Attenuation of resting tremors via PID control

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Abstract

Current mechatronic solutions for Parkinson's Disease include wearable technologies that directly suppress tremors and tools that mitigate the vibrational magnitudes they experience by stabilizing themselves using closed-loop control. Prototypes of the aforementioned devices have been shown to successfully decrease tremor magnitude, thereby improving overall dexterous control or stability, respectively. This work leverages the servomotors and PID control scheme of the prior art, as well as information extrapolated from a need-knower interview, to address the need of drinking fluids. An actuated mug was prototyped with the goal of attenuating the magnitude of vibrations the mug experiences using two servomotors that are driven by a gyroscope to control pitch and roll. Further work pertains to laboratory testing of the device's performance in comparison to a standard mug as well as human subject trials for evaluation in true Parkinsonian conditions once the device has been validated as efficacious in the aforementioned testing.

I. Introduction

Parkinson's disease (PD) is a neurodegenerative disorder that, over time, may significantly impair motor control and the ability for the body to perform other, "non-motor" functions. The cardinal symptoms of PD: bradykinesia, muscular rigidity, rest tremor, and benign positional vertigo; all concern motor functionality [1].

In an effort for the device in question to be discrete and not marketed as an assistive device exclusively for people with PD (PwPD), highlighting the incidence of other disorders that induce tremor is crucial to understanding the potential consumer base of the product. Given the nature of the proposed device, tremor is the symptom being addressed. The aforementioned rest tremor has been found to develop in around 70% of PwPD [2]. With respect to epidemiology on a global scale, PD is fairly common having affected approximately four million people, and essential tremor has been found to affect around 5% of senior citizens (which, based on the current senior population of the world would suggest approximately 30 million people) [3]. Evidently, even neglecting other tremor syndromes, this particular symptom is a widespread concern that should be addressed.

A. Background

There are various symptoms and medications associated with PD. Diagnosis of PD requires bradykinesia accompanied by at least one of the other three aforementioned cardinal symptoms, and the diagnostic tool provided by Sveinbjornsdottir also notes sixteen separate "exclusion criteria." Sveinbjornsdottir gives the diagnostic definition of the tremor associated with PD as a "[4 to 6 Hertz] rest tremor." Despite PD's large prevalence, treatment primarily aims to cope or manage symptoms experienced by PwPD and further research is required to improve the quality of life of PwPD [4]. Thus, medication does not provide guaranteed management of symptoms, nor does it provide improvement of the condition itself. Despite medication, many tasks performed by several PwPD were described to necessitate significantly more time and assistance due to dexterous concerns. Overall coordination also was found to be inversely related with stress and anxiety, which would be considered by caregivers, who are careful to avoid being "overprotective," when providing assistance [5].

Determining the degree of severity of symptoms in PwPD is generally described using the Unified Parkinson's Disease Rating Scale (UPDRS). More specifically in regards to the issues discussed in this paper, there are tasks designed to evaluate the gross and fine motor control of the upper extremities, described by the UPDRS-UE score [6]. Other means of assessment have been explored and accepted as viable, including the Purdue Pegboard test and Jebsen Taylor Hand Function Test (as discussed in Mak et al.).

There are a number of currently accepted assistive devices and technologies used to assist PwPD. A holistic view of the technologies in a publication by Julie Swann reveals that many of the devices related to dexterous maneuvers are intended to decrease the degree of fine motor control required to perform said maneuvers [7]. For instance, there are weighted pens to aid stability during writing, and drinking cups with broader handles or "drinking spouts" to prevent spillage and ease the task of drinking a liquid.

However, more complex, mechatronic solutions (that are not yet widely adopted) in terms of assistive technologies are being researched and developed every day. On the topic of managing tremors, Faizan et. al. are developing a wearable tremor suppression device. A "temporal response" is recorded by the device in order to control the vibrational frequencies of "dual passive vibration absorbers," a method that was found to reduce tremor magnitude by up to 57.25% [8]. This would be ubiquitous by design as it would consistently manage tremors. However, other technologies are more niche and nuanced, yet effective in performing the associated task(s) intended by their designers. Two publications were found to discuss tools that manage tremors via stabilization of the tool about its handle. One of these two papers discusses the simulation of a "tremor attenuation system" that is used as a multi-tool, while the other details the prototyping of a spoon that attenuates tremors as well as provides monitoring of the condition of the consumer [9], [10]. Both devices share the utilization of two servomotors that are counter-driven, with respect to a tremor, based upon a PID control scheme and have been found to be effective in reducing the magnitude of vibration experienced by the tool. The former claims a reduction in magnitude of up to 75%, whereas the latter qualitatively claims a reduction of magnitude significant enough such that PwPD can consume their food with no spillage.

The need of drinking fluids when discussing mechatronic solutions is not addressed in the prior art. As the mechatronics mentioned in both Abbasi et al. and Baby et al. intend to maintain the level of the device such to prevent instability, the use of servomotors and PID control is what appears to be accepted based upon the prior art when attenuating vibrations about the handle of a device. As mentioned, there are cups with broader handles or spouts that reduce the need for fine motor control, however applying the aforementioned mechatronics to this need would perform the same task. Naturally, drinking fluids is an essential part of any persons' life. However, Sveinbjornsdottir claims that anywhere from 40-80% of PwPD experience oral motor disorder in relation to swallowing, and more than half experience speech disturbance. Based on both the numbers provided above as well as logical thought, we believe that swallowing could present an issue when it comes to communication, making the need of consuming fluids ever more crucial to improving the quality of life for PwPD.

B. Overview

We propose that an actively controlled coffee mug will suppress resting tremors to effectively reduce spilling in amount and frequency compared to a passive coffee mug design. The actuated mug would utilize PID feedback controls as mentioned in *Section III* to reduce the effect of tremors it experiences from PwPD. The need that this device addresses was identified following an interview with a PwPD which can be found in *Section II*. The prototype of this device is described in *Section III* along with the proposed methods of testing. We believe our work here will influence further research as mentioned in *Section IV* into actively controlled daily items to enhance the quality of life of PwPD.

II. Preliminary Results

We contacted an older adult who was diagnosed with PD 13 years ago and they agreed to conduct an interview through a Zoom call. We sought out to better understand their quality of life and daily activities performed with PD. They practiced neurosurgery for 42 years and we could tell that they were very proud of their work. Our primary focus of the interview was dexterous manipulation. We asked them about hand tremors, a common symptom of PD, and they assured us that their hands did not shake and showed us their hands. To any question addressing dexterity our participant would shortly respond claiming it was not an issue. After getting this response a couple times we decided that this symptom either did not apply or that they were not comfortable talking about it. We moved on and continued to get to know our participant, but we still needed information about dexterity. We decided to conduct another interview with their caregiver who has observational experience with the individual's symptoms. The caregiver informed us that when tremors did occur that she would have to hold their cup while they drank or physically give them their medication. We were able to gain a better understanding of the needs of our participant through the interview with their caregiver. Table 1 below shares some of the questions conducted during the caregiver's interview, her answers, and the interpreted needs that we found. She walked us through her shift with the individual with PD and informed us of the activities that she helped them with. The discrepancy in the two interviews about the severity of hand tremors lead us to our first and most important need: discretion. We will focus on creating a device that is discrete, while increasing stability during resting tremors. We propose to build a functional prototype addressing the need of drinking coffee, which is one of our participants daily activities. They told us that caffeine agitates their PD symptoms, but they still enjoy the taste so they drink decaf coffee. With this knowledge we started to design the device.

Question/Prompt	**Interviewee Statement**	**Identified Need(s)**
Do you think he down played his symptoms and why do you think that might be?	”Yeah, it kind of almost seemed like he might be a little prideful in his hands, which makes it since seeing he was a surgeon for however many years.”	Participant cares about others knowing of his tremors. Device needs to be discrete.
How do you help him with his medication?	”I actually have to physically have to insert the medication into his mouth because his tremors are so bad.”	Hand to mouth coordination and fine motor skills need to be increased.
When do you help him the most? And what other kinds of things do you help him with?	“Sometimes he can make himself a cup of coffee and sometimes he totally needs assistance. It's completely dependent on how bad the tremors are.”	Device can be used at all time with or without tremors.

III. Methods

We started with an initial prototype in Figure 4 (Appendix A-C) to create a PID controller code (Appendix A-A). The circuit diagram of the device can be found in Appendix A-B. We want to maintain the position of the liquid container (Fig:1A.5) of the mug to reduce spilling while the handle experiences tremor motion. To maintain the orientation of the liquid container, a gyroscope (Fig:1A.7) collects positional data of the cup and this controls the active motors adjusting to a desired position. The position of the handle (Figure 1A.9) held by the user is translated to the cup. The gyroscope is sending its signal to an Adafruit Huzzah ESP32 Feather (Fig:1A.1). A closed-loop PID control scheme (Fig:1.B) is encoded and subsequently uploaded to the board using Arduino. Once the ESP32 receives the signal the PID works to send feedback. This, in turn, drives the servomotors to the desired orientation. One motor (Fig:1A.4) adjusts the position about the Y axis or the pitch of the gyroscope (Fig:2.B), while the other motor (Fig:1A.7) adjusts the position about the X axis or the roll of the gyroscope (Fig:2A.C). On the topic of power supply, different components are receiving different levels of electromotive force. The voltage breakout (Fig:1A.2) has an input voltage of 9V given by the battery (Fig:1A.6) while able to output two channels of 5V and 3.3V. The sensor and the micro-controller are both receiving 3 Volts of EMF, whereas the two servo motors are receiving 5 Volts of EMF. After fine tuning the PID controller we move on to create the aesthetics of the design and propose a way to study the device stability and effectiveness in reducing spilling.

In order to create a discrete device, the various mechatronic components must be made inconspicuous with the exception of a button located on the handle used to active the controls (Fig:2.A). As seen in Figure 1, all components are hidden within the body of the mug. This is a second iteration prototype and we will continue to make changes to the body and mechatronic components. The prototype components are bulky, loud and not as accurate as some of the components we would like to use. Using brushless DC motors instead of servomotors would reduce noise and provide a smoother feedback transition while adjusting the position. Using smaller components will allow for the liquid container to be bigger and not have to increase the overall size of the mug.

The way this device interfaces with the consumer is fairly simple. The hand grasping the handle of the mug would be fairly similar to that of a standard mug, however the handle would expectantly be more broad such that it can conceal the mechatronic components, as discussed above. This would prove useful in assisting PwPD as this reduces the need for fine motor control. Furthermore, broadened handles on mugs are currently featured in the assistive technologies mentioned in *Section I-A*. When attempting to drink from the mug, the control scheme saturates the signal at an angular displacement of 15 degrees with respect to the vertical (Fig:2.D), which permits tilting of the device beyond 15 degrees of rotation of the handle. The device is still able to correct about the roll of the gyroscope while drinking occurs but the pitch will be saturated and therefore not correcting for tremor in that direction.

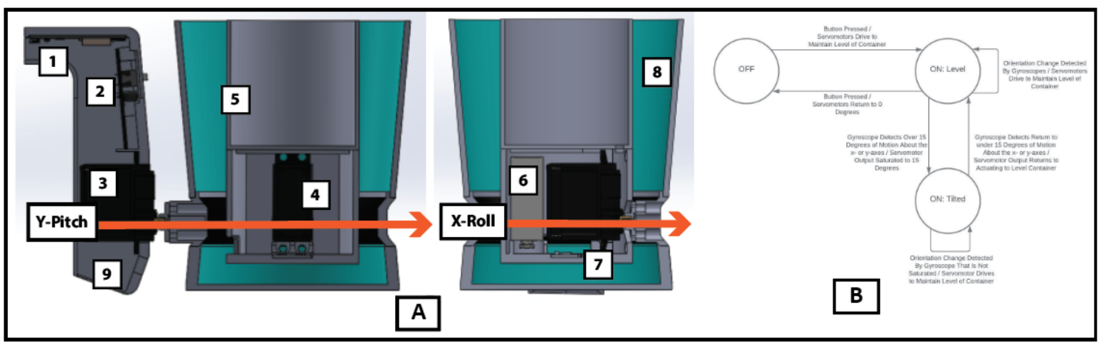

Fig. 1. (A)(Cross sectional CAD view about the Y-Axis (left), Cross sectional CAD view about the X-Axis (right), 1:Adafruit Huzzah ESP32 Microcontroller, 2:Voltage breakout board, 3:Y-Pitch MG 996R Servo Motor, 4:X-Roll MG 996R Servo Motor, 5:Liquid Container, 6:9V Battery, 7:MPU6050 6-Axis Gyroscope, 8:Outer Cup Container, 9:User Handle) (B)(Finite State Machine Control Scheme)

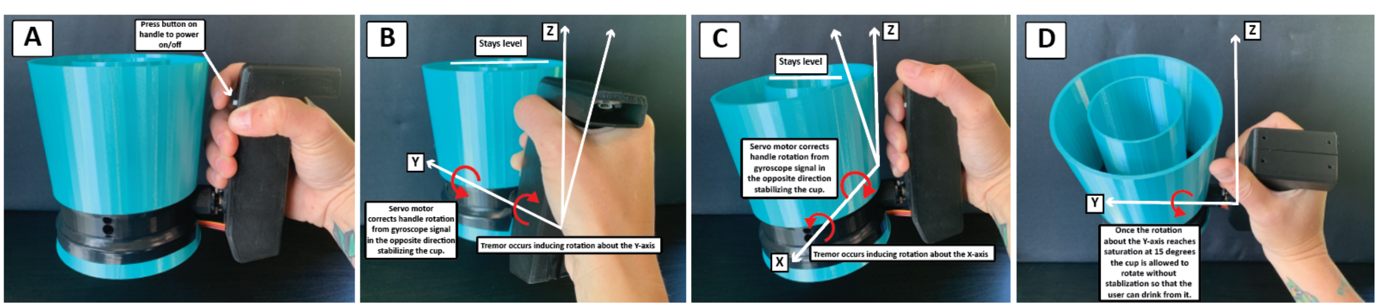

Fig. 2. Prototype Functions: (A) Power on/off (B) Control about the Y-Axis (C) Control about the X-Axis (D) Saturation of the Y-Axis to allow drinking from the cup

To test this device we have some proposed options. Creating a controlled observational test would give initial functional data. Mentioned in *Section I-A* resting tremors occur at approximately 4-6 Hertz this frequency would control motion used to test the function of the device. Controlling the handle motion to oscillate at the above frequency about both axes for a set amount of time while liquid is in the cup will provide an observable simulated test. The metrics of this test would be counting the amount of times that spilling occurs and then measuring the amount of liquid in the container at the end of each test. The same test will be conducted using a passive mug, with the same controlled motion. We believe that the active cup will spill less liquid in a smaller amount than the passive cup. After further iterations of the device it would prove useful to conduct human subjects trials. We could allow participants to use the product in the home and then collect data such as amount used and satisfaction using the device. Further we could also monitor speech function of the user if they choose to use the device frequently. We would get a better understanding if the ease of use of the cup allows for the user to drink more often. This design is a starting point that can provide thought to how this technology can be used in many areas that require automated stability.

IV. Intellectual Merit

The work discussed in this paper addresses the need of fluid consumption, which was beyond the scope of the prior art discussed in *Section I-A*. An endeavor into an unaddressed need demonstrates the widespread applicability of feedback control and should inspire other engineers to produce other everyday items that incorporate mechatronics. Further work into the needs addressed here could leverage the current design to create a more advanced or discrete device by, for instance, implementing a third controlled degree of freedom or by utilizing more compact mechatronic components as mentioned in *Section III*. The scope of this work does not yet evaluate the efficacy of the device in question, however it provides the foundation needed for another engineer to produce a testable device.

V. Broader Impact

This device is premature with regards to marketability, however the work performed thus far is promising in terms of easing the act of drinking and improving the quality of life for PwPD. Wressle et al. noted that even trivial tasks, such as drinking water, required more time and assistance for PwPD. Having realized a relationship between swallowing and speech impairment in a number of PwPD, an actuated mug will encourage PwPD to consume fluids as needed when considering communication as well as thirst, as the device would provide the assistance needed and increase the convenience of drinking fluids. As discussed in *Section I*, the benefits in assistance and convenience would also extend to a large population of people that experience non-Parkinsonian tremors. With hopes of providing the finalized product to the population of interest, the device is intended to be made open source for others to produce.

References

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Appendix A
Investigational Device Details

A. Code 1: PID Controller

```
#include "Wire.h"
#include <MPU6050_light.h>
#include <ESP32Servo.h>

Servo pitch;
Servo roll;

MPU6050 mpu(Wire);
unsigned long timer = 0;

// Time Parameters
float elapsedTime, time1, timePrev;
// PID for Roll
float roll_PID, pwm_L_F, pwm_L_B, pwm_R_F, pwm_R_B, roll_err,
    roll_previous_error;
float roll_p=0;
float roll_i=0;
float roll_d=0;
// PID roll constants
double roll_kp=1;
double roll_ki=0.001;
double roll_kd=0;
float roll_desired_angle = 0;

// PID for Pitch
float pitch_PID, pitch_err, pitch_previous_error;
float pitch_p=0;
float pitch_i=0;
float pitch_d=0;
// PID pitch constants
double pitch_kp=1;
double pitch_ki=0.001;
double pitch_kd=0;
float pitch_desired_angle = 0;

float PWM_pitch, PWM_roll;


void setup() {
  Serial.begin(9600);
  Wire.begin();
  mpu.begin();
  Serial.println(F("Calculating gyro offset, do not move MPU6050"));
  delay(1000);
  mpu.calcGyroOffsets();
  Serial.println("Done!\n");
```

```


  // Y-Axis Motor Attached to the Handle of Device
  pitch.attach(32); //servo motor for pitch
  // X-Axis Motor Attached to the Bottom of the Cup
  roll.attach(12);  //servo motor for roll
}

void loop() {
  mpu.update();
  timePrev = time1;
  time1 = millis();
  elapsedTime = (time1 - timePrev) / 1000;


  Serial.print("X : ");
  Serial.println(mpu.getAngleX());
  Serial.print("Y : ");
  Serial.println(mpu.getAngleY());
  int x = mpu.getAngleX();
  int y = mpu.getAngleY();
  //Serial.printf("%d %d %d\n", millis(), x, y);

    // Error Calculations
    roll_err = x - roll_desired_angle;
    pitch_err = y - pitch_desired_angle;
    Serial.print("Roll error : ");
    Serial.println(roll_err);
    Serial.print("Pitch_error: ");
    Serial.println(pitch_err);

    // Proportional Gains
    roll_p = roll_kp*roll_err;
    pitch_p = pitch_kp*pitch_err;

    // Integral Controller
    if(-2 < roll_err < 2){
      roll_i = roll_i+(roll_ki*roll_err);
    }
    if(-2 < pitch_err < 2){
      pitch_i = pitch_i+(pitch_ki*pitch_err);
    }

    // Derivative Controller
    roll_d = roll_kd*((roll_err - roll_previous_error)/elapsedTime);
    pitch_d = pitch_kd*((pitch_err - pitch_previous_error)/elapsedTime);

    // PID Controller
    roll_PID = roll_p + roll_i + roll_d ;
```

```
    pitch_PID = pitch_p + pitch_i + pitch_d ;
    Serial.print("Roll PID : ");
    Serial.println(roll_PID);
    Serial.print("Pitch PID : ");
    Serial.println(pitch_PID);

    // PWM Constraints
    if(roll_PID < -30){roll_PID = -30;}
    if(roll_PID > 30) {roll_PID = 30; }
    if(pitch_PID < -30){pitch_PID = -30;}
    if(pitch_PID > 30) {pitch_PID = 30;}

    roll_previous_error = roll_err;      //Remember to store the previous error.
    pitch_previous_error = pitch_err;    //Remember to store the previous error.

    PWM_pitch = 90 - pitch_PID;              //Angle for each motor is 90 plus/minus the PID value
    PWM_roll = 90 - roll_PID;

    pitch.write(PWM_pitch);                  //Finally we write the angle to the servos
    roll.write(PWM_roll);
}
```

B. Circuit Diagram

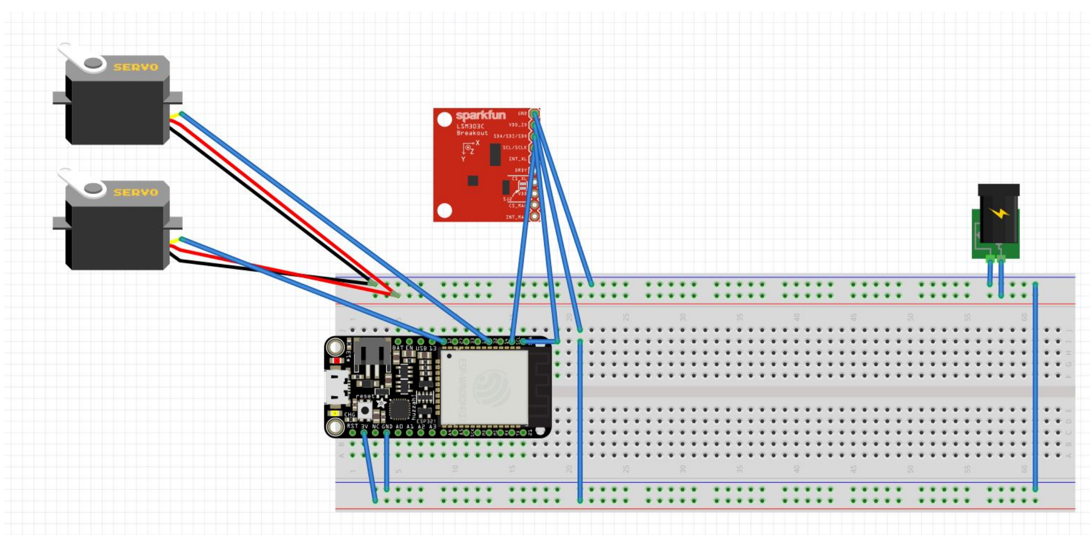

Fig. 3. Wiring Diagram of Device creating through Fritzing

C. Initial Prototype

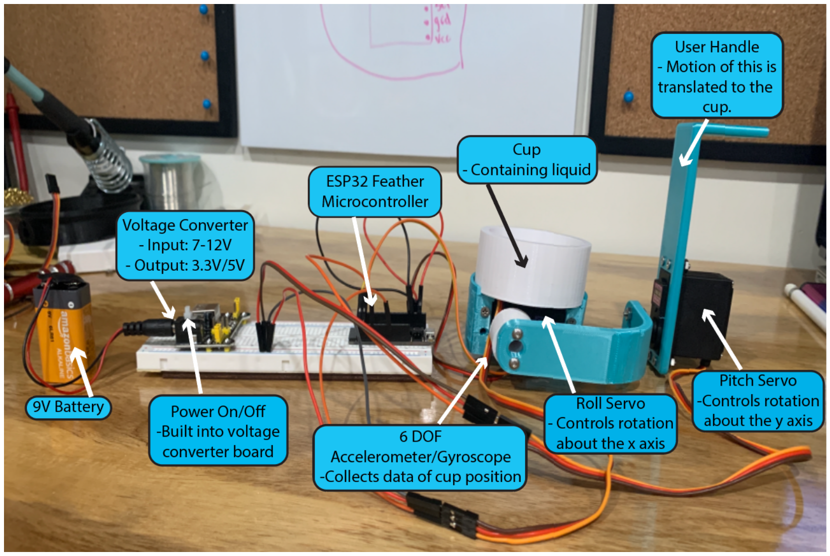

Fig. 4. Described here is the first prototype used to create the PID code used to controller the actuation of each servo motor (on