参赛队员姓名：Susie Meng Di Yuan

中学：Dulwich College Beijing

省份：Beijing

国家/地区：China

指导教师姓名：Dominic Williams

指导教师单位：Dulwich College Beijing

论文题目：Tableware Jitter Elimination Technology for Parkinson's Patients

# Tableware Jitter Elimination Technology for Parkinson's Patients

By Susie Meng Di Yuan

## Abstract

The neurological condition of Parkinson's disease causes involuntary shaking of the hands and body, leading to frustration with eating. Current tableware with jitter elimination technology on the market is extremely expensive, such as Gyenno Spoon, 299 USD, and Liftware Steady, 195 USD. They also cannot complete the detection and diagnosis of patients' conditions. Through engineering design and technological innovation, this project developed a low-cost jitter elimination technology that is applied to IoT and minimizes the impact of tremors during eating. It uses artificial intelligence to adapt tableware to various jitter records of the patient's condition and provides a diagnosis. The prototype uses the ESP32 development board as the main control, an MPU6050 gyroscope for motion attitude detection, and a MacBook as the server. The system completes the information transmission between the prototype and the server through the MQTT protocol. It can store the data in the cloud, use the PID algorithm for motion control, and use an AI model to diagnose the disease according to the data stored in the server. A 54% decrease in food spilled using the technology was shown, and medical experts on Parkinson's disease also look forward to the product. Additionally, it only costs about 5% of Gyenno Spoon and 7% of Liftware Steady. This technology demonstrates the potential of computerized motor control and artificial intelligence in the medical field, providing new solutions to problems in specific groups.

**Keywords:** Parkinson's Disease, Jitter Elimination Technology, Low-Cost Solution, IoT, AI

# Table of Contents

# 1 Introduction

## 1.1 Background

Parkinson's disease, named after James Parkinson, is a neurodegenerative disorder that primarily affects the central nervous system, particularly the movement control centers of the brain. [1] Pathological symptoms of Parkinson's disease include tremors, bradykinesia, rigidity, stiffness, postural instability, and impaired balance. [2] The prevalence of PD is approximately 1-2 per 1000 of the population worldwide, affecting 1% of the population above 60 years. [3] Simple tasks like dressing, eating, writing, or walking may require extra time and effort. Moreover, PD patients also struggle with memory and attention, mood disorders, and sleep problems. Due to their tremors, people with Parkinson's disease (PD) also frequently feel embarrassed and lack confidence, which hinders their ability to engage socially and often makes it difficult for them to carry out daily chores at work and home. [2]

There are various approaches to relieving symptoms and improving the quality of life for individuals with Parkinson's disease, such as medications, physical therapy, deep brain stimulation, supportive care and counseling, and assistive devices. However, there is no complete treatment for tremors yet. [4]

Some assistive devices include ample grip, weighted cutlery, and weighted lead wrist cuffs. [5] Stabilizing mechanisms appear in many fields, such as air crashes, industrial robots, and video stabilization. Devices specifically aimed at tremor elimination in eating using an embedded gyroscopic mechanism include the Liftware Steady Spoon and Gyenno Spoon. Studies have shown that the spoons are non-invasive, user-friendly, and effective. [6] The spoons have also been shown to be the patient-preferred device in a head-to-head trial with a large grip, weighted cutlery, and swivel spoon for a cohort of PD and essential tremor patients who self-reported difficulty with eating tasks. [7] However, jitter elimination technology on the market is costly, such as the GYENNO Parkinson Spoon, which costs 299 USD [8], and the Liftware Steady, which costs 195 USD [6]. People had to eat cheaper with other utensils that cost 5 to 100 USD, such as heavier spoons, but their help was minimal. An alternative way is to hire a caregiver, which costs around 15 to 20 USD per hour, eliminating independent eating.

## 1.2 Project Aim

Through engineering design and technological innovation, this study developed a solution that can not only solve the problem of eating in patients with Parkinson's disease but also apply to IoT. First, I developed a low-cost anti-tremor cutlery that minimizes the impact of tremors during eating. Then, I used IoT technology to upload patient tremor information. Finally, I built a machine-learning model to assess the severity of the condition. People, therefore, can be self-sufficient, self-reliant, and self-assured.

### 1.3 Significance and Innovation

This technology will help patients cope better with eating difficulties, improve their quality of life and autonomy, and gain confidence. At the same time, it demonstrates the potential of computerized motor control and artificial intelligence in the medical field, providing new solutions to problems in specific groups [9]

## 2 System Implementation

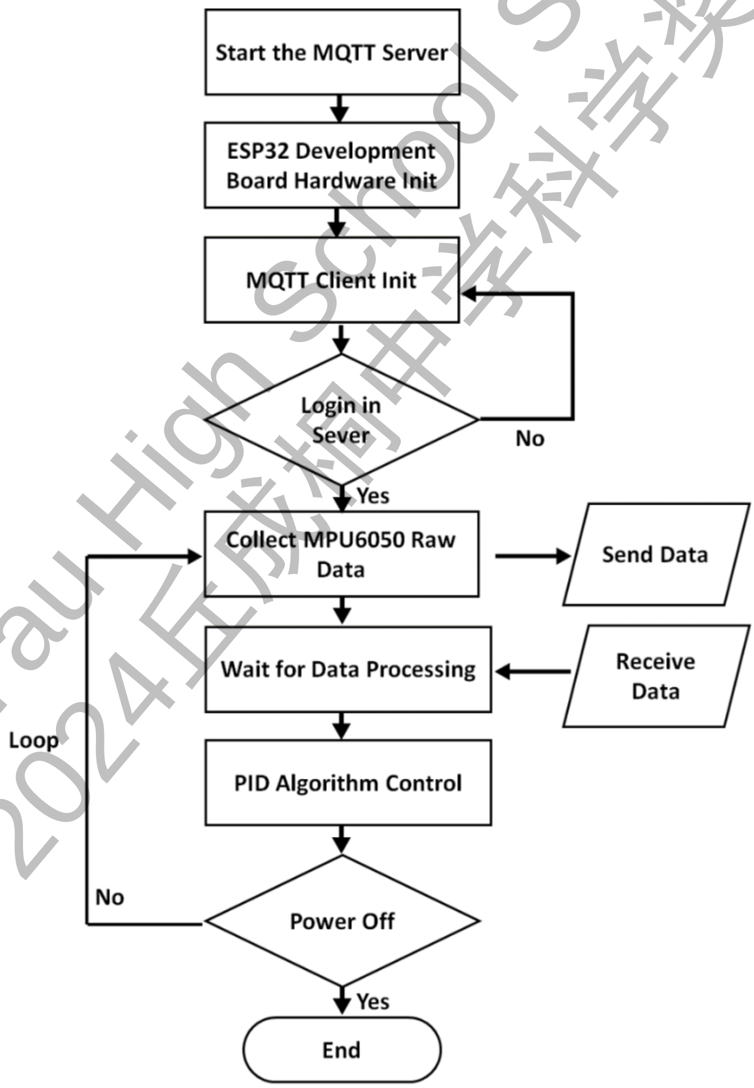


Figure 1. Overall flowchart for the process

The whole system includes an ESP32 development board, an MPU6050 gyroscope, and two servomotors (initially, I planned to use 3 servomotors). ESP32 development board transmits and runs the program, processes the data from MPU6050, and controls the servomotors. MPU6050 provides the movement's attitude angle, acceleration, and angular velocity. Through the MQTT network protocol, I realize dithering data upload. The PID algorithm offers the system with motion control.

## 2.1 Hardware

### 2.1.1 ESP32

I aim to select a development board that is low enough in cost and can meet the performance requirements. The factors to be considered are computing power, energy consumption, storage, deep learning, etc. Deep learning not only requires higher computing power of chips but also puts forward specific requirements for storing devices because deep learning needs to store a large amount of data. These will also lead to an increase in energy consumption and chip heating. Consider adding heat dissipation devices, which will further increase energy consumption and weight, and the electric energy inside the tableware is limited. I consider using only one chip to meet the PID performance. The development board ESP32 integrates many modules, including Bluetooth, Wi-Fi, etc., which supports the expansion of functions. It includes processing basic inputs from analog and digital sensors to far more complex calculations with an RTOS. It has 30 General Purpose Input/Output (GPIOs). Additionally, it is very cheap and sold for about 22.5 RMB (Around 3.16 USD). [10]

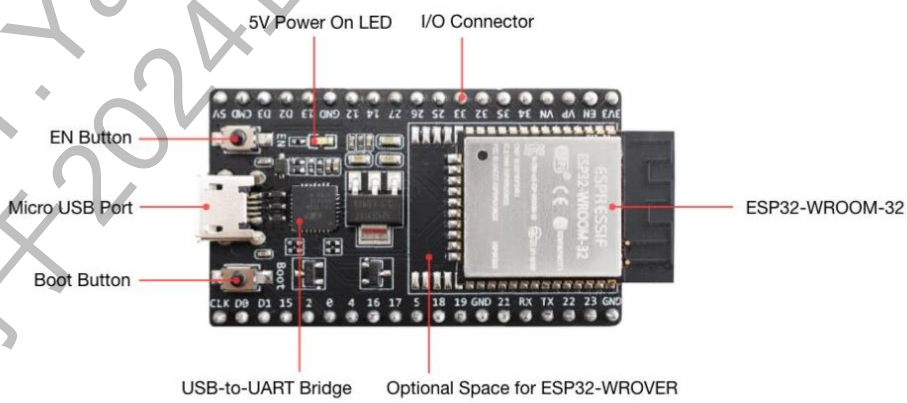


Figure 2. Overview of ESP32 from medium.com

2.1.2 MPU6050

The MPU6050 is an Inertial Measurement Unit that combines a MEMS gyroscope and accelerometer (3-axis) and uses a standard I2C bus for data communication. The gyroscope has 131 LSB/°/s, and a full-scale range of ±250, ±500, ±1000, and ±2000 °/sec (dps). The User-programmable accelerometer has a full-scale range of ±2g, ±4g, ±8g, and ±16g. Additionally, MPU6050 comes with a 1024-byte FIFO (First in, first out), which helps to reduce system power consumption, and a 12C communication interface up to 400Khz. When the gyros are rotated about any of the sense axes, the Coriolis Effect causes a vibration that is detected by the MEM inside MPU6050, and the signal is amplified, demodulated, and filtered to produce a voltage that is proportional to the angular rate. Acceleration along the axes deflects the movable mass and unbalances the differential capacitor, which results in sensor output. Output amplitude is proportional to acceleration. [11,12]

The embedded digital motion processor (DMP) is used to compute motion processing algorithms; it takes data from the gyroscope and accelerometer to provide motion data like roll (x-axis), pitch (y-axis), and yaw(z-axis) angles. Additionally, the microcontroller will take the readings from the angle through an I2C, and a PWM flag is given to the servo motor through the motor driver so that the spoon can be stable.

As shown in Figure 1, the working principle for this project started from the ESP32 and MPU6050, which will read and process the data when the tableware has tilted or shaken. The servomotor will be driven as the device's output to stabilize the assistive device.

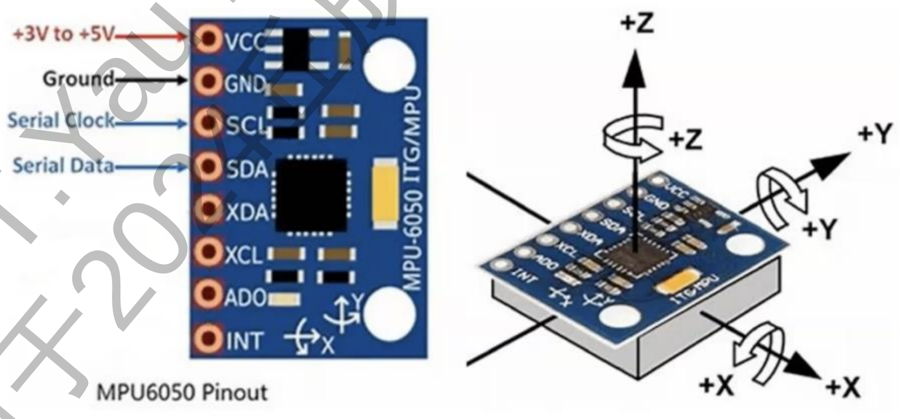


Figure 3. Overview of MPU6050 from researchgate.net

### 2.1.3 Final Design

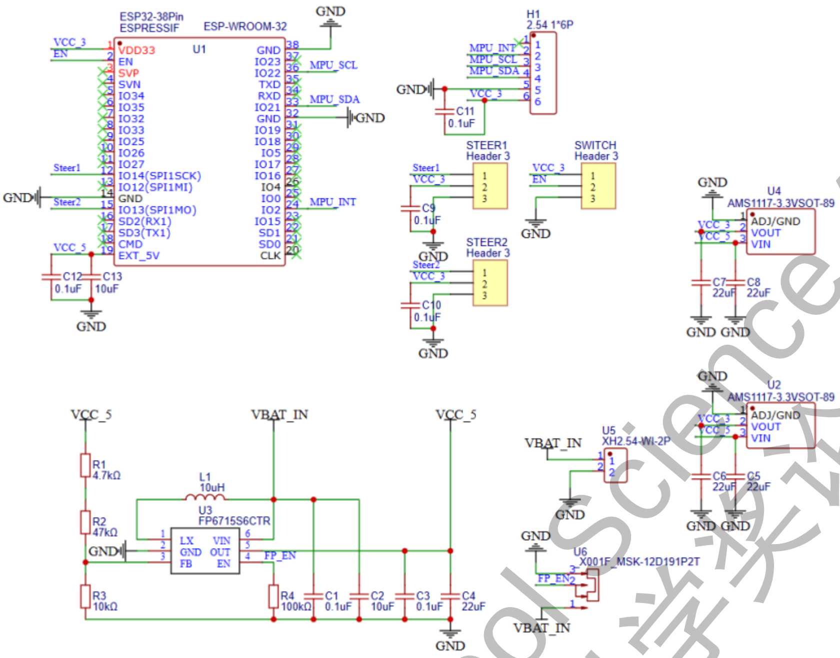


Figure 4. Electrical Diagram for the system

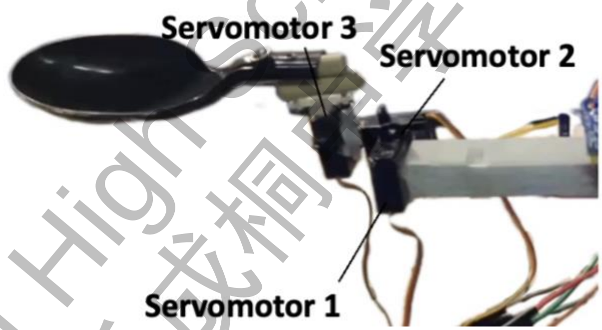


Figure 5. First Prototype design

After the first prototype testing, I discovered that the change in the yaw angle would not significantly affect the food spilled, and it cannot be effectively corrected. To get food into the mouth, the user will move the spoon so that the food can be poured. However, the yaw orientation program will judge the movement as a tremor and affect the user's eating. Additionally, adding a third motor will increase production costs since one servomotor will cost 25RMB. Therefore, the 3rd servomotor was removed. Moreover, the problem of insufficient power supply was shown; the boards were easily burnt and broken, so a buck converter was added to give a stable voltage of 3.7V.

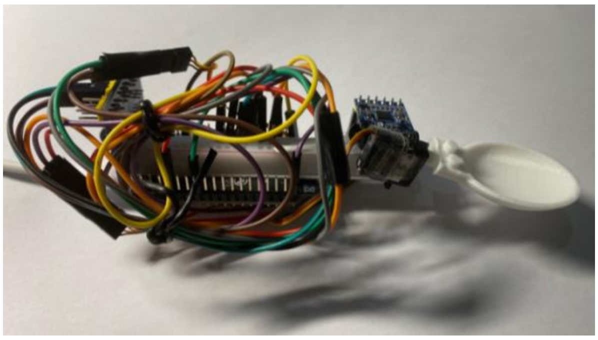

Figure 6. Second Prototype design

Figure 7. 3D printed case and spoon

For the second prototype shown in Figures 6 and 7, disorganized wires and the bulky case have received several comments on the problem of the inconvenience it may bring to the users. Therefore, on this basis, I changed the design of the hardware and the case to make it closer to the shape and style of an ordinary spoon.

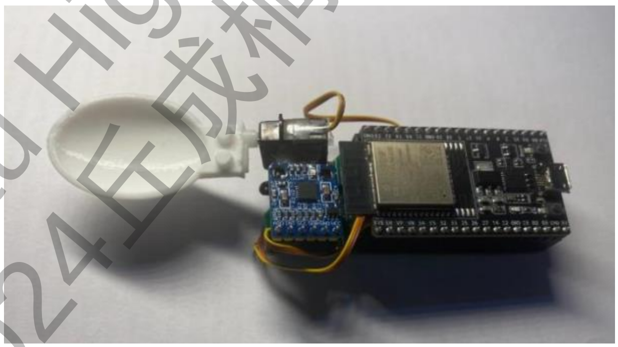

Figure 8. Final Prototype design

### 2.1.4 Total Cost

| Component | Price in RMB | Price in USD |
|---|---|---|
| ESP32 development board | 22.5 | 3.16 |
| MPU6050 | 8.6 | 1.21 |
| Buck converter | 3 | 0.42 |
| Servos | 50 | 7.03 |
| Piece of bread board and wires | 4 | 0.56 |
| 3D printing of spoon and case | 4 | 0.56 |
| Total | 92.1 | 12.95 |

Figure 9. Total Cost of the spoon, price from Taobao.com

As shown in Figure 7, the total cost of the whole spoon is only about 92.1 RMB (12.96 USD), and only 4.33% of the spoon was designed by GYENNO, and 6.65% was designed by Liftware. This has met the aim of lowering the cost of the spoon.

## 2.2 Program

### 2.2.1 PID

The three parameters in the PID algorithm are proportional, integral, and differential. By synergizing the three parameters, reasonable control of the motion state can be maintained.

$$u(t) = k_P e(t) + k_i \int_0^t e(t)\, dt + K_d \frac{de(t)}{dt}$$

The proportional parameter calculates the error value et and the difference between the set point and the process variable. Then, the error value is multiplied by the proportional gain, $K_p$. The Integral parameter weights each error value, which determines $K_i$, the integral gain. The differential parameter uses the difference between the current and previous error values. It divides it by the time between measurements, dt, to illustrate the rate of change of the process variable. The derivative gain, $K_d$, changes the weight of the D parameter to compensate for sharp fluctuations and decrease the oscillation of the spoon. In general, the proportional parameter fixes the current error, the Integral parameter considers the previous mistake, and the derivative parameter considers future errors, giving the PID algorithm functions of fixing and predicting errors and offering the spoon smooth motion control. The PID algorithm, therefore, can calculate and order the servomotors, which are attached to the spoon, to turn by the calculated angles. Thus, the spoon can remain horizontal and balanced. [13]

### 2.2.2 MQTT

Inspired by the Internet of Things, the project configures an artificial intelligence algorithm in the computer as the IOT server and analyzes the data uploaded by tableware. I utilized the MQTT network message protocol for the communication between the hardware and the server. As MQTT is a messaging protocol based on standards, designed for machine-to-machine communication, it is commonly used by IoT devices, which often need to send and receive data over networks with limited resources and bandwidth. MQTT is favored for data transmission in cases such as my project because it is simple to implement and efficiently handles IoT communication. It facilitates messaging both from devices to the cloud and from the cloud to devices. [14]

### 2.2.3 Machine Learning Models

The tremor data of Parkinson's patients can be used to train a prediction model which can judge the patient's condition. After the power of the device has been turned on and it starts running, the MCU collects the sensor data and uploads them via the MQTT protocol as mentioned to the server. The data will then be stored based on timestamps in a CSV file and analyzed using machine learning models.

Four models are used to analyze the acquired tremor data: KNN, Decision Tree, Adaboost, and Random Forest.

K-Nearest Neighbors (KNN) is a non-parametric, supervised learning classifier that groups individual data points by proximity. It can be used for both classification and regression tasks. The advantage of KNN is that it is easy to implement and adapt and needs a few hyperparameters to run it. However, KNN usually could perform better on high-dimension data, could be more efficient, and is prone to overfitting. [15]

Decision Tree is also a non-parametric, supervised learning algorithm that has a hierarchical tree structure that consists of a root node, branches, internal nodes, and leaf nodes. It can be used for both classification and regression tasks. The decision tree model has high flexibility, is easy to interpret, and can handle various data types, which means it requires little to no data preparation when used. [16]

The AdaBoost model is an ensemble learning algorithm. It sequentially trains a series of weak learners on the training set. Each learner focuses on the data points that the previous ones misclassified. Then, it adjusts the weights of these data points, assigning higher weights to incorrectly classified instances. A new weak classifier is then trained according to the updated weight distribution and assigned a coefficient that reflects its importance in the overall model. Finally, it combines the predictions of all weak learners through a weighted sum to form the final prediction. The AdaBoost model can handle noisy data and outliers with relatively high accuracy. However, AdaBoost can be computationally expensive and can lead to overfitting. [17]

The Random Forest model is a machine-learning method based on decision trees. Same as KNN and the decision tree, it can be used for classification and regression tasks. The Random Forest model improves prediction accuracy and stability by combining multiple decision trees. The benefits of the Random Forest model include its ability to reduce the risk of overfitting, handle high-dimensional and nonlinear data, and provide high flexibility. However, it requires more substantial memory and computational resources and is difficult to interpret and debug due to its complexity. [18]

# 3 Prototype Testing and Results

## 3.1 Prototype Testing and Data collection

To test the stability of the spoon, I have contacted several doctors to ask if I could let their patients try the spoon design. I reached out to Dr. Hao, the associate professor and deputy chief physician of the Department of Neurology at Peking Union Medical College Hospital. Dr. Hao has allowed me to let her patients try the spoon and gave me helpful feedback. I followed Dr. Hao Honglin's outpatient service at the hospital. To complete the test quickly, I asked each patient who visited Dr. Hao Honglin’s clinic if they would be willing to participate in the test on the spoon I designed (the test was conducted directly in Dr. Hao Honglin's office). I briefed them on what the spoon did demonstrate how to use it, and asked if they would like to try it out. I seek the consent of themselves, their family and Dr. Hao Honglin. After they sign the consent form,

The patients were asked to:

1. Hold the spoon when it has been turned off for 5 seconds with 5 M&Ms.
2. Hold the spoon when turned on for 5 seconds with 5 M&Ms.

The test lasted about five minutes and was conducted under the supervision of Dr. Hao Honglin. The test was carried out without affecting Dr. Hao Honglin's normal visits. In total, 17 participants were involved in the test.

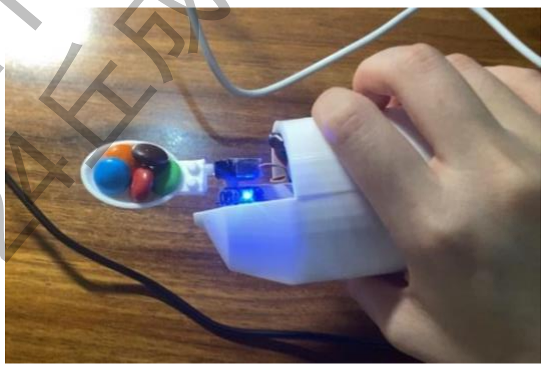

Figure 10. Demonstration

Except for one patient with a tremor in their right leg and two other patients with only tremors in their lower jaw and backache, respectively, as their symptoms, all subject’s hand tremor has been determined from a ranking level of 1-5, with 1 meaning nearly no tremor, 2 for slight amplitude tremor, 3 for medium-level tremor, 4 for high-level tremor, and 5, very high-level tremor. The jitter data of patients with different conditions were also collected during the experiment for training and testing the prediction models.

| Subject | Level of Tremor (1-5) | Number spilled when spoon turned off | Number spilled when spoon turned on | Difference |
|---|---|---|---|---|
| **1** | 1 | 1 | 1 | 0 |
| **2** | 2 | 2 | 0 | 2 |
| **3** | 1 | 0 | 0 | 0 |
| **4** | 5 | 5 | 3 | 2 |
| **5** | 2 | 2 | 1 | 1 |
| **6** | 3 | 3 | 1 | 2 |
| **7** | 4 | 4 | 2 | 2 |
| **8** | 3 | 3 | 1 | 2 |
| **9** | 2 | 2 | 1 | 1 |
| **10** | 1 | 1 | 0 | 1 |
| **11** | 4 | 3 | 2 | 1 |
| **12** | 1 | 1 | 1 | 0 |
| **13** | 2 | 3 | 1 | 2 |
| **14** | 2 | 2 | 0 | 2 |
| **15** | 3 | 2 | 1 | 1 |
| **16** | 5 | 5 | 4 | 1 |
| **17** | 2 | 2 | 0 | 2 |
| **Average** | 2.2 | 2.411764706 | 1.11764706 | 1.29411765 |

Figure 11. Table of results

## 3.2 Data Analysis

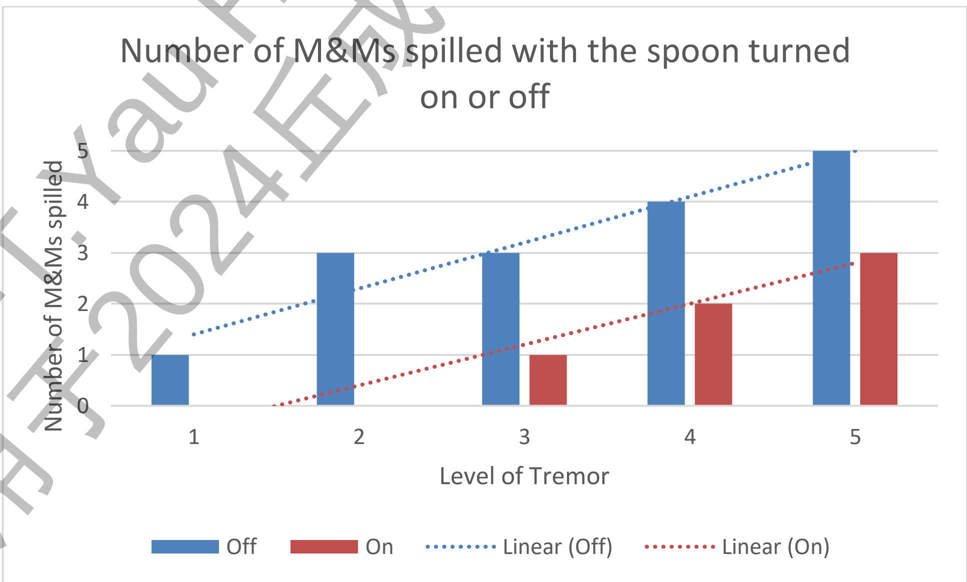


Figure 12. Graph of results

Based on the results in Figures 16 and 17, it is shown that the spoon is proven to be very effective for all levels of tremors, in that a 54% decrease in the number of M&Ms spilled has shown when turned on compared to the turn-off. This meets the aim of targeting the spoon to fit a broader range of tremors. The spoon is also more effective for high-level tremors, and the difference between the number of M&M spilled has been more significant than the lower level of tremors.

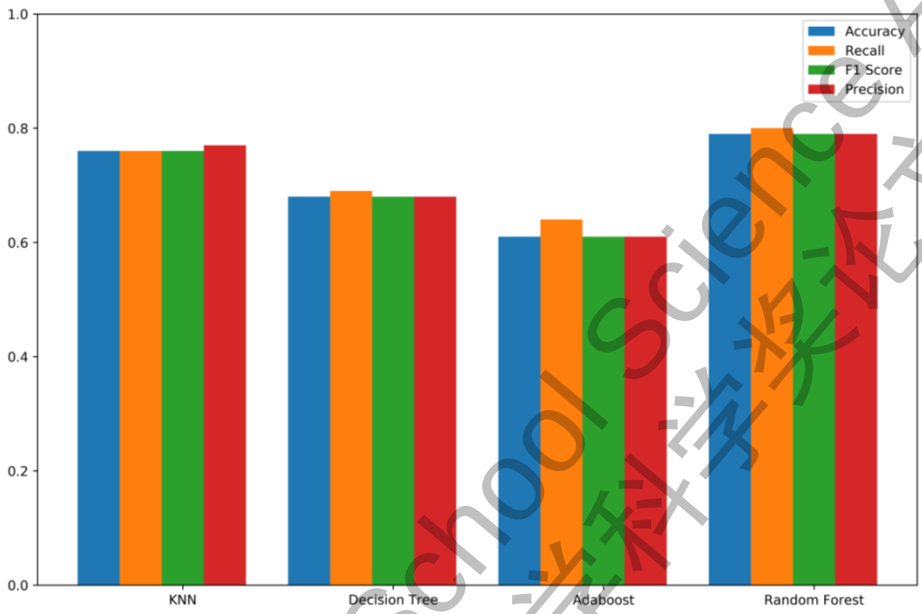


Figure 13. Performance analysis of prediction models

For each model, 80% of the data was used as the training set, and 20% was used for the testing set. They all must diagnose the patient's level of tremor from 1 to 5 based on the dataset; the higher, the more severe. The datasets used for each of the four models are the same, and every 5 datasets for levels 1 to 5 contains at least 2000 lines of data. Every line includes the rotation angle and acceleration of the three angles: roll, pitch, and yaw for a timestamp. The performance of the four machine-learning models for diagnosis is evaluated using methods such as recall, precision, accuracy, and score. Integrating the four metrics, the random forest algorithm is best suited for diagnosing Parkinson‘s disease with a high accuracy of 80%, higher than all KNN, Decision Tree, and Adaboost. The specific reasons may be as follows:

Firstly, it is understandable that Random Forest performs better than KNN and Decision Tree because Random Forest's ensemble learning method combines the predictions of multiple decision trees to make more accurate predictions. Therefore, its generalizability and robustness are based on a single estimator such as KNN and Decision Tree.

Secondly, Adaboost may have the lowest Accuracy, Recall, F1 score, and precision among all because it has overfitted. Random Forest is less likely to overfit because it randomly selects different subsets of data to train on and averages the results. Moreover, the weightage of votes among all trees in random forests is equal. In contrast, Adaboost may lead to the wrong final result due to problems in weighting between weak classifiers, which may affect its overall performance.

## 4 Feedback and Discussion

During the testing, patients and family members of the patients gave positive feedback to the spoon and were impressed by the product. Nevertheless, they suggested it would be even better if a tutorial taught the patients how to hold and use the spoon. I also thought this was important because most PD patients are above 60 years old, and they may also experience other diseases, such as Alzheimer's disease.

Dr. Hao was delighted to see this design, and she is happy to see the product results. Several improvement points were suggested, and I will consider them for future work. Firstly, I would like to improve the performance of the spoon on lower-amplitude tremors. Changing the MPU6050 gyroscope and accelerator to a gyroscope and accelerator with a higher sensitivity is possible. However, a balance between higher cost and better performance will need to be found. Secondly, changing the 3D-printed parts to metal would be helpful so the spoon could weigh even more, as weight also limits tremors. Lastly, redesign the shape of a spoon so the soup will be less likely to spill out.

## 5 Conclusion

In conclusion, the prototype has been designed, and the program has been programmed successfully. All three aims, which are designed a jitter elimination technology for Parkinson’s patients, with low cost, high range amplitude adaptability, and use artificial intelligence to cope with the tableware to fit more variety of tremors, make prediction of future motions, and give a more user-friendly response, has been met.

The spoon can help patients cope better with eating difficulties, improve quality of life and autonomy, gain confidence, demonstrate the potential of computerized motor control and artificial intelligence in the medical field, and let PD patients be self-sufficient, self-reliant, and self-assured.

To further improve and produce a quality product, an elder-friendly tutorial could be created to increase weight by replacing 3D-printed parts with metal, redesigning the shape of a spoon to fit better with soup and liquids, design a multifunctional end effector with a spoon, fork, and other purposes. Additionally, the spoon's performance on lower-amplitude tremors can be increased using a gyroscope and accelerator with a higher sensitivity, but the cost will also rise.

Most importantly, this project could be ported to a more mature IoT platform, such as MIJIA and Apple, or an app could be developed independently for this project. An IoT platform to realize automatic data upload, analysis, and return, and finally complete the automatic setting inside the tableware. Collecting more Parkinson's patient data is also essential to improve model accuracy.

Deep learning, such as the Multilayer Perceptron (MLP), can also be used to optimize the jitter elimination technology to adapt to more extensive and more amplitude contexts. A multilayer perceptron is a feedforward neural network consisting of fully connected neurons with a nonlinear activation function. Since MLP is widely used to distinguish data that is not linearly separable and high-dimensional data and has strong expressive power, it can work in cooperation with PID to predict future values. Therefore, it could increase the spoon's response speed, providing users with a faster, smoother experience. Also, it can ‘train’ the device to self-adapt to different tremors.

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From Scratch to EV3, to underwater robotics to Arduino robots, and extending my experience into computer-aided design (CAD), Python, C++, the First Robotics Competition, and ISEF, thanks to my school's STEM curriculum and resources (maybe not naming dog robots as Susie), I have always enjoyed design, engineering, and research. I've founded a service organization and hosted multiple events to fundraise for children with chronic diseases who come to Beijing to seek better medical care. The genuine excitement comes from seeing and experiencing the moments when others can benefit from my actions. Therefore, I have always been involved in research related to medical devices or in the broader field of a combination of Biomedical Engineering, Mechanical Engineering, Computer Science, and Mathematics. This idea of designing a "Tremor elimination spoon" arose when I witnessed an elderly man with tremors struggling to eat during an unexpected visit to my grandfather's nursing home. Later, I researched and learned about the technology currently on the market and determined my research goal which can benefit many who may be limited from the access of tremor or jitter elimination technology on the market, something as important as daily needed necessities for them. This also fits my desire to inspire more people like me, girls especially, to join and research in the STEM field. Throughout the process, I have encountered multiple challenges, not limited to connection errors, bugs in coding, and server communication problems. thus, I want to thank creators from GitHub, YouTube, CSDN, and other online platforms for providing some essential solutions for the problem. Most importantly, I would like to thank all my friends, parents, and teachers who encouraged me throughout the research and helped me provide the resources when I needed them.

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Meeting and discussing my feedback with experts in Biomedical Engineering guided me to develop my prototypes further to a great extent. I will thank one of the judges of the Sichuan Science Fair, who suggested potential improvements to my project (at that time, it was the second prototype).

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