Self-Balancing Food Tray

ECE 445 Design Document

Team 31

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1. Introduction

1.1 Problem

Even for waiters and waitresses with experience, it may be a struggle to carry out and balance trays of food and beverages at restaurants while navigating around customers and rows of tables, especially with heavier and unevenly loaded trays. This is especially true when going to lower the tray down onto a nearby table or onto a folding servers table as the transition in height introduces potential dangers in stability.

With the recent growing popularity of robotic and automated waiters, the need for a self-stabilizing platform or tray could prove valuable to this emerging technology. Modern day waiter robots are slow, boxy, and require the user to ultimately still take the food off of the robot's carrying trays. With a small stabilizing platform, robots can be built to move faster with less risk and can actually serve food to a table like an actual waiter would.

1.2 Solution

Our solution is to make a small, easy to carry electronic multi-axis gimbal stabilizing system to be inserted/carried between the server's hand and tray that will stabilize the serving tray in real time. This would ensure that no drinks or food tip over while serving customers when encountering smaller/slower impacts and disturbances, allowing the restaurant to save costs on lost food, drinks, and dishware while preventing dangers such as hot food being spilled on the nearby patrons.

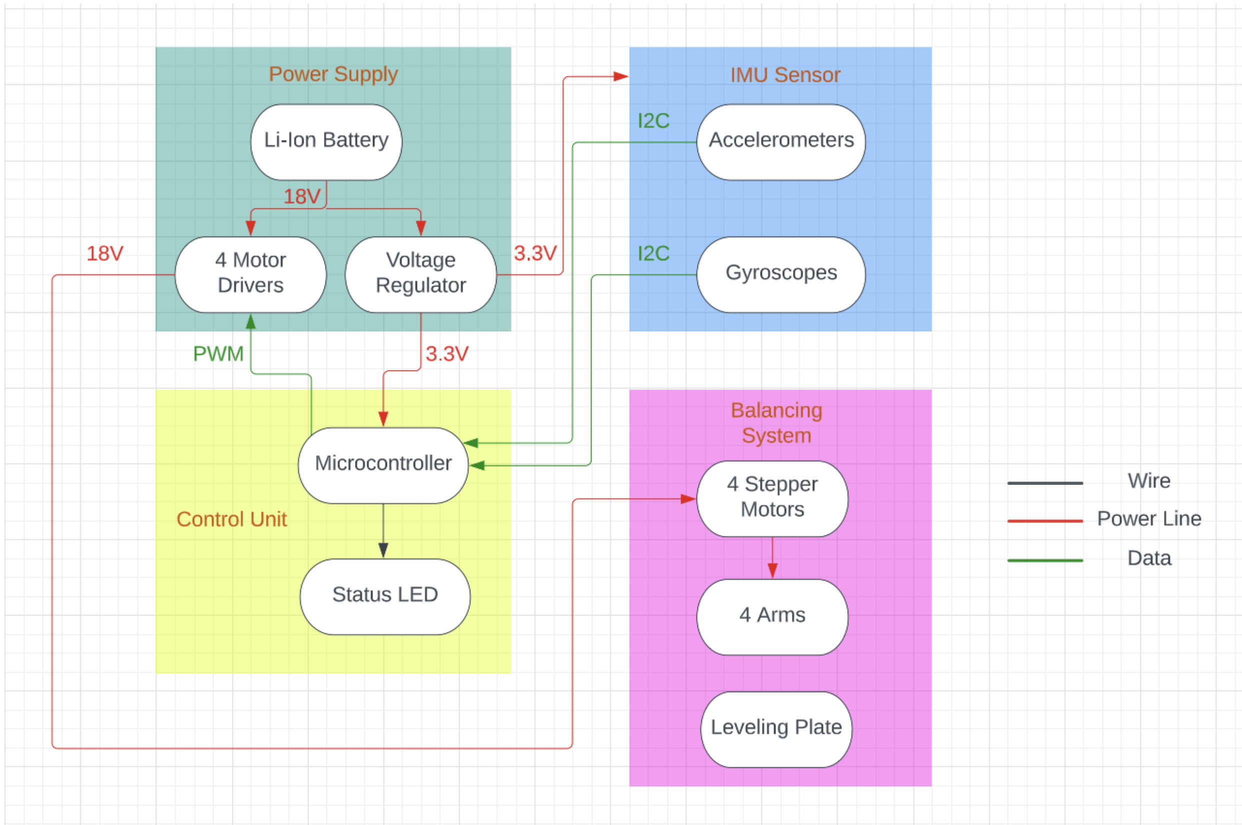
1.3 Visual Aid

1.4 High Level Requirements

- 2.3.1 Manipulate 4 motors in a way that the tray can be angled at minimum 5 degrees in each direction.
- 2.3.2 Able to balance at least 5 open-top cups or containers of water while moving at a normal adult walking pace of 2.5 mph to 4mph
- 2.3.3 Handle weights of up to 2 lbs representing a tray of food and drinks while maintaining active leveling

2. Design

2.1 Block Diagram



2.2 Functional Overview and Block Diagram Requirements

2.2.1 IMU

The inertial measurement unit (IMU) will be our primary form of detecting the state of the tray and determining whether it is considered balanced for our system. The IMU will contain gyroscopic and acceleration data, both of which we will leverage as part of our PID algorithm. The part that we chose to use for this project is the MPU-6050.

Requirements	Verifications

Deliver gyroscope and accelerometer data within accuracy threshold of 0.1 degrees and 0.01 meters per second squared.	Check gyroscope and accelerometer data with known constant angles/acceleration and confirm accuracy of 0.1 degrees and 0.01 meters per second squared.
No drift large enough to affect data accuracy and PID algorithm by more than 5% std.	Record data over a period of 10 seconds with constant load and plot error data to confirm accuracy of 5% std.

2.2.2 Power Supply

All four stepper motors will be each powered by a driver board. The driver must be capable of delivering enough current and voltage to drive the motor it is assigned to while also being capable of handling the same or higher number of microsteps as the motor. This power driver will in turn be connected to a rechargeable battery. To meet these as well as our below listed requirements, we'll use a Milwaukee 18V 2A rechargeable battery.

Requirements	**Verifications**
All four stepper motors should be able to run smoothly at 75% max voltage for at least one hour at half maximum load.	Confirm that the balancing system can run for one hour at half maximum load.
Quick swappable battery system will be replaceable by the user in less than one minute.	Run 10 trials of replacing the battery within a minute and have at minimum 8 successes. These trials will be done by volunteers who are informed of the proper way of replacing the batteries.

2.2.3 Control Unit

The Teensy 4.1 development board will take the IMU's gyroscope and accelerometer data to measure angular tilt and velocity. This data will be used to make the necessary adjustments as it is fed into the PID algorithm running onboard the microcontroller, which sends the adjustments in angle as PWM signals to the Balancing System.

Requirements	**Verifications**

PID algorithm must be able to stabilize sudden increases in weight of up to 1 lb on outer edges of tray	Test by lightly dropping weights of up to 1 lb on an empty tray and see if it can counter the imbalance while not dropping the weight.
Microcontroller buses must be able to send data to all 4 motors simultaneously up to a PWM frequency of 200 MHz	Create a test script that demonstrates stepper motor capabilities to rapidly change speeds and/or direction based on inputted wave-like motions.

2.2.4 Balancing System

The balancing system will consist of the aforementioned four stepper motors. These motors will control the distance the four arms will bend or extend. These arms will consist of three solid pieces: one piece connected to the tray, another connected to the motor shaft, and lastly a linkage piece between the two. The three pieces will be connected via two revolute joints which will allow the arm to freely rotate in one degree of freedom (up and down). Overall, the adjustments will be made on the pitch and roll axis, not on yaw. The stepper motors we chose to use will be Nema 17s.

Requirements	**Verifications**
The system can balance itself to within while the user is walking at an average adult walking pace of 3 mph.	Place weights totalling 2 lbs dispersed along the tray while walking at a speed of 3mph. We will measure the distance walked and the time walked to calculate the speed.
Create four arms of identical specifications with at most 3 mm of variance between all parts.	Measure finished parts with digital calipers to verify accuracy of dimensions between all parts.
Use stepper motors which are rated at greater than .25 ft pounds of torque each to carry a load of 2 lbs on the tray.	Test by placing a weight of 5 lbs within the central area of tray and seeing if load can be handled adequately.

2.3 Tolerance Analysis

The most critical part of the successful completion of our gimbal stabilizing food tray lies in the fine tuning of the microcontrollers leveling system. Controlling each of the four motorized arms independently in order to successfully balance a regular sized food tray will require us to have a quick and accurate leveling algorithm. We will need to run real world tests with a loaded up food tray to test and dial in the leveling system and make adjustments as necessary. Once we get it dialed in we will be able to run a leveling simulation to see the maximum angle the tray gets off-level while the system is and the user is actively walking.

3. Cost and Schedule

If the plan for this project is to be able to reproduce it for widely available use, a cost analysis must be completed in order to determine the estimated cost to consumers should a product like this be available. We will also need to establish a schedule for ourselves, both so as to have a reference of our progress as a group as well as to estimate how long a project like this will take if any other team of engineers were to design and produce this project.

3.1 Cost Estimate and Analysis

3.1.1 Labor

Description	Price per Unit	Total
Taylor Labor	$50.50 per hour 8 hours per week for 8 weeks	$3,232
Mitchell Labor	$50.50 per hour 8 hours per week for 8 weeks	$3,232
Jay Labor	$50.50 per hour 8 hours per week for 8 weeks	$3,232
Total		$9,696

3.1.2 Parts

Description	Price Per Unit	Total
4 Nema 17 Stepper Motors	$13.00	$52.00

4 TI DRV8825 Driver Chips	$18.00	$72.00
1 Teensy 4.1	$31.50	$31.50
1 Adafruit 3886 IMU	$12.95	$12.95
Raw Aluminum Frame Material	$10.00	$10.00
Fabrication of Frame	$100.00	$100.00
Total		$278.45

3.1.3 Total

Description	Total
Labor	$9,696
Parts	$278.45
Overall Total	$9,974.45

3.2 Schedule

Week	Task	Taylor	Jay	Mitchell
Feb 20 - Feb 24	● Begin ordering all parts	●	●	●
	● Finish Design Document	●	●	●
	● Begin Receiving Parts	●	●	●
	● Complete mechanical design of components			●

Feb 27 - Mar 3	● Send out parts to be machined			●
	● Start Looking into PCB design	●	●	●
Mar 6 - Mar 10	● Submit PCB design Order	●	●	●
	● Plan to receive most of machined parts at during the week	●	●	●
Mar 20 - Mar 24	● Assemble frame of balancing system			●
	● Program and prototype Teensy for stepper motor control	●	●	
	● Ensure reliable I2C data reading IMU	●	●	
Mar 27 - Mar 31	● Program PID control loop for control unit and IMU subsystems	●	●	
	● Assemble physical parts of the balancing subsystem.			●
	● Second PCB order if necessary	●	●	●
April 3 - April 7	● Anticipated troubleshooting of software	●	●	●
	● Miscellaneous adjustments	●	●	●
April 10- April 14	● Filler week	●	●	●
April 17 - April 31	● Filler week	●	●	●

4. Ethics and Safety

4.1 Ethics

Code I.1 of the IEEE ethics code states, “to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment”. Our gimbal system will strive to provide a safe experience, in accordance with code number one of the IEEE code of ethics, to both the user and customers who may be at the receiving end of the product's capabilities.

Code II.5 of the IEEE ethics code states, “to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, to be honest and realistic in stating claims or estimates based on available data, and to credit properly the contributions of others”. We will provide credit to sources we received inspiration from and or received pertinent information from in the construction of our project in accordance with the code of ethics.

4.2 Safety

[1] There will be no exposed wiring to prevent liquids or other debris from potentially shocking the user.

[2] The motorized arms will not move in a motion too quickly where the user or surrounding people could be injured

[3] If the weight limit of the system is exceeded the system should handle it in a way that the stabilizer system is overridden and the product essentially turns off to prevent possible stress to the motor system as well as unpredictable behavior from the leveling system.

5. References

5.1 Visual Aid Images

[1] (n.d.). "Female Hand Holding Something." Depositphotos.
https://depositphotos.com/77620065/stock-photo-female-hand-holding-something.html

[2] Kuhn. (2021). "The Octo-Bouncer: Advanced Bouncing Patterns." YouTube.
https://www.youtube.com/watch?v=lYyAMDYzJQM

[3] Food Tray: (n.d.). "Oval Restaurant Serving Trays NSF Certified Non-Skid Food Service Hotel Bar Tray." Overstock.
https://www.overstock.com/Home-Garden/Oval-Restaurant-Serving-Trays-NSF-Certified-Non-Skid-Food-Service-Hotel-Bar-Tray/30827966/product.html

5.2 Documents

[4] "IEEE code of ethics," IEEE, Jun-2020. [Online]. Available:
https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 6-Feb-2023].