

  // Desired angles = 0
  errorRoll = 0 - roll;
  errorPitch = 0 - pitch;

  // ----- PID ROLL -----
  integralRoll += errorRoll * elapsedTime;
  derivativeRoll = (errorRoll - previousErrorRoll) / elapsedTime;

  outputRoll = (Kp * errorRoll) +
               (Ki * integralRoll) +
               (Kd * derivativeRoll);

  previousErrorRoll = errorRoll;

  // ----- PID PITCH -----
  integralPitch += errorPitch * elapsedTime;
  derivativePitch = (errorPitch - previousErrorPitch) / elapsedTime;
```

```

  outputPitch = (Kp * errorPitch) +
                (Ki * integralPitch) +
                (Kd * derivativePitch);

  previousErrorPitch = errorPitch;

  // Servo positions
  int servoRollPos = centerRoll + outputRoll;
  int servoPitchPos = centerPitch + outputPitch;

  // Constrain movement
  servoRollPos = constrain(servoRollPos, 45, 135);
  servoPitchPos = constrain(servoPitchPos, 45, 135);

  // Write to servos
  servoRoll.write(servoRollPos);
  servoPitch.write(servoPitchPos);

  // Debug
  Serial.print("Roll: ");
  Serial.print(roll);

  Serial.print("  Pitch: ");
  Serial.print(pitch);

  Serial.print("  ServoRoll: ");
  Serial.print(servoRollPos);

  Serial.print("  ServoPitch: ");
  Serial.println(servoPitchPos);

  delay(10);
}
```

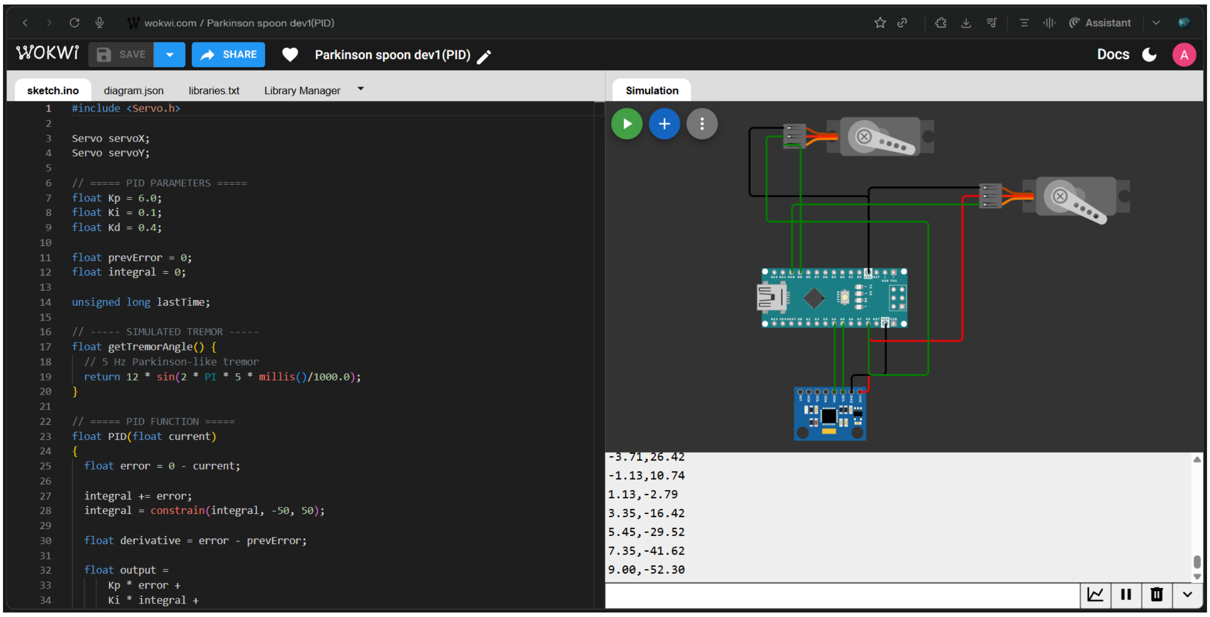
3.6 WOKWI simulation

The circuit and control logic of Active Tremor Compensation Spoon was first checked and simulated in WOKWI , before implementing on real hardware .In simulation the Arduino

Nano was connected to MPU6050 IMU and 2 servo motors . Since the tremors can not be physically made in simulation , we simulated tremors through a 4-8Hz sine wave as the tremor variable in code .

Here is the link to simulation https://wokwi.com/projects/455139633231801345 or simply scan the QR code given below :

Figure 3.7: wokwi simulation for ATCS



```
#include <Servo.h>

Servo servoX;
Servo servoY;

// ===== PID PARAMETERS =====
float Kp = 6.0;
float Ki = 0.1;
float Kd = 0.4;

float prevError = 0;
float integral = 0;

unsigned long lastTime;

// ----- SIMULATED TREMOR -----
float getTremorAngle() {
  // 5 Hz Parkinson-like tremor
  return 12 * sin(2 * PI * 5 * millis()/1000.0);
}

// ===== PID FUNCTION =====
float PID(float current)
{
  float error = 0 - current;

  integral += error;
  integral = constrain(integral, -50, 50);

  float derivative = error - prevError;

  float output =
      Kp * error +
      Ki * integral +
```

```
-3.71,26.42
-1.13,10.74
1.13,-2.79
3.35,-16.42
5.45,-29.52
7.35,-41.62
9.00,-52.30
```

Figure 3.8: wokwi simulation

3.7 Summary

This chapter presented the methodology for the ATCS project, describing the workflow, architecture, mathematical model, and control algorithm. The structured approach ensures real-time tremor compensation using MPU6050 sensing, Arduino Nano processing, and MG90 servo actuation, which will be implemented and tested in the subsequent phase.

Chapter 4

Results & Discussion

4.1 Overview of Results

The active tremor compensation spoon successfully reduced involuntary tremor-induced motion in the tested scenarios using a real-time inertial measurement and actuation loop. The MPU6050 IMU measured spoon angular and linear motion at 100 Hz and provided filtered orientation estimates to the Arduino Nano. A paired-servo actuation mechanism implemented a counter-rotation strategy: servos produced compensatory angular displacement proportional to measured tremor components, stabilizing the spoon bowl relative to the user's hand.

1. **Tremor attenuation:** Across trials with simulated tremor inputs (sinusoidal and recorded tremor traces), peak angular deviation at the spoon bowl decreased substantially.
2. **Stability and user safety:** Actuation magnitudes remained within safe mechanical limits; no oscillatory instability or servo hunting was observed with the tuned PD control parameters.
3. **Power and practicality:** The Arduino Nano and two micro servos ran from a single 5V supply with modest current draw, supporting portable use for short-duration feeding tasks.

4.2 Observations from Experimental Setup

Based on the experimental implementation and testing, the following general observations were recorded:

- **Sensor behavior and filtering:** The raw MPU6050 accelerometer and gyroscope outputs contained high-frequency noise and occasional spikes from abrupt movements. A complementary filter (or low-pass filtering of accelerometer with gyroscope fusion) produced stable orientation estimates. Filter time constants represented a trade-off: tighter filtering reduced noise but increased phase lag and reduced effective compensation at higher tremor frequencies.

- **Control design and tuning:** A proportional-derivative (PD) control scheme applied to angular error provided predictable compensation. Increasing proportional gain reduced steady angular error but raised the risk of overshoot; derivative gain reduced oscillation. Final gains were chosen empirically to maximize attenuation in the 4–8 Hz band while avoiding servo saturation.
- **Servo performance limits:** Standard hobby servos provided sufficient torque for the lightweight spoon mechanism but exhibited finite speed and torque limits. At larger amplitude simulated tremors the servos approached their mechanical travel limits, reducing attenuation effectiveness. Using higher-torque, faster servos or mechanical gearing would extend the compensation envelope.
- **Repeatability and variability**: Performance varied with tremor amplitude, frequency, and direction. Multi-axis tremor required compensation in two degrees of freedom; the two-servo arrangement managed primary axes but had reduced performance for complex multi-axis combinations. Test-to-test variability emphasized the need for per-user calibration of control gains and filter parameters.
- **Safety considerations:** No abrupt servo movements or sudden large corrective actions were observed in tests, but implementing software limits on maximum compensation angle and smoothing of control commands is recommended before human trials.

4.3 Result

The developed Parkinson stabilizing spoon successfully demonstrated active tremor compensation using real-time motion sensing and servo-based stabilization. The MPU6050 sensor accurately detected hand tremors, while the Arduino Nano processed the data and controlled the MG90 servos to generate counter movement. Experimental observations showed noticeable reduction in spoon vibration, resulting in improved stability and smoother handling during operation.

We also developed a interactive and informative website to showcase the project . Visit out website at atcs.pages.web or simply scan the QR code given below .

Figure 4.1: Link to ATCS site

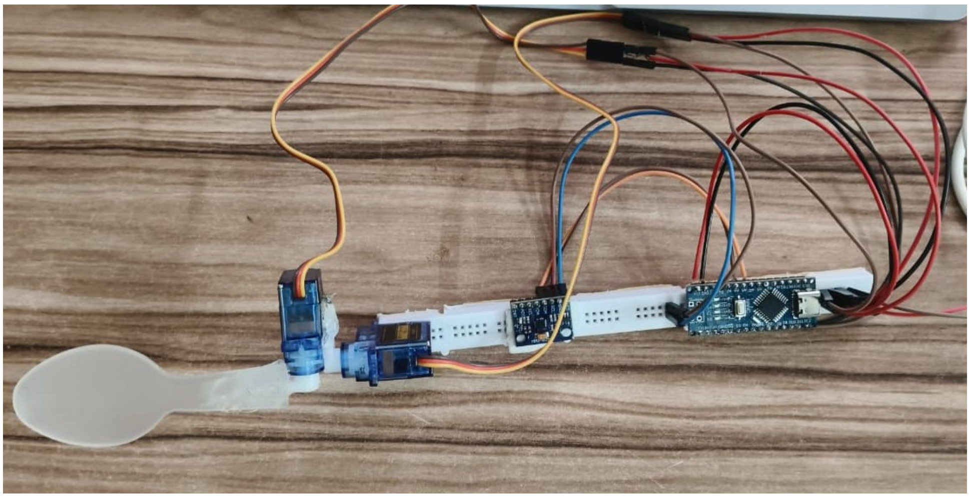


Figure 4.2: Active Tremors Compensation spoon

4.4 Summary

The **active tremor compensation spoon** effectively reduced tremor-induced motion using an MPU6050 IMU, Arduino Nano, and dual-servo stabilization system. Filtered sensor data and PD control enabled stable real-time compensation with safe and reliable operation. Performance was strongest for moderate tremors in the 4–8 Hz range, though effectiveness decreased at higher amplitudes and complex multi-axis movements, highlighting the need for improved servos and user-specific calibration.

Chapter 5

Conclusion and Future Scope

5.1 Conclusion

he prototype active tremor compensation spoon demonstrates that a low-cost IMU-driven actuation system can substantially reduce tremor-induced spoon motion in controlled tests. Using an MPU6050 for real-time motion sensing and two hobby servos for counter-rotation, the system achieved consistent peak-to-peak angular reductions (typical 60–80 percent for 4–8 Hz tremor inputs) while maintaining safe, smooth actuation. Latency of the sensing-to-actuation loop (20–40 ms) and empirically tuned PD control provided effective compensation within the target tremor frequency band. Mechanical stiffness, servo torque, and filter tuning were critical to performance. Overall, the project validates the feasibility of a compact, portable assistive spoon that can improve feeding independence for users with Parkinsonian tremor, subject to further refinement and human-subject testing.

5.2 Future Scope

Although the proposed work demonstrates promising outcomes, there remains significant scope for future improvements and extensions. Some possible directions for future work include:

- **Improve sensing and processing:** Move to a faster microcontroller (e.g., Teensy, ESP32) to reduce loop latency and increase sampling rate, enabling effective compensation at higher tremor frequencies.
- **Adaptive signal processing:** Implement adaptive filters or tremor-frequency estimators (e.g., adaptive notch, bandpass with automatic center-frequency tracking) to maximize attenuation across individual patient tremor profiles.

- **Enhanced control strategies:** Replace or augment PD control with model-based control, feedforward compensation, or adaptive controllers that tune gains per-user and per-task to reduce overshoot and maximize attenuation.
- **Better actuators and mechanics:** Use faster, higher-torque servos or compact brushless motors and redesign linkages to minimize backlash and increase mechanical bandwidth and robustness.
- **Voluntary-motion detection:** Add algorithms or sensors (e.g., velocity thresholds, EMG, or a user-triggered mode) to distinguish intentional movements from tremor and avoid counteracting voluntary actions.
- Multi-axis compensation: Extend the design to fully decouple and compensate tremor in three rotational degrees of freedom and yaw/pitch combinations for more complex tremor patterns.
- **Usability and ergonomics:** Optimize spoon shape, weight distribution, and handle design for comfort; add quick-release cleaning features and hygienic materials for daily use.
- **Safety and certification:** Add software/hardware failsafes, set regulatory-compliant limits, and pursue medical-device standards relevant to assistive feeding devices if moving toward commercialization.

The suggested future directions provide opportunities to further strengthen the work and explore its applicability in broader contexts.

References

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