Parkinson's Disease Assist Device using Machine Learning and Internet of Things

Cyril Joe Baby, Angshuman Mazumdar, Harshit Sood, Yash Gupta, Abhipsa Panda and Poonkuzhali R.

***Abstract*—The main purpose of the paper is to construct a prototype of a spoon which senses the hand motion of an individual suffering from Parkinson's disease. It gives a counter motion to the trembling actions of a patient's hand, in order that they don't spill their food. The movement of the hand acts like feedback to a microcontroller that operates two servos that provide counter-motion. There are Inertial Measurement Units positioned on the spoon that measure the deviations in yaw, pitch, and roll of the spoon and thus govern the counter balancing action of the servos. A PID controller is used to maintain a tilt to the spoon's angle and as a consequence the spoon is kept at a level plane. Features such as IoT and Machine Learning have been integrated into the system, that enables the product to monitor changes. IoT is used in the device to monitor the sensor reading remotely and analyze the progress of the patient. Machine Learning is used to detect any anomalies in the sensor data from the device. If an anomaly is detected the device send a mail alert to the well-wishers of the patient.**

***Index Terms*—Pitch, Roll, MSP430, IMU, Servo Motor, PID controller, Euler, CAD, Polycarbonate, Butyl Rubber, IoT, Machine Learning**

I. Introduction

THIS paper concentrates on designing a device with the aid of which people suffering from PARKINSON's disease can consume food with ease with minimal spillage [1]. Over the world, food is consumed with the help of a spoon, primarily, and due to this disease, people affected by it cannot keep the spoon stable enough to have a hassle-free experience of consuming their meals [2]. The most effective way to resolve this difficulty is to make a device which counters the hand motion, to make vibrations minimal.

The device designed then ought to be attached to the head of a spoon (applies to forks and knives as well). This device can further be understood by looking at the suspension system of vehicles. The springs and shock absorbers in vehicles counter the bumps and deformations on the surface of the road to provide a smooth ride for the passenger. Shock absorbers do not completely eliminate the problem that is a pot-hole filled road; it only provides a relatively smoother ride. Similar is the case with our proposed design. Let us further look into the example of a pot-hole filled road, and how a suspension system helps to counter the bumps - the road texture and bumps can be considered as the input and the suspension setup counter acts these bumps, with the output being a smooth and hassle-free ride.

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If we draw parallels with our device, the motion of the hand is the input and the degree of motion is calculated through a microcontroller (MSP430), that provides a pair of servos the negative or opposite value which then ensures that the spoon remains stable. Now-a-days IOT is being used in many systems to make life easier as well as to achieve complex and sophisticated things like in smart homes, portable wearable devices like smart watches, in smart cities, in industries it is clubbed with big data and is used for various purposes. In agricultural field addition IOT has led to good growth of crops as their growth can be monitored regularly. It has been a huge success in the field of healthcare as well. It can be used to measure heartbeat of a person, find out the temperature of his body etc., collect it together and send the data to doctors and family members, which can be used for monitoring the condition of the person.

Machine Learning is used to help computers and machines learn how to act like humans and based on that improvise their learning with time. It uses different algorithms to predict the most accurate outcomes. This is done by feeding a huge set of inputs or data set and after an analysis of those data sets an outcome is predicted which lies in an acceptable range. There are 2 categories of machine learning wiz. Supervised and unsupervised. The supervised algorithm requires human intervention. The data acquired is sorted out by humans and then applied to the system whereas in case of unsupervised algorithms no human intervention is required. The machine takes the input and applies to the system itself according to the pre-defined instructions.The rest of this paper is describes the section II and III explained hardware and equations.The section IV and V is described the IOT and PID control.Section VI and Section VII is Discussion of the methodology.

II. Hardware

The paper is based on the hardware implementation of this concept, with which we aim to construct a real-life prototype. In this section, we will be discussing the various hardware components used and the way these components assist to obtain the goal as mentioned in the abstract.

A. MPU-6050 Gyrosensorsensor

The MPU-6050 sensor is ideal as it combines the gyro sensor and accelerometer sensors into a single chip and it is reasonably-priced also. The specifications are:

- I2C Digital-output of 6 or 9-axis data in rotation matrix, quaternion, Euler Angle, or raw data format
- Tri-Axis angular rate sensor with a range of ±250, ±500, ±1000, and ±2000 dps and Tri-Axis accelerometer with a range of ±2g, ±4g, ±8g and ±16g

Analyzing the values from this sensor is simple, the sleep mode needs to be turned off and then the raw data values can be read from the gyro sensor using the Microcontroller

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[3]. Communication between the gyro sensor module and the Microcontroller is achieved via I2C serial communication through the serial clock (SCL) and data (SDA). This sensor gives the ROLL, PITCH and YAW values which are crucial for us to calculate the counter values that will be sent to the motors later. The MPU-6050 is an IMU that measures the angle and rotation of the spoon, relative to a mean starting position. This sensor input is fed to the PID controller which opposes any tilt happening on the spoon and consequently, the spoon is kept stable within the plane.

B. ADXL-345 Accelerometer

The ADXL345 is a small, thin, low power, triple-axis MEMS accelerometer. It has a high degree of resolution (13-bit) measurement up to ±16g [4]. The output is digital and is in the format of 16-bit twos complement, which can be easily acquired through either an SPI (3- or 4-wire) or an I2C digital interface. This sensor is the core element of the device, that will keep relaying the pitch and roll positions of the device.

C. MSP-430

The MSP430, also known as a mixed-signal microcontroller, is a microcontroller family from Texas Instruments. It has been designed around a 16-bit CPU, the MSP430 is targeted for low cost and, especially, low power consumption embedded applications. This gives it an edge over its competitors, for our device, as it fulfills the necessary criteria we are looking in a mobile device such as a self-balancing spoon. The MSP430 does the calculations, from the raw input fed in by the IMUs, calculated the negative value of those, and feeds it further to the pin wherein the servo motors are linked. All that is achieved in an instant and in real-time.

D. Servo Motors

A dual servo motor setup is used in the device. These servos are connected to the spoon and the mechanism is set up in such a way that it moves the spoon based on the input the MSP gives it. The motors have been linked up in such a way that they move in the direction completely opposite to the motion of the hand. This counter movement done by the servos plays a vital role in keeping the spoon-head stable.

III. Calculations And Equations

The raw values from the gyro sensors will be sent into the MSP430 which will calculate the current roll and pitch and push the negative values of the same, so as to give the complete opposite values to the servo motors. This is basically known as Euler transformation [5].

The Euler transformations consist of various matrix, 3 to be exact, known as rotation matrices which are a representation of roll, pitch and yaw as shown in Fig. 1. When the movement is “rotation about x-axis”, it is called ROLL, “rotation about y-axis” is called PITCH and “rotation about z-axis” is called YAW [6]. Rotation matrices, each are a 3x3 matrix and have the format as shown in Eq. 1,2,3.

E. Roll

$$R_\phi = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & -\sin\phi \\ 0 & \sin\phi & \cos\phi \end{bmatrix} \tag{1}$$

F. Pitch

$$R_\theta = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix} \tag{2}$$

G. Yaw

$$R_\psi = \begin{bmatrix} \cos\psi & -\sin\psi & 0 \\ \sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{3}$$

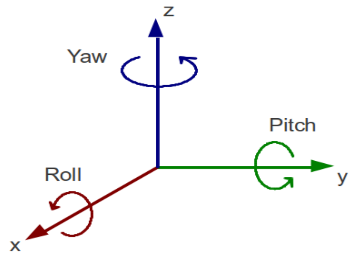

Fig. 1. Depiction of Yaw, Pitch and Roll

The overall rotation matrix, in pitch, yaw and roll terms taken into consideration, can be obtained by matrix multiplying the individual matrices. It is defined as shown in Eq. 4.

$$R_{\phi,\theta,\psi} = \begin{bmatrix} c_\psi c_\theta & c_\psi s_\phi s_\theta - s_\psi c_\phi & c_\psi c_\phi s_\theta + s_\psi s_\phi \\ s_\psi s_\theta & s_\psi s_\phi s_\theta + c_\psi c_\phi & s_\psi c_\phi s_\theta - c_\psi s_\phi \\ -s_\phi & s_\phi c_\theta & c_\phi c_\theta \end{bmatrix} \tag{4}$$

IV. PID Control

PID is the abbreviation for Proportional, Integral and Derivative actions [6]. Hence, a PID controller is responsible for applying all these three things to an input. The three basic coefficients vary for different PID controllers, and each can be custom set to satisfy an equation and target a specific application in order to get the best response.

P-Control Response

Proportional control or simply P-controller produces the control output proportional to the current error. Here the error is the difference between the set point and process variable (i.e., e = SP – PV) [7]. This error value multiplied by the proportional gain (Kc) determines the output response, or in other words proportional gain decides the ratio of proportional output response to error value. Its equation can be defined as shown in Eq. 5.

$$MV = Kce + b \tag{5}$$

I-Control Response

Integral controller or I-controller is mainly used to reduce the steady state error of the system. The integral component integrates the error term over a period of time until the error becomes zero. This results that even a small error value will cause to produce high integral response. At the zero-error condition, it holds the output to the final control device at its last value in order to maintain zero steady state error, but in case of P-controller, output is zero when the error is zero. Its equation can be defined as shown in Eq. 6 [8].

$$MV = \frac{1}{T_i}\int edt + MV_o \qquad (6)$$

D- Controller Response

A derivative controller (or simply D-Controller) sees how fast process variable changes per unit of time and produce the output proportional to the rate of change. The derivative output is equal to the rate of change of error multiplied by a derivative constant [8]. The D-controller is used when the processor variable starts to change at a high rate of speed. Its equation can be defined as shown in Eq. 7.

$$output = T_d \frac{de}{dt} \qquad (7)$$

In most of the PID controllers, D-control response depends only on process variable, rather than error. This avoids spikes in the output in case of sudden set point change by the operator. And also, most control systems use less derivative time td, as the derivative response is very sensitive to the noise in the process variable which leads to produce extremely high output even for a small amount of noise. Total PID controller equation is shown in Eq. 8.

$$MV = Kce + \frac{1}{T_i}\int edt + Td\frac{de}{dt} \qquad (8)$$

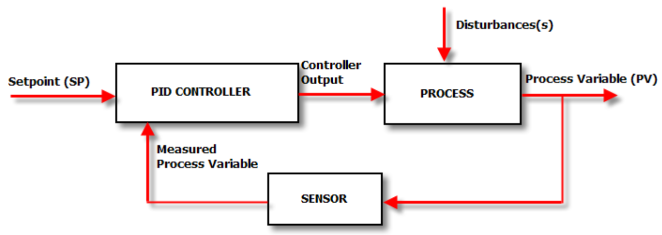

Fig. 2. An Ideal PID controller

Therefore, by combining proportional, integral, and derivative control responses, a PID controller is formed (Fig. 3). PID controllers find universal applications; but, one must know the PID settings and tune it properly to produce the desired output. Tuning means the process of getting an ideal response from the PID controller by setting optimal gains of proportional, integral and derivative parameters [9].

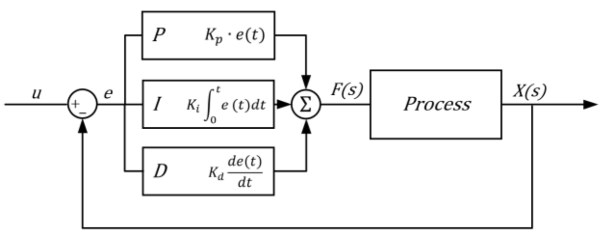

Fig. 3. PID Control Process

V. IoT AND MACHINE LEARNING

Internet of things is an interconnection of a devices that help in computing large amounts of data be it from digital equipment, from animals or from people that are identified uniquely. IOT is used to collect data from the sensors which can be attached anywhere like in the pacemaker to observe the heartbeat of a person, in the leg joints to see if the joint is reacting in a desired manner or not.

In this paper we will be using the IOT for measuring the inputs from the Self Balancing Spoon. IOT is being added in our project for the very important task of observing the condition of the person suffering from Parkinson's disease. As mentioned earlier in Parkinson's disease the hand of the person keeps on shaking. This possess a problem for him while performing different day-to-day tasks especially eating. So, the application of IOT in addition to the system of Self Balancing Spoon ensures that the data is collected regularly without fail. Now, this data is collected from the accelerometers and IMU's (Inertial Measurement Unit) attached to the system. Now this data is recorded and a graph is made based on the input values using Microsoft Azure IOT suite. Using this data, we can see the sudden worsening in the condition of the person suffering with Parkinson's disease and based on the values previously collected we can send an alert to the doctor and the family members so that they will also become aware of the situation. This helps as proper steps can be taken to ensure the welfare of the patient as the doctor can decide or change the current course of the treatment, make a change in medications that will slow the worsening of this disease.

In our project we have used one of the unsupervised algorithms which allows the system i.e. Self-Balancing Spoon in our case to take the data sets, analyze them on the basis of algorithm and apply it in the most suitable manner to produce the desired results. Machine learning is used in our project to monitor the data set provided through IOT and then process it and then apply to the spoon. It is a known that Parkinson's disease increases with time. So, the machine learning will monitor the deteriorating rate of the patient's condition and if the condition worsens more than the expected rate then it will send the alert to the patient's family and also inform the doctor. Machine Learning can also be used to detect the progress rate of the patient or to monitor if the patient needs any urgent medical attention.

Software used- Microsoft Azure IOT and ML suite [10].

It uses its own operating system which is called Microsoft Azure. All the data is collected and pushed into a SQL database online which is in turn used to monitor the data. The data can be accessed from any remote internet enabled device having the required login credentials [10]. More over the data can also be visualized in a graphical format using Power BI which is a feature of Microsoft Azure which in turn provides a better understanding of the large amounts of data collected. The anomaly detection on the sensor data is done using Linear Regression model of Machine Learning tool in Azure.

VI. METHODOLOGY

The proposed apparatus is a self-balancing spoon that gets raw IMU gyro sensor data, which are the inputs and through the help of a device such as an MSP, controls a couple of servo motors, arranged in such a way that they provide a counter motion, to the tremors of the hand, by using a PID control mechanism. For optimal results, the raw data from the IMU gyro sensor can be preprocessed, so as to remove persistent noise and also to get the normalized form of the final values.

Over the input data, a filter known as a median filter shown in Eq. 9 is applied. This is done to essentially eliminate all instances of persistent noise in the input raw values, obtained from the gyro sensor. A median filter considers the value of the center-most pixel in a particular window to be the median value in that window. Hence random noisy values are eliminated. A median filter is a single window spatial filter which is mainly utilized to remove salt and pepper noise. It replaces the center-most pixel of a window with the median of the neighboring pixels [4-5].

$$g(x,y) = median\left(\sum_{i=-1}^{1}\sum_{j=-1}^{1} f(x-i,y-j)\right) \tag{9}$$

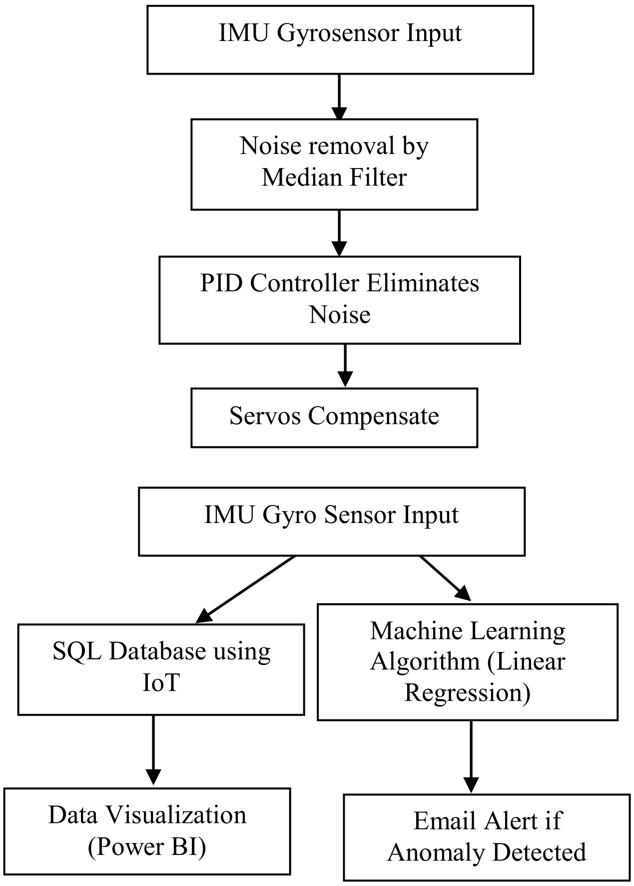

Fig. 4. Proposed Model

The raw gyroscopic sensor values are fed into the PID control algorithm (Fig. 4), after all possible noise has been removed. Using the PID control algorithm and the IMU raw inputs, an angle change is determined. This angle change is used to counter the motion of the tremors. The servo is turned to that angle to counter any tilt acting on the spoon. This permits the spoon to be rigid and strong, and facilitates patients suffering from Parkinson's disease to consume their food in a proper manner. The model also enforces a set of rules to counter the jerks due to tremors or shaking of the spoon, in the patient's hand. **T**he data from the sensors is uploaded to the SQL Database on Microsoft Azure (Fig. 5). The sensor readings are also plotted real time using Power BI (Fig. 6).

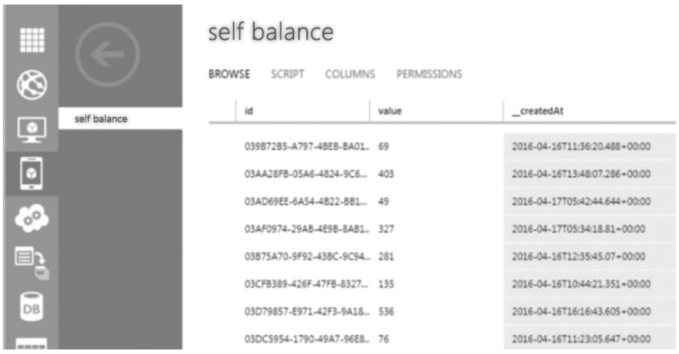

Fig. 5. SQL Database

Fig. 7 shows the flow diagram of the Machine Learning approach using Microsoft Azure. We have used a linear regression model to predict the extent of the anomaly in the sensor data. This anomaly can refer to a sudden worsening in the situation of the patient having Parkinson's disease. Sudden jerks or instability in sensor data can denote worsening of condition of the patient. The Linear Regression model predicts the extent of the anomaly in sensor data and if a threshold is crossed a mail is sent as a warning to the well-wishers of the patient [11-12].

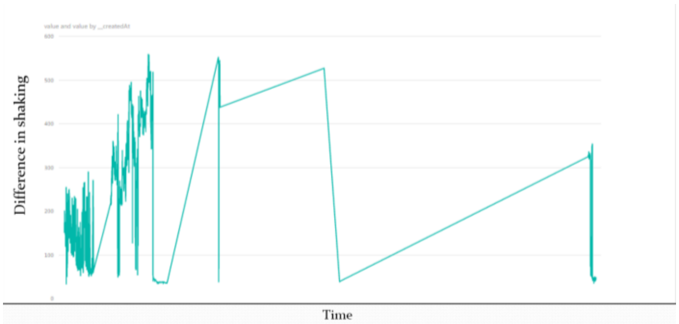

Fig. 6. Visualisation of Sensor Data

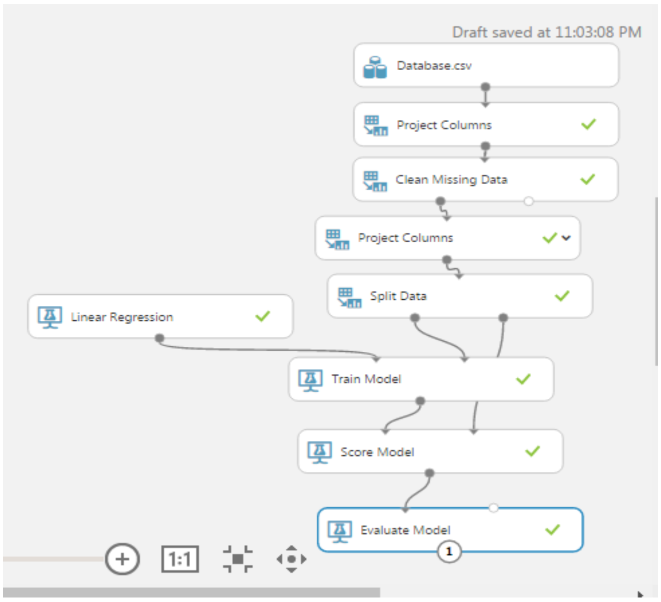

Fig. 7. Machcine Learning Model

VI. Fabrication

From a design perspective, the penultimate goal in mind was to fabricate a device, that will enable a patient of Parkinson's disease to easily consume their food without any hassles. This called for the device to be rigid, as well as light weight, and one that is heat and water resistant. The approach we've considered here, is to use a mixture of elastic rubber-like substances to form the flexible neck and 3D print the outer shell, where the user will hold, using a Polycarbonate as the source material (Fig. 8). PC has high toughness, temperature resistance, easily adhesive to other PC parts, as well as being dimensionally stable.

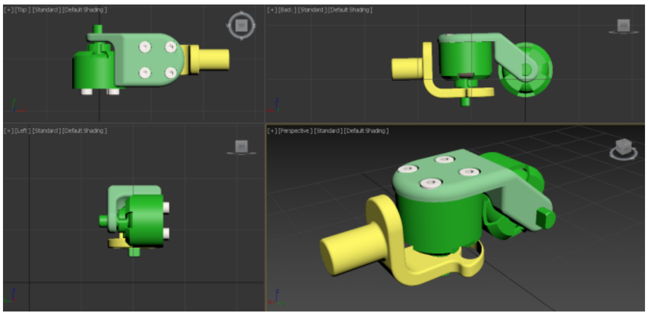

Fig. 8. Motor placement for fabricated product

Also, for the flexible part of the neck, a form of butyl rubber can be used. This will give us air-tight advantages, as well as flexibility at the same time. The plane of the spoon is attached to a two-motor system which enables stability in two axes. The sensors are placed on the body of the spoon to get the roll and pitch of the device.

VII. Results

The results of the PID control for movement of the spoon is simulated and outputs are shown in Fig. 9. Fig. 9 depicts the mean or inactive position of the spoon. It also shows how the spoon will bend for a change pitch. The figure also depicts a change in pitch and roll. From the images, we can conclude that the spoon remains stable, even though the hand is still shaking. The motors placed in the spoon provide two axes stability to the spoon based on the sensor values from the inertial measurement unit.

Fig. 9. CAD Simulations

The sensor data from the device is monitored online. The sensor data is sent to an online database using IoT. An alert is also sent if there is an anomaly in the sensor data. Machine Learning is used to predict worsening of condition in patients and the necessary alert is sent. In Fig. 10 you can see an alert being sent when there is an anomaly detected by the Machine Learning algorithm.

Fig. 10. Warning Alert

Hence, this work uses the concepts of PID Control, IoT and Machine Learning to make a very useful and handy device for people suffering from Parkinson's disease. There are various advantages to the device:

- The effects of hand tremors can be significantly subdued, to the point where the user can easily have their meals spill-free.
- The spoon head can be replaced with many other modular units such as a fork, or a soup spoon etc.
- The device has low power consumption.
- It is a closed-loop system.
- The spoon, as a whole, can be produced as a modular unit and can be manufactured by everyone.

VIII. Conclusion

This work has a much wider scope as implementation can crossover to other disciplines such as autonomous robots, and drones and also can be carried over to larger forms of machinery such as autonomous automobiles and aircraft. The fundamental concepts in the paper are being evolved and enhanced, so that they can be retrofitted into drones and ground robots, as of now. Another aspect we look to touch upon, is to provide cost effective medical devices to the general public, so that everyone has access to affordable healthcare. This venture also aims to reduce the costs incurred while developing technologies such as this, so as to provide and promote a Do-It-Yourself environment, that people can easily jump into, which will result in reducing unnecessary manufacturing costs significantly and hence making it cost effective. The layout we are creating inside the spoon can emerge as the base for other self-balancing structures that are based on the principle of a closed loop system.

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