A Self Stabilizing Spoon for Parkinson's Patients, with Application Enabled Remote Monitoring

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Abstract - *Parkinson's disease is the second most common neurodegenerative disease, generally occurring in older people and often due to severe nerve cell damage which affects the person's movement and daily activity. The patient's first symptoms might be unintended shivering and tremors in the hand, rendering it impossible for them to accomplish everyday tasks like eating food out of a bowl. In this paper, we aim to use the principles of IoT and sensor networks to create a stabilizing spoon for patients suffering from Parkinson's disease. The stabilizing spoon compensates for unintended tremors or shivers received from the user and calibrates its head against these forces, thus always keeping the spoon bowl stable. A prototype of the device was built using a gyroscope to measure the angle of the motions, paired with an accelerometer to measure the speed of these motions, to assist patients' eating process. Another part of the holistic product is a mobile application for the doctor to monitor the patient's progress. The spoon will send all relevant sensor readings to a server set up by us. These readings will be statistically analyzed and displayed over to the designated doctor for him/her to monitor and diagnose patients remotely.*

Key Words: Parkinson's Disease, Gyroscope, Accelerometer, Calibration, Sensor Networks, Internet of Things, Stabilization, Biomedical Instruments, Android Application, Cloud Connectivity

1.INTRODUCTION

Recent advancements in IoT (Internet of Things) technologies have enabled the production of cost-effective solutions to embed sensor networks and controlled systems. This has made it easier to deploy an IoT based infrastructure which can track, control, and monitor your devices. We have noticed a drastic improvement of intelligent biomedical assistance technology in the latest breakthroughs. New emerging technologies have made life easier for people who are functionally challenged, with novel devices such as biomechatronic components in place of human limbs and AI (Artificial Intelligence) based object classification devices for the visually impaired. With the help of such technologies and its protocols, we have designed and developed a stabilizing mechanism and integrated it in a spoon, to be used by patients needing assistance in their eating process.

Parkinson's disease is a neurological degenerative disease that results in irrepressible shivers in the limbs, making it excruciating for the patient to lift food with a utensil. The disease's symptoms can vary from person to person and might even be overlooked for long durations if they are mild. The condition of the patient worsens over the years and might even lead to difficulty in walking and talking. The exact cause of the disease is still unknown, due to which it does not have a cure. The only hope for these patients is the potential these biomedical assistance instruments hold.

Stabilizing mechanisms are employed in various areas like photography (gimbals) and aircrafts to compensate for the unintended motion and vibration of the process. In this paper, we propose a methodology to implement these advanced controlled stabilizing mechanisms into a low-cost prototype. A Self Stabilizing Spoon, which keeps itself steady as the hands of the user shiver or have tremors. It adjusts the position of its head if its rear end receives any unprecedented tremor [Figure 1 & 2]. In today's market, such devices are only manufactured by big companies at exorbitant prices [10 & 11], which are not affordable for the common man.

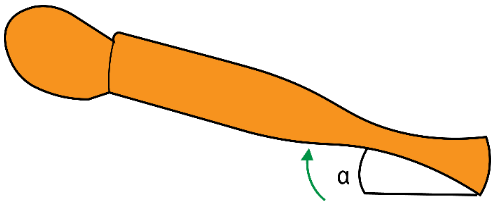


Fig -1: The spoon is moved upwards in angle α

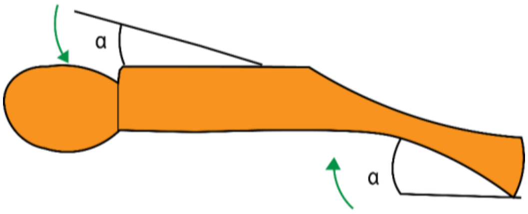
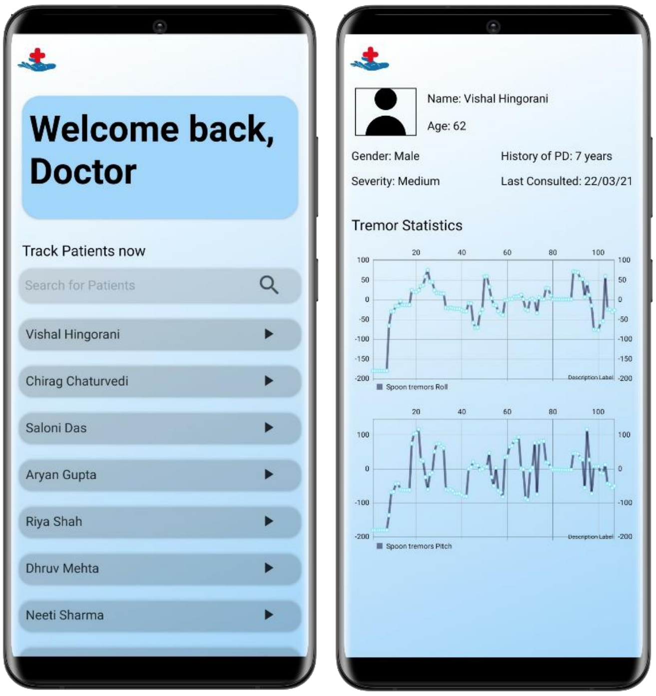


Fig -2: The spoon head moves downwards in angle α

The prototype works with an Arduino Uno as a microcontroller, and a 5-volt battery to source the power. The sensor used is an IMU (Inertial Measurement Unit) MPU6050, which consists of a three-axis gyroscope and a three-axis accelerometer placed orthogonally to each other [8]. An accelerometer measures inertial acceleration and a gyroscope measures rotational position about to a specific coordinate system. Combined they can detect where an object is in space and how fast it moves into a particular angular position, by taking into consideration the roll, pitch, and yaw of the tilt, with reference to the cylindrical coordinate system. Two servo motors (SG90) of high precision on positional feedback placed perpendicular to one another serve as the electromechanical components. They are rotated according to the readings taken in by the sensors, to produce the desirable calibration. A nodeMCU is attached to the system to enabled cloud connectivity and send sensor values to the developed application.

The prototype is coupled with a mobile application for remote monitoring of the patient's progress. As the patient uses this spoon to stabilize all unintended tremors, these tremors are statistically analyzed and can be displayed in forms of real time graphs to a designated doctor. These graphs can be categorized between breakfast, lunch, and dinner for a doctor to get a better idea of the patient's progress. This enables remote tracking and social distancing. The doctor can offer diagnosis and even therapeutic measures without needing to come in physical contact with the patient.



Name: Vishal Hingorani
Age: 62
Gender: Male
History of PD: 7 years
Severity: Medium
Last Consulted: 22/03/21

Fig -3: Screenshots of developed application

As it is imperative for any medical supervisor to have a look at the patient's movements when the disease concerns severe nerve cell damage, this application enables them to have a thorough visualization of said movements without needing to meet the patient or come in any sort of physical contact.

2. LITERATURE REVIEW AND RELATED WORKS

[1] The work "Robust DOBC for stabilization loop of a two-axes gimbal system." By Ren, Wei, et al. lays the foundation for the idea of stabilization and calibration in a gimbal like manner, with two degrees of freedom. A disturbance compensation strategy based on disturbance observer control (DOBC) is proposed to solve parameter perturbation, friction, coupling and external turbulence for two-axes gimbal control system. Uncertainties, friction, coupling shortcoming of gimbal system is summed up as a disturbance suppression problem, and achieving disturbance compensation through feedforward channel of DOBC. However, the compensation effects of DOBC are determined by modeling accuracy of the nominal plant and feedforward filter design.

[2] The US patent "Stabilizing unintentional muscle movements." By Pathak, et al. has been a pioneer in the field of stabilizing spoons. It has depicted a model of a stabilizing mechanism, along with a remote non-contact position sensor, coupled with a processing unit. The work is extremely detailed and one of the first in the field. The prototype does not specify the type of microcontroller or processing unit to be equipped, but rather suggests an 8-bit ATMEGA8A programmable microcontroller as an option, along with an inertial sensor and a motion sensor, similar to the gyroscope and accelerometer used in our device.

[3] The paper "Self-Stabilizing Spoon for Parkinson's Ailment" authored by Jaswanth, D. K., et al. introduces a concept very similar to ours, with the Arduino Nano as a controller. The stabilizing mechanism involves reading ADC values from a gyroscope and an accelerometer in the GY-273 module and applying equal and opposite calibration after converting these values. The motors used are analog (HS-125MG) instead of digital ones. Our paper has applied an equivalent approach, and has taken into consideration the speed of tremors, resulting in instant calibration and the least possible latency.

[4] The paper "Preliminary design of an active stabilization assistive eating device for people living with movement disorders." authored by Turgeon, Philippe, et al. proposes the idea of a mounted damping mechanism facilitated by magnetic encoders along with a gyroscope and an accelerometer. The system is operated using Atmel's SAM E70 ARM CortexM7 as a microcontroller. The highly complex Cartesian velocity-based damping algorithm relies on the user to operate the device via an external handle connected to the motor assembly, gearbox, transmission, and encoders. The only drawback of this model is that the device loses its portability and simplistic approach required by patients of neurodegenerative diseases, as these are usually coupled with memory disorders like Dementia. This study provides valuable insights into the different motions and tremors faced by the patient during different actions.

[5] The research "The Stabilizing Spoon: Self-stabilizing utensil to help people with impaired motor skills." by Abrahamsson, Johan, et al. describes a stabilizing mechanism programmed on the Arduino Nano, with the same motors and sensors as our project. They have provided various

algorithms and codes to calibrate the device, with a few being sourced from other projects and one being original. The paper provided an astute performance(frequency) analysis of fast and slow oscillations on MATLAB in the incredibly detailed research.

[6] The research "Preliminary Evaluation of Active Tremor Cancellation Spoon for Patients with Hand Tremor" by Ripin, Zaidi Mohd, et al. is a take on testing the efficacy of these highly priced stabilizing spoons in the market, mainly Liftware [10]. The spoon is experimented with solid and liquid foods in various orientations at different frequencies of tremors. They also examined various load capacities of the device. The findings of these tests are remarkable and provide insights on how well our device compares with the market standards.

[7] “Development of MEMS Accelerometer based Hand Tremor Stabilization Platform” authored by Chowdhury D. et al. introduces an innovative concept of MEMS (Micro Electromechanical System) gyroscope and accelerometer to measure angular momentum. It is programmed on the AVR microcontroller giving 3 degrees of freedom through the tri-axis IMU. An error analysis of the accelerometer is provided with very well explained mathematics and physics. This paper has the most progressive work by far in the field.

3. METHODOLOGY

The spoon is required to maintain a horizontal position, with respect to two axes. Two servo motors will be placed orthogonally to each other to establish a system of two degrees of freedom. With this setup in place, the spoon is intended to maintain its spoon bowl in a horizontal position.

3.1 Electronic Connections

The microcontroller Arduino Uno sources remote power from a 5-volt battery connected to its VCC junction. The sensor interrupt is received through a digital pin, while the data is transferred through an analog pin, along with the pulse. The servo motors are aligned on top of one another, perpendicularly. This is done to provide two degrees of freedom. They are operated by designated digital pins. The sensor and the servos receive their VCC and grounding through the Arduino or a connected breadboard. The circuit configuration is depicted in figure 4.

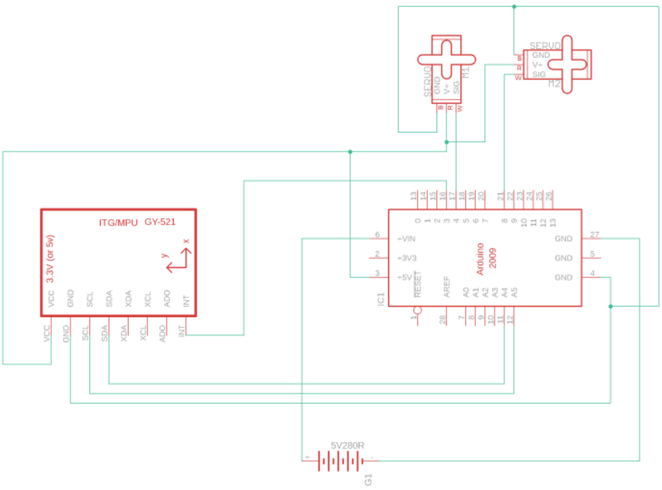


Fig -4: PCB Schematic Circuit Diagram designed on Eagle

3.2 Initialization

To achieve the desired results, the sensors and the electromechanical components are supposed to assess the environment first and learn what the frame of reference is for the user. The sensors get calibrated before they can be used for a period of 3000ms, where they read the angular readings and average them out for the period, these readings stand as the basis of the user’s position. The MPU6050 sensor provides X, Y, Z, and temperature readings for the initial calibration period, where we store and calculate the first three and disregard the temperature values. This process is depicted below in figure 5.

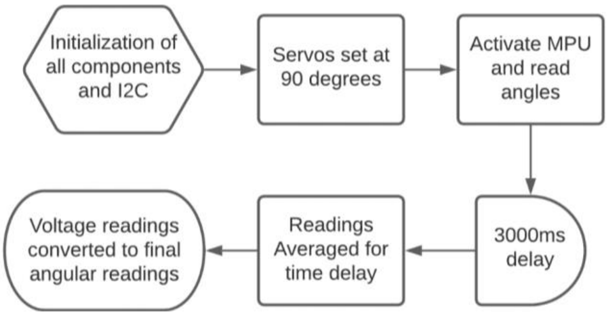


Fig -5: Initial Calibration Algorithm

3.3 Conversion of Voltages to Angular Readings

The MPU6050 sensor gives voltage (ADC) readings as their output, and we are supposed to convert them into regular coordinates. These values have to be divided by their LSB sensitivity, which depends on their full-scale select, which is determined by the 3rd and 4th bit of the register 27(GYRO_CONFIG) and 28(ACCEL_CONFIG).

Table -1A: Sensitivity table for Accelerometer [8]

AFS_SEL	FULL SCALE RANGE	LSB SENSITIVITY
0	±2g	16384 LSB/g
1	±4g	8192 LSB/g
2	±8g	4096 LSB/g
3	±16g	2048 LSB/g

Table -1B: Sensitivity table for Gyroscope [8]

FS_SEL	FULL SCALE RANGE	LSB SENSITIVITY
0	±250 °/s	131 LSB/°/s
1	±500 °/s	65.5 LSB/°/s
2	±1000 °/s	32.8 LSB/°/s
3	±2000 °/s	16.4 LSB/°/s

3.4 Stabilization

Once the gyroscope and accelerometer values have been converted to angular readings, they have to be 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 are considered while converting the values using the equations depicted below.

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

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

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.

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

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

3.5 Cloud Connectivity and Application enabled Remote Monitoring

After angular values are put into effect for stabilization and calibration of the spoon, they are pushed on to a server. The values pushed are still in the cylindrical coordinate system. This cloud connectivity is achieved using NodeMCU. The server is set up on Firebase [Google]. Angular Values between the desired range (-180 to 180) are parsed through. To achieve server connectivity, a Google Services file must be retrieved in JSON format with a set of all required addressed and passwords to access the database. This enables real-time communication.

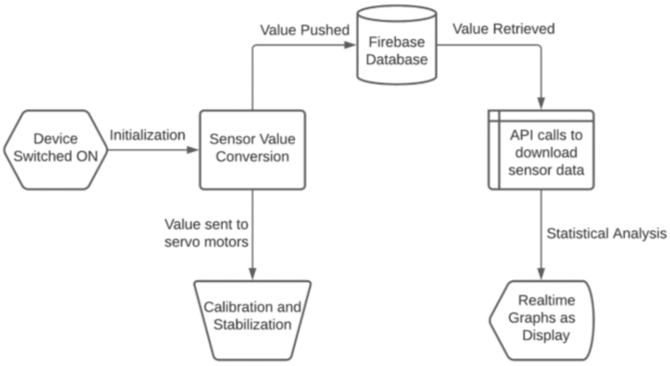


Fig -6: Algorithm to push and retrieve sensor data using the Firebase Database

3.5 Real-time Application Enabled Remote Monitoring

The mobile application is developed with the Android Native Development Kit using Java and Kotlin. The application will download all these values from the server on a real-time basis. They are then displayed in form of two graphs: Roll and Pitch. [Figure 3].

To make the graphs work in real time in a synchronized fashion, a Database Reference should be created in the given activity. This Database Reference will act as a pointer to an individual column or row of the stored data. This reference will issue an alert to the application whenever new data is added or existing data is deleted. This helps in the graphs work in real time synchronization with the hardware. The graphs keep changing as the device is used and updates itself as new tremors are detected.

The said statistical data refreshes every 2 milliseconds as the sensor is calibrating at 500°/second [Table 2] with respect to the gyroscope sensitivity of 65.5 LSB/°/s [Table 2]. This sensitivity can be changed according to the speed of the device and connectivity.

4. RESULTS

The self-stabilizing spoon was built on a small piece of cardboard to analyze and simulate tremors. The device could successfully calibrate against all unintended motions while providing 2 Degrees of Freedom (DOFs) as Roll and Pitch. Along with stabilization, it could also achieve internet connectivity and communicate with the application.

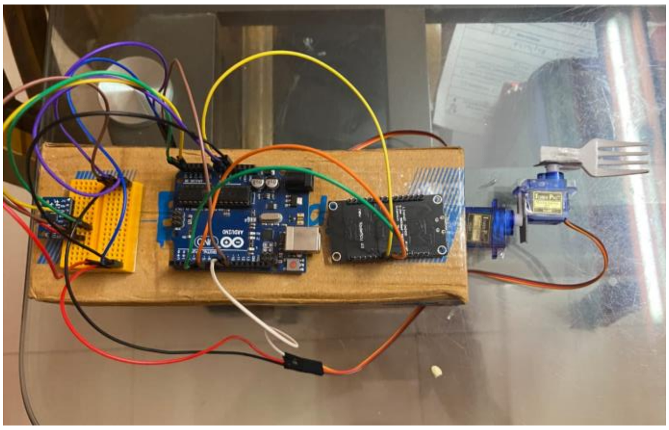


Fig -7: Self-Stabilizing Spoon – MPU6050 sensor (far left) with Arduino Uno (middle) and a nodeMCU (right) with two sg90 servo motors (far right) holding a fork head

The sensor data was immediately pushed onto the server with a specific unique ID to each value. This data was then successfully downloaded by the application and converted into statistical graphs to represent the data. These graphs are interactive and can be scrolled around and zoomed into, to make specific analysis of all available data possible for the designated doctor. The obtained results are in form of roll and pitch movements instead of X, Y, Z displacements are the values are still in the cylindrical system. The following graphs were formed after sufficient simulation and testing.

1) Roll

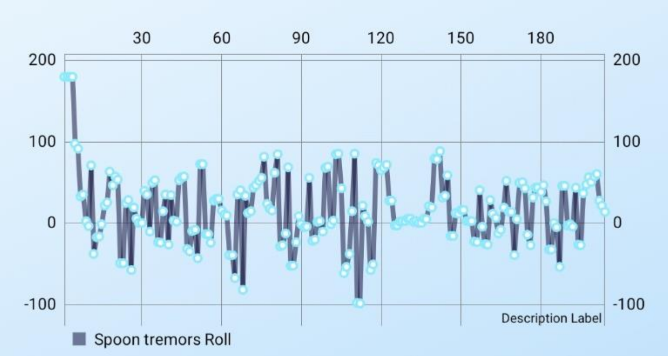


Fig -8: Tremor Roll Statistics

2) Pitch

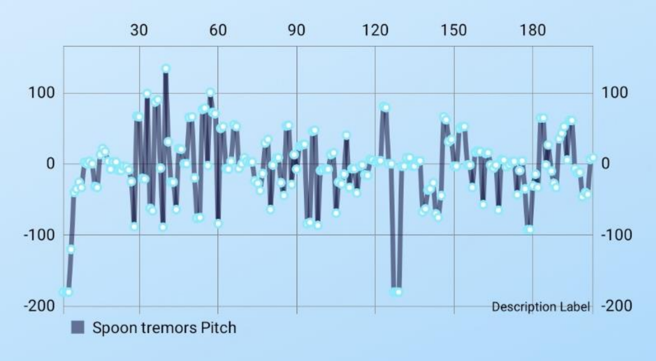
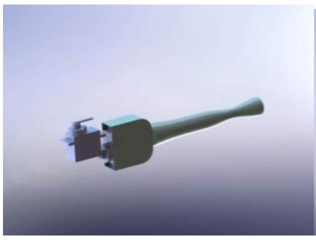


Fig -9: Tremor Pitch Statistics

5. REAL ISTRUMENT

The prototype was reimagined as a real hardware tool with a 3D printed plastic casing with all PCBs and sensors drilled inside, and this idea was designed and simulated using SolidWorks. The sensor would be placed inside the handle, while the motors would be cased towards the front, just behind the spoon bowl. The following figures contain a design-based visualization and vision of what a real instrument could look and feel like.



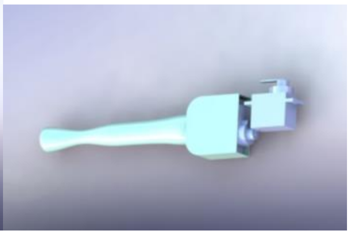


Fig -10: View 1 (left) **Fig -11:** View 2 (right)

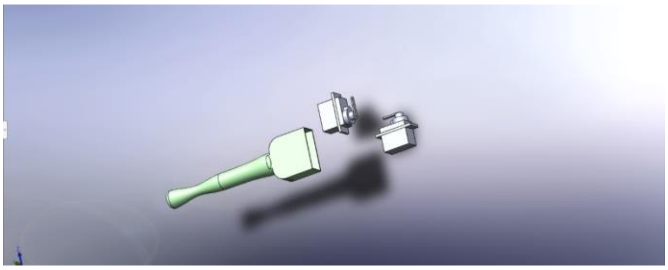


Fig -12: Exploded View

The challenge of an effective prototype is to fit multiple controllers and other actuators in one small confined casing. With this three-dimensional modelling of the product, we can better predict exactly how and where the components must be placed. Prototyping also gave us an insight of the required sizes of all components.

6. CONCLUSIONS

Parkinson's has had a deep effect on patients' life, not just in a physical manner. The constant dependency on others' help for daily activities is emotionally taxing in an unimaginable sense. The developed prototype delivered desirable results and possessed the capabilities to make the lives of these functionally impaired people better than they were yesterday. The applications of the device are not limited to Parkinson's but can also be applied to patients with severe Cerebral Palsy or other neurodegenerative diseases.

The prototype has some room for improvement and requires some changes if it has to be deemed usable for people with high-frequency tremors. The servo motors (SG90) are too slow to calibrate faster tremors, with no shortcomings in the algorithm. Although the device in its current state could be useful for people with limited motor impairments. A more advanced motor such as the MG90s or a separate DC motor would probably be more effective in practice.

Cloud Connectivity in biomedical devices is an unexplored concept and this project forms the roots of this technology. As a true pioneer in the industry, this implementation has the potential to massively spread and make an impact on people's lives as the first device to integrate remote tracking for a disease with nerve cell damage.

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