ECE 16 Final Report - Team K: Ultimate Frisbee Development

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This is the final report for the ECE 16 customer need project that we were tasked with. In the paper, we will be discussing the entire process of designing, building, and testing the device. Specifically, the following aspects of the process will be discussed in detail: Customer Need Request, Need Assessment, Background Research, Design Alternatives, Solution Proposal, Development plan, System Testing and Validation, Final Design, and a Discussion around Challenges and Limitations to our system.

CCS Concepts: • **Computer systems organization** → Embedded systems; Sensors and Actuators; • **Hardware** → Communication hardware, interface, and storage.

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1 CUSTOMER NEED REQUEST

Our customer for this project, Max Gibson, had a need, particularly in regard to his hobby of playing ultimate frisbee at UCSD. As a veteran member of the club on campus, one of his tasks is to help newer members of the club get better at throwing the frisbee with proper technique. The problem is that this is extremely time-consuming for both himself, as well as other veterans of the club, as they have to constantly monitor and give advice to newer members, both in-person, as well as if they were reviewing footage.

For this reason, our customer wanted a device that could numerically break down the throwing technique of an individual. Specifically, he wanted a device that could record the angle and max spin at the instance of the throw, so that members can see improvement themselves, without having to rely on others. This would also make their improvement process faster and more efficient. He also wanted the device to be lightweight and circular, to avoid intrusion with the thrower's hands, or affect the weight of the frisbee itself.

2 NEED ASSESSMENT

Through an initial interview with our customer, there were a few more specifications we got to know about the device. Out of what we discussed, there were 4 major specifications that we narrowed down, in order for the device to satisfy our customer's needs.

- The device will only be used during practices, with the thrower standing still.
- The device will be placed at the center of the bottom of the frisbee, with a 2 - 2.5 inches distance from the edge so that the thrower's hands won't make contact with the device.

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- The customer prefers the device to record the maximum spin rate of the frisbee when thrown right out of the hand and it should be able to record both a front-hand and back-hand throws.
- The customer also needs the device to be able to record the angle at which the frisbee is leaving the hand since the initial angle of the frisbee can significantly affect the trajectory of the flight.

To get a better idea of the task at hand, we decided to conduct a survey about the features we would incorporate into the device using the Kano method, and analyzed our results in that manner as well. The following subsections will first explore the questions posed by the survey and the results of the survey. The second subsection will analyze the results to decide which features would be best for the device.

2.1 Survey Questions and Results

Before we break down the results, here are the 6 questions we asked to determine the best features for the device. Using this survey, we interviewed 8 people including our customer, who are from the ultimate frisbee team or are normal frisbee players.

(1) How would you feel if the device has a permanently mountable function to the frisbee?
How would you feel if the device does NOT have a permanently mountable function to the frisbee?
How important is the feature above for solving your need?
(2) How would you feel if the device has a camera attached to the frisbee?
How would you feel if the device does NOT have a camera attached to the frisbee?
How important is the feature above for solving your need?
(3) How would you feel if the device has a display (to display readings) attached to the frisbee itself?
How would you feel if the device does NOT have a display (to display readings) attached to the frisbee itself?
How important is the feature above for solving your need?
(4) How would you feel if the device can relay readings to your phone after a throw (or any bluetooth feature)?
How would you feel if the device can NOT relay readings to your phone after a throw (no bluetooth feature)?
How important is the feature above for solving your need?
(5) How would you feel if the device is circular (centered in the middle) on the frisbee?
How would you feel if the device is NOT circular on the frisbee?
How important is the feature above for solving your need?
(6) How would you feel if the device changed the weight of the frisbee significantly?
How would you feel if the device does NOT change the weight of the frisbee significantly?
How important is the feature above for solving your need?

Figures 1-3 give some basic information about the participants of our survey, as well as the results of the survey itself.

2.2 Survey Analysis and Explanation

Figure 4 shows the survey analysis of the features, using the Kano method.

From a combination of the Kano method as well as the level of importance of each feature, we were able to decide the features for our initial prototype. There was a very clear indicator that a **Bluetooth feature and a circular shape** of the device were necessary for the device (mostly attractive, with some musts and one-dimensional). There was a split in the responses of **feature 1**

Timestamp	Name	Gender	Age
5/4/2023 10:17:50	max	male	20
5/5/2023 15:52:49	Nilesh Mukundan	Male	20
5/5/2023 16:00:13	Daniel	Male	21
5/5/2023 17:13:21	Sumedh	Male	20
5/6/2023 16:29:13	Franklin	Male	19
5/6/2023 19:22:32	Amean	Male	20
5/7/2023 13:28:19	Richie Tay	male	21
5/7/2023 13:51:28	Dawson Tam	Male	20

Fig. 1. Basic information about participants

1a. How would you feel i	1b. How would you feel i	How important do you thi	2a. How would you feel i	2b. How would you feel i	How important do you thi	3a. How would you feel i	3b. How would you feel i	How important do you thi	4a. How would you feel i
I like it	I am neutral about it	Moderately important	I dislike it	I am neutral about it	Slightly important	I am neutral about it	I am neutral about it	Somewhat important	I like it
I expect it	I am neutral about it	Moderately important	I like it	I can tolerate it	Very important	I am neutral about it	I am neutral about it	Neutral	I like it
I can tolerate it	I am neutral about it	Moderately important	I dislike it	I expect it	Not at all important	I dislike it	I expect it	Moderately important	I like it
I like it	I am neutral about it	Moderately important	I like it	I am neutral about it	Moderately important	I like it	I am neutral about it	Neutral	I like it
I can tolerate it	I expect it	Very important	I am neutral about it	I expect it	Slightly important	I am neutral about it	I am neutral about it	Neutral	I like it
I like it	I can tolerate it	Neutral	I dislike it	I like it	Not at all important	I expect it	I can tolerate it	Somewhat important	I expect it
I like it	I am neutral about it	Moderately important	I like it	I can tolerate it	Not at all important	I like it	I can tolerate it	Not at all important	I expect it
I can tolerate it	I am neutral about it	Moderately important	I dislike it	I like it	Not at all important	I am neutral about it	I expect it	Moderately important	I like it

Fig. 2. Results of the survey Part 1

4b. How would you feel i	How important do you thi	5a. How would you feel i	5b. How would you feel i	How important do you thi	6a. How would you feel i	6b. How would you feel i	How important do you thi
I can tolerate it	Moderately important	I am neutral about it	I am neutral about it	Somewhat important	I expect it	I like it	Slightly important
I can tolerate it	Very important	I like it	I dislike it	Extremely important	I dislike it	I like it	Extremely important
I can tolerate it	Very important	I can tolerate it	I dislike it	Somewhat important	I dislike it	I expect it	Extremely important
I can tolerate it	Somewhat important	I expect it	I can tolerate it	Neutral	I expect it	I like it	Moderately important
I dislike it	Very important	I like it	I dislike it	Extremely important	I dislike it	I like it	Extremely important
I dislike it	Extremely important	I am neutral about it	I am neutral about it	Neutral	I dislike it	I like it	Extremely important
I can tolerate it	Very important	I expect it	I dislike it	Extremely important	I can tolerate it	I like it	Extremely important
I dislike it	Extremely important	I like it	I can tolerate it	Extremely important	I dislike it	I like it	Extremely important

Fig. 3. Results of the survey Part 2

	Feature 1	Importance	Feature 2	Importance	Feature 3	Importance	Feature 4	Importance	Feature 5	Importance	Feature 6	Importance
Max	A	Moderately important	R	Slightly important	I	Somewhat important	A	Moderately important	I	Somewhat important	R	Slightly important
Nilesh Mukundan	I	Moderately important	A	Very important	I	Neutral	A	Very important	O	Extremely important	R	Extremely important
Daniel	I	Moderately important	R	Not at all important	R	Moderately important	A	Very important	M	Somewhat important	R	Extremely important
Sumedh	A	Moderately important	A	Moderately important	A	Neutral	A	Somewhat important	I	Neutral	R	Moderately important
Franklin	I	Very important	I	Slightly important	I	Neutral	O	Very important	O	Extremely important	R	Extremely important
Amean	A	Neutral	R	Not at all important	I	Somewhat important	M	Extremely important	I	Neutral	R	Extremely important
Richie Tay	A	Moderately important	A	Not at all important	A	Not at all important	I	Very important	M	Extremely important	R	Extremely important
Dawson Tam	I	Moderately important	R	Not at all important	I	Moderately important	O	Extremely important	A	Extremely important	R	Extremely important

Fig. 4. Survey Analysis using the Kano method

(attractive and indifferent), but this still indicates that we should include a permanently mountable function, even if it is of moderate importance. **Feature 3**, the in-built display on the device, had a mostly indifferent response, with slight importance, so we decided to only add it if we have time. **Feature 2** was a bit more complicated since there were almost an equal number of attractives and reverses. There were more reverses with an additional indifferent as well. Ultimately, we took this into account, as well as the low importance of it throughout all the responses, and decided to not include a camera on the device. **Feature 6** had a clear response to it. We should design the device such that it won't alter the balance or weight of the frisbee by too much.

3 BACKGROUND RESEARCH

There were 3 things that we researched, before the initial prototype for the device. The first of which was the frisbee parameters. We discovered that in ultimate frisbee (and most common frisbees in that case) the frisbee that is used has a mass of 175 grams, a diameter of 10.5 inches, and a height of 1.31 inches. Second, we deeply researched the importance of spin and angle to a throw. This was necessary for understanding the problem at hand. Ultimately, we learned that the spin and angle directly relate to how the frisbee will travel in the air. The spin of the frisbee is what keeps the flight of the frisbee stable so it does not have any rotation of itself in the air. The angle of the frisbee throw will determine the trajectory of the frisbee in the air after the throw. The last thing we researched was the component that we were going to use in order to measure the angle and spin. The MPU6050 is a 3-axis sensor that is capable of detecting acceleration as well as spin (gyroscope). This is what we will use moving forwards.

4 DESIGN ALTERNATIVES

At first, we contemplated using the Arduino Nano as our MCU for the device, which would hook up to a 9V battery. Upon further consultation with our customer as well as the professor, in order to satisfy the customer's needs, the device would need to be much lighter. This would mean that the MCU and the massive 9V battery would need to be removed from the device, for something much lighter. The professor then provided us with a TTGO T7 V1.3 (ESP32 device), and a much lighter 3V Li-Po battery. This made the device much more compact, and, overall, fit our customer's needs better.

Although the Bluetooth feature was a very attractive feature, as shown by the survey, as we discussed the issue with the professor, we got some valuable feedback. The professor told us that the Bluetooth feature was not completely necessary in order to satisfy our customer's needs unless the customer needed the feature to view past data. If not, the feature would simply obfuscate the device's intended purpose. Based on this we decided to ask our customer if they would need historical data in order for new frisbee members to view their improvement. However, all he needed was a benchmark that would be set by one of the more experienced throwers (in regards to spin and angle), and the newer member to attempt to replicate and/or get close to that standard. Since he said this, we also asked if then, he would be interested in removing the Bluetooth feature, and instead, making the OLED display the main method in which information was relayed. After the benchmark was set, it would simply be reset for the inexperienced thrower, and the could try to reach that standard. Our customer was satisfied with this suggestion so we decided to go along with this idea instead for the proposal.

5 SOLUTION PROPOSAL

Based on our customer's needs, we had the features established for our initial prototype:

(1) The device will be mountable and can be detached from the frisbee.
(2) The device will be light to not affect the throw and also circular to not alter the hand placement and not give discomfort to the thrower.
(3) The device will have an OLED display to show the maximum spin and instant angle of throw.

NOTE In the initial project proposal, we had a Bluetooth feature as well. But because the design alternatives were already stated (which we discussed after the project proposal was made), the Bluetooth feature here was also omitted.

6 DEVELOPMENT PLAN

Figure 5 below shows the development plan for the 3 weeks leading up to the final prototype and final presentation.

7 SYSTEM TESTING AND VALIDATION

This section will be going over the entire process of building the prototype, mentioning the successes and failures we had with our iteration cycles. The first 2 subsections will go over a description of

SPRINT PLAN

Week	Due Date	Task	Person
8	Wed.	Soldering of Device (ESP32, OLED, Gyro)	Tianhao/Praveen
8	Sun.	CAD Design of Device	Praveen
8	Sun.	Base Code for Angle and Spin of Gyroscope	Norberto
9	Wed.	3D Print Finished	Praveen
9	Wed.	ICA 8: Project Update	Norberto/Praveen
9	Fri.	HW6 Challenge 1/2 Documentation	Praveen
9	Sun.	Testing of Gyro Spin, Finalization of Spin code (HW6 Challenge 3)	ALL
10	Mon.	ICA 9: Customer Check-in	Tianhao
10	Wed.	Code for calculating spin and angle at the instance of throw (BUILD COMPLETE)	ALL
10	Thurs/Fri.	FINAL TESTING (Testing of angle, as well as overall accuracy using methods discussed in class.	ALL
10	Sat.	Poster	ALL
10	Sun.	HW7 Documentation	ALL
Finals	Wed/Thurs	Final Report	ALL

Fig. 5. Development Plan for Project

both iteration cycles we went through, and the last 2 subsections will go over the tests that we ran in each iteration.

7.1 Iteration 1: Initial Encapsulation Design + Displaying Spin and Angle

In this iteration, we designed our first encapsulation for the device, which consists of an ESP32 module, OLED display, and a gyroscope. For the functionality itself, for this iteration, we were able to display the spin at any given moment, and show the angle at any given moment. For us, this was just a starting point. We recognized that although the spin and angle were displaying properly, it did not satisfy our customer's need, as he wanted the device to calculate the angle at the instance of the throw as well as the max spin of the frisbee itself. We acknowledged this as we talked about it with our customer. As for the device, he provided us with valuable feedback that we could use to redesign the product. There were 2 main deficiencies with the device. The first was that the reset button of the device was too far into the device to reach comfortably. The second concern was that there were gaps in between the top of the device and the bottom, which was attributed to the height of the encapsulation for the gyroscope and ESP32. Since the height was so large, when the wires went over it, it would bulge the top too far from the bottom of the device. So for the next iteration, we aimed to first complete the functionality that met our customer's needs. Then, we aimed to do a complete redesign of the device encapsulation, so that the wires would completely fit within the bounds of the bottom of the device, and that the reset button, as well as the charging port and on/off switch, would be easier to access.

7.2 Iteration 2: Average Angle + Max Spin + New Design

In this iteration, we implemented the functionality of the device to meet our customer's needs. During testing with our customer, he liked the new design, so we will continue with this on to the next iteration. However, while the max spin was calculated correctly, we noticed that the angle had very high variability in accuracy. The way the angle was calculated in this iteration was by taking a sample of the average angle over the first 0.5 seconds after a throw. After consulting with our customer, however, he referred us back to the original need which was the angle at the instance of the throw, not a couple of seconds after the throw. Furthermore, while the angle was correct on some tests, it was highly inaccurate on others, showing angles like 85 degrees, when the actual angle was around 20 or 30 degrees. From further testing, we figured out that the incorrect readings were a result of 2 things: wind and applied force. The cause for both reasons was due to the way that angle is calculated, on any accelerometer. The angle is calculated by taking the magnitude of all 3 vectors of acceleration and finding the angle between that vector and the az vector, in order to find the tilt angle of the frisbee. So, when the wind hits the frisbee, and slight vibrations occur, it messes with the angle calculated by the accelerometer. Even worse, even the acceleration that we apply to the frisbee at the instance of the throw, affects the angle calculation of the frisbee, since the magnitude of x and y at that instance is so high, which messes with the angle calculation itself. In the final iteration, we will find a way to calculate the angle of the throw right before the throw occurs, to get a better angle calculation. When discussing with our customer about this idea, he was satisfied with the device working this way. The reason for this modification is that the angle calculation is most accurate when there is 0 applied force on the frisbee, and moreover the accelerometer.

7.3 Iteration 1: Testing

Spin Testing: To demonstrate that our gyroscope function works, we decided to conduct 5 tests. The test was conducted by attaching a long object (hammer) to the frisbee, before rotating the object as uniformly as we could with the handle. Below are the details of each trial; the time was recorded by stopwatch. Although the rotation of the frisbee with the long object was not perfect (human error in spinning consistency), the gyroscope range of rpm was still within the acceptable range so that we could declare the gyroscope was still accurate. **Figure 6** below shows the results of the 5 tests. The first two tests are named SpinSlow.gif and SpinFast.gif, and a demonstration of the max spin functionality (MaxSpin.gif), are all shown in this link: https://drive.google.com/drive/folders/1dpkB8EJmbpP7aIcEm665dLsHlFnb1MPR?usp=sharing

Angle Testing: To test the angle of the frisbee we conducted 5 tests, finding the actual angle with a protractor and lining up the frisbee with that angle, and using the recorded angle from the device to find the percent error. For the second trial, it was hard to calculate percent error for 0 degrees, so we slightly increased the ground truth angle to 1, and measured from there. **Figure 7** below shows the results of the 5 tests.

Initial Encapsulation Design: The initial design for the encapsulation is at this link, the file named ProtoInside.jpg: https://drive.google.com/drive/folders/1dpkB8EJmbpP7aIcEm665dLsHlFnb1MPR?usp=sharing. While one of the support structures broke apart before taking this picture, you can clearly see that one, even with the gyroscope support, it is way too high for the wires to entirely go over, and the top piece to fit snugly over it. Secondly, if you see the outline of the support structure for the esp32, it is way too far inside, meaning that it would be difficult to access the reset button, which is vital to the usage of the device.

Trial Number	Time for 2 revolutions	Range of Gyroscope (RPM)	Actual RPM
1	3.5 sec	32-41	34
2	1.9 sec	59-65	63
3	2.3 sec	46-55	52
4	3 sec	34-43	40
5	3.7 sec	28-35	32

Fig. 6. 5 Tests showing the actual spin and recorded spin from the device. Notice how all actual values are within the recorded value range

Trial Number	Recorded Angle (Deg)	Actual Angle (Deg)	% Error
1	47	45	4.4
2	3	1 (Frisbee is facing down)	2
3	177	180 (Frisbee is facing up)	1.67
4	92	90	2.2
5	63	65	3.07

Fig. 7. 5 Tests showing the actual angle, recorded angle, and percent error. Since the percent error is low across the board, the stationary angle function works.

7.4 Iteration 2: Testing

First, for this iteration, we implemented the new base design, which features an extension outside the inside of the device, for easier access to the charge port, the on/off button, and the reset button. To make sure that the components stay in place, and that the top will never fall off, we hot-glued the components inside the device and superglued the top of the device.

The device is then attached to the frisbee via Velcro. During testing, the velcro was strong enough to withstand the impact of the frisbee on the ground, and would not fall off of the frisbee. We made sure of this by chucking the frisbee at the ground, and seeing whether or not the device would fall off. The final design, as well as the CAD for the bottom of the device, is named FinalDesignFront.jpg, FinalDesignBack.jpg, and FinDesignCAD.jpg at this link: https://drive.google.com/drive/folders/1dpkB8EJmbpP7aIcEm665dLsHlFnb1MPR?usp=sharing

For the testing of the functionality itself, after we figured from the tests in the first iteration, as well as the first couple of trials during the second iteration, the spin and max spin were pretty much producing the same results, and were working as intended. For this reason, we decided to heavily test the angle, since before this (previous iteration), we only tested the angle in a stationary situation, not when it was thrown. But with the limitations stated above in challenge 1, the test proved to us that the angle calculation was not working as intended. **Figure 8** shows the results that we gathered from 5 random trials from the many trials that we ran through (most were inaccurate). The first of the 5 tests recorded is named Iteration2.gif, located at this

Trial Number	Recorded Angle (Deg)	Actual Angle (Deg)	% Error
1	67	30	90
2	50	1 (Frisbee is facing down)	49
3	73	45	62
4	94	90	4.4
5	82	60	36

Fig. 8. 5 Tests showing the actual spin and recorded spin from the device. Notice the extremely high percent error. Indicates a massive problem with code.

link: https://drive.google.com/drive/folders/1dpkB8EJmbpP7aIcEm665dLsHlFnb1MPR?usp=sharing. After the first couple of trials, we stopped recording videos of the trials since the values being displayed were so far off of the angles that we could estimate just off of observation. At this point, we decided to go back to the drawing board for the angle calculation code.

Final Testing: Once the final iteration was complete (more details later), we decided to test the device to make sure it worked accurately. For the angle calculation validation, we used a protractor to calculate the angle of the frisbee when thrown. Then the display on the OLED was compared with the result from the protractor. For the max spin, we put a marker on the frisbee and used a slow-motion camera to film the throw. Since the spin slows down over time, we calculated the time it takes to complete the first two revolutions and converted the result into RPM in order to compare it to the displayed max spin on the device. **Figure 9** shows each of the techniques we used to test.

8 FINAL DESIGN

For the final prototype, the main thing we needed to iterate from the previous version was the angle detection. This time, we made it so that the angle will be calculated right before the instance of the throw, so that the applied force from our hands would not affect the detection of the angle. This provided much more accurate results, since the angle was calculated before there was any applied force, yet still satisfying our customer's need of getting the angle of the throw at the beginning. With that finished, here is how it works. After you switch the device on, the user will have a timer that counts down from 5, to let them know when to throw. Once the countdown is finished, the user will need to go into their throwing stance in 2 seconds, where the device will calculate the angle. Then, they can throw the frisbee, which is when the max spin will be recorded. Finally, the user can go check their frisbee to see the angle of their throw, as well as the max spin. To record again, they can press the reset button located on the bottom left of the device. Here is a video of the final prototype in action!

https://drive.google.com/file/d/1chbTFoyrGmR4GrUipraGYlTkuMDpuTuB/view

9 CHALLENGES AND LIMITATIONS

The main challenge that we faced was calculating the angle of the throw, from finding an equation that calculates the tilt angle from the sensor parameters to also readjusting the code for each

Fig. 9. Final Testing: On the left, angle calculation; On the right, frisbee marking for spin.

iteration to account for the limitation of the sensor when calculating the angle. Another challenge was accounting for extraneous factors, like air resistance and wind. Because of these issues, we spent too much time trying to figure out what was wrong with our device physically, when we simply were not accounting for it. In the future, for a project like this, we hope to figure out how to circumvent this issue altogether, perhaps by implementing some custom filter to take those factors out of the equation. Unfortunately, at the moment, we do not have the knowledge to do that.

We also need to note some of the system's limitations. The first is that in order to receive the most accurate result, the throw can't be made in a fluid motion. Rather, the user needs to go into the throwing position, before the angle is detected. Secondly, the device cannot measure more than 333 rpm, because the gyroscope itself can only detect 2000 deg/s of rotation, which is roughly 333 rpm. This is something that is an interesting, but out-of-scope issue, as through research, we learned that most commercial gyroscopes are within this range, and nothing more.

ACKNOWLEDGMENTS

Thanks to Professor Wang and our TAs for assisting us through the quarter and with the project.

10 REFERENCES

Here are the links that we used to assist us with our project:

- MPU 6050 Starter Code: https://github.com/ElectronicCats/mpu6050
- Frisbee Dimensions: https://usaultimate.org/programs/disc-standards/
- Ideal throws of Frisbees: https://ultimatefrisbeehq.com/ultimate-frisbee-throws/
- Physics of a Frisbee Throw: https://afda.com/the-physics-of-disc-flight