Autonomous Drone Navigation (December 2023)

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Vivek Patel (EE), Michael Ferrari (EE), Jack Walsh (CE), Matthew Glover (CS), Atharva Khadgi (CS), and Vamshi Kuturu (CS)

I. Problem Definition

A. Customer Requirements

In recent years, the utilization of drones has witnessed a substantial increase in various industries, ranging from agriculture and infrastructure inspection to search and rescue missions. These applications often require drones to navigate autonomously from a predefined starting point to a set destination. However, there are specific scenarios were relying solely on GPS for navigation is not feasible or reliable. This challenge has given rise to the need for the development of self-navigating drones that can operate in GPS denied environments, including dark and low visibility conditions. This section outlines the customer needs and provides a background for the development of a self-navigating drone system that fulfills these requirements.

B. Engineering Requirements & Restraints

- Independent Navigation: The primary customer need is the capability to navigate autonomously without reliance on Global Positioning System (GPS) signals. This is crucial for scenarios where GPS signals may be unavailable or unreliable, such as indoors, urban canyons, or remote areas with obstructed satellite visibility.
- Low-Light and Dark Environment Operation: The drone must be capable of operating effectively in low-light and dark environments, including nighttime operations. This capability is essential for applications like surveillance, security, and search and rescue missions conducted during nighttime hours.
- Obstacle Avoidance: The drone should be equipped with sensors, such as onboard cameras and LiDAR (Light Detection and Ranging), to detect and navigate around obstacles in its path. This is crucial for safe and collision-free navigation in complex environments.
- Robustness and Reliability: Customers expect a robust and reliable system that can be performed consistently under various conditions. This includes resistance to environmental factors such as wind, rain, and temperature variations.
- User-Friendly Interface: A user-friendly interface is essential to enable operators to input destinations, monitor the drone's status, and adjust mission parameters easily. Intuitive controls and real-time feedback are important aspects of the user interface.

II. Flow Chart Diagrams

A. Overall System Diagram

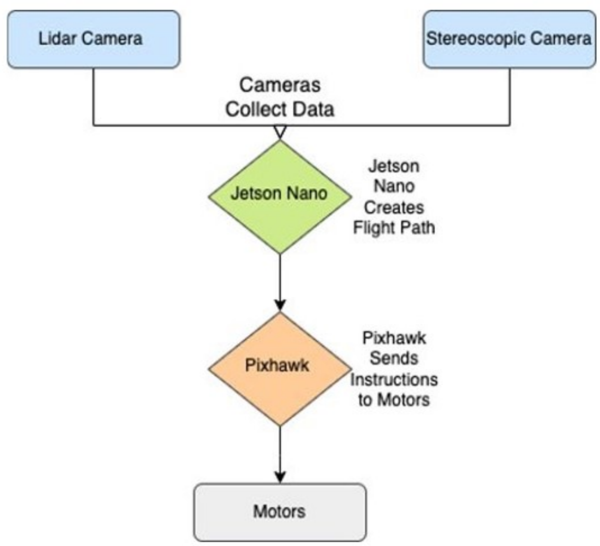


Fig 1. Showcased in the Overall System Diagram is a LiDAR Camera, Stereoscopic Camera, Jetson Nano, Pixhawk, and the motors of the drone. The system functions by allowing the cameras to collect and send images of the environment to the Jetson Nano. From there the Jetson Nano will utilize this data, to create a flight path. This flight path will be sent to the Pixhawk, so it can send induvial instructions to the 6 motors of the drone.

B. Software Diagram

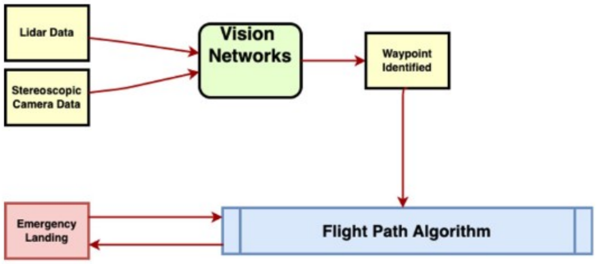


Fig 2. The Software Diagram explains how the algorithms in the Jetson Nano will operate. The camera data will be feed into vision networks that are trained to detect the position of the waypoint. Once the waypoint is detected, this information will be sent to the Flight Path Algorithm, where it will utilize the images to create an obstacle free and efficient flight path to the waypoint. If for any reason this algorithm were to crash or break, we have implemented an emergency landing feature for ethical and safety reasons.

III. Team Roles, Weekly Communication, Document Sharing and Project Management

To work as efficiently as possible, tasks have divided amongst all team members for maximum productivity. Additionally, a schedule of weekly meetings and method for document sharing has been put in place this entire semester. This section outlines the role of each team member, weekly schedule of meetings, method of document sharing, and project management.

A. Team Roles

In terms of team roles, each engineering student has been assigned a specific task to lead. Vivek Patel has been assigned the roles of programming the Jetson Nano to allow the hazard and flood lights on the PCB to operate during nighttime conditions. Additionally, Vivek has been learning the software for the flight path algorithm to be able to complete it next semester without the guidance of the CS students. Michael Ferrari has been assigned the task of designing and testing the PCB. Michael has been designing the PCB using KiCad and had breadboarded the design as well. Jack Walsh has designed, and 3D printed parts needed for this project using Fusion 360. These parts include a mount to hold the cameras, and a new case to protect the hardware. Together all three of the engineering students have also worked on testing the drones flight in the designated drone room as well. We also have had the help of three computer science graduate students that have primarily worked on developing our software system which includes the flight path algorithm.

B. Weekly Communication

Weekly meeting has taken place every Tuesday and Thursday of this semester, in which all 6 team members have attended. These meeting take place in the Senior Design Lab in the McCormack building of the UMass Boston Campus at 1pm. During these meeting, project plans, management, and goals are discussed. Along with this, each week on Fridays at 11am, all 6 team members and Professor Materdey have a meeting via Zoom. During this meeting, weekly objectives and progress are discussed.

C. Document Sharing

All documents used for this project are uploaded to the Microsoft Teams folder, that all 6 team members and Professor Materdey have access too. Documents that are inside this folder include weekly reports, data sheets, and helpful resources.

D. Updated MS Project

	10 days	**Mon 9/18/2**	**Fri 9/29/23**		**55%**
Evaluate timeline	1 day	Tue 9/19/23	Tue 9/19/23		90%
Review old project report	5 days	Wed 9/20/2	Tue 9/26/23	2	100%
Research ideas	5 days	Wed 9/20/2	Tue 9/26/23	2	70%
design problem statement	5 days	Wed 9/20/2	Tue 9/26/23	2	100%
rought draft	10 days	Mon 9/18/2	Fri 9/29/23		0%
Prototyping phase 1	**40 days?**	**Mon 10/2/2**	**Fri 11/24/23**	**1**	**22%**
software	**40 days?**	**Mon 10/2/2**	**Fri 11/24/23**		**22%**
discover required software: These softwares include the ones used in last years project, which are Pixhawk, ROS, Jetson Programming, and more.	5 days	Mon 10/2/23	Fri 10/6/23		80%
Work with CS Students to make Progress on ML Component.	12 days	Tue 12/5/23	Wed 12/20/23		20%
Learn how to use ArduPilotand use ArduPilotto turn the drone on and off.	5 days	Mon 10/23/23	Fri 10/27/23		50%
Review code that was made by last years team.	2 days	Fri 10/6/23	Mon 10/9/23		70%
purchase software and liscences if needed.	2 days	Mon 10/9/23	Tue 10/10/23	9	95%
Develop software	**30 days?**	**Wed 10/11/**	**Tue 11/21/2**	**13**	**1%**
hardware	**40 days?**	**Mon 10/2/2**	**Fri 11/24/23**		**22%**
Build item list and consider what parts need to be replaced. Consider if it is best to either continue to use the Jetson Nano from last year or if it would be best to start over with a different microcontroller.	5 days	Mon 10/2/23	Fri 10/6/23		50%
Make final decision on upgrading Jetson Nano to the Jetson Xavier and make final decision on purchasing 4D Lidar Camera.	5 days	Mon 10/23/23	Fri 10/27/23		0%
Develop hardware and integerate with software.	30 days	Mon 10/9/23	Fri 11/17/23	18	20%
Design and 3D Print New Case for Hardware.	1 day	Mon 10/2/23	Mon 10/2/23		50%
Design PCB that holds the lights on KI-Cad.		Mon 10/2/23			15%
First Testing Phase: In this phase we will run test to see how the drone performs in both indoor and outdoor settings. It would also be important to see how the drone perfroms in the dark.	10 days	Wed 11/22/23	Tue 12/5/23		10%
Initial testing of sensors and data collection from them such as the ZED 2 camera and the 2D lidar	11 days	Tue 11/7/23	Tue 11/21/23		50%
Test drone to see if it flys well and is stable.			Tue 11/28/23		0%
Second Building Phase	**63 days**	**Mon 1/22/2**	**Wed 4/17/2**	**1**	**0%**
Last test and finalization and report. The last test should evaluatethe performance of the drone. If the drone performance has dropped we should consider going back to the orginal product before we implemented the phase two changes.	10 days	Wed 4/17/24	Tue 4/30/24	17	0%

Formal reports and presentations				0%
Formal Design Presentation (FDP)	1 day	Sun 10/15/23	Sun 10/15/23	100%
Project Readiness Presentation (PRP)	1 day	Fri 12/1/23	Fri 12/1/23	80%
Design Validation Presentation (DVP)	1 day	Fri 3/15/24	Fri 3/15/24	0%
Final Product Presentation (FPP)	1 day	Wed 5/1/24	Wed 5/1/24	0%
five Project Specific Success Criteria				0%
Design a software that runs an AI to create a map from the starting location to the landing spot	160 days	Thu 9/21/23	Wed 5/1/24	45%
The drone should have the capabilities to operate fully autonomously at night	160 days	Thu 9/21/23	Wed 5/1/24	40%
The drone should have an operation mode that allows it to make an emergency landing in the safest viable area	160 days	Thu 9/21/23	Wed 5/1/24	35%
The drone should be designed with comparability to hive networks, and other autonomous system additions	160 days	Thu 9/21/23	Wed 5/1/24	30%
To have the drone map a designated area	160 days	Thu 9/21/23	Wed 5/1/24	50%

Fig.3 The figure above is the Updated MS project with percentages to go with each subtask listed. This MS projects showcases that project has gone through significant progress from both a hardware and software perspective.

IV. Skills/Tools, Resources, Inventory, and Budget

A. *Skills/Tools*

- Fusion 360
- MATLAB
- LTSpice
- Jetson Nano Programming
- KiCad

B. *Resources*

- ROS website
- Digi-key
- Reddit/Github
- YouTube
- NVIDIA Developer

C. *Inventory/Budget*

Below is a table of every part that has been bought thus far along with a table of the projects current inventory. Our estimated total budge it $600 and so far, $579.14 has been used. The total estimated budget is very low because our project is repurposing a lot of the parts that were bought from last year's team. The rest of the budge will be allocated towards buying smaller parts such as propellers incase the ones, we currently have break. Close to 90% of the estimated budget has been used.

Inventory

F550 Hex Drone
Jetson Nano
Zed Camera
2D LiDAR Camera
4D LiDAR Camera
LED chip
Lipo battery charger
Lipo battery
Fan for Jetson nano
DC Step up transformer
Heatsink for led chip

Budget

Item	Quantity	Unit Price	Total Price
LED chip	2	$9.74	$19.48
Lipo battery charger	1	$35.99	$35.99
Lipo battery	1	$59.19	$59.19
Fan for Jetson nano	1	$13.50	$13.50
DC Step up transformer	1	$12.99	$12.99
Heatsink for led chip	1	$8.99	$8.99
4D Lidar	1	$429.00	$429.00
Total	8		$579.14
Estimated Budget			$650.00

V. Five Project Specific Success Criteria

1.) Design software that runs AI/ML to create a flight path from the starting location to the landing spot.

2.) The drone should have an operation mode that allows it to make an emergency landing in the safest viable area.

3.) The drone should be able to detect waypoints.

4.) The drone should have the capabilities to operate fully autonomously at night.

5.) Design PCBs and cases so the circuitry can fit compactly on the drone and not decrease the drone's performance, while also protecting the hardware.

VI. Project Break Throughs and Progress on PSSCs

Regarding the first PSSC, much of the flight path algorithm has been developed and tested using the AirSim Software. The algorithm functions by first analyzing the camera data and detecting the way point. Then the algorithm will have the drone read the waypoint to get its next set of instructions. If the waypoint is not readable from the drone's current position, then the drone will move forward until it can read the waypoint. The next step for this PSSC is to test the algorithm using the actual drone instead of the AirSim software. This PSSC has been evaluated to be 60% complete.

Significant progress has been made regarding the second PSSC as well. For this PSSC a emergency landing function was implemented into our software. This function is called whenever the flight path algorithm crashes or breaks for any given reason. This feature has also been tested using the AirSim software and the next step for this PSSC is to test the function on the actual drone. This PSSC has been evaluated to be 70% complete.

PSSC 3 has been recently changed because the team decided to modify our approach. This modification included having the drone detect waypoints. This semester we have been using pretrained vision networks to detect waypoints. The waypoints we have chosen for the initial implementation is humans, but the goal for the final implementation is to have the waypoint be a QR code. The vision networks are very good at detecting humans using the ZED camera data. Additionally, we have set up the ZED camera to detect multiple humans at a time and indicate which humans are closer to the camera. The next steps of this PSSC include training the vision networks and testing it while the drone is flying. This PSSC has been evaluated to be 40% complete.

The fourth PSSC is mostly covered by our PCB design, which includes hazard and flood lights that will turn on in night conditions. The PCB has been designed and breadboarded. The next steps for this PSSC are to order the PCB and test it in nighttime conditions while the drone is flying. This PSSC has been evaluated to be 30% complete.

For the developed of PSSC 5, a new case is currently being designed to compactly fit all the hardware needed for this project. Along with this a new mount has been designed and 3D printed to hold and protect the cameras as well. The last step for this PSSC is to order the PCB and validate it to make sure it is sturdy and will protect the hardware. This PSSC is evaluated to be 60% complete.

VII. Ethical Considerations

Throughout the entire semester multiple ethical considerations have been put in place to allow for maximum safety to be achieved. These ethical considerations include implemented an emergency landing feature, to ensure that if the flight path algorithm ever breaks then the drone will land immediately which eliminates the chance of anyone getting hit by the drone. Additionally, the drones flight is currently being tested in a designated drone room which is enclosed by nets. This ensures that while testing the drone cannot leave the designated space and encounter any obstacles or people. Lastly, next semester we will be spending most of our time testing our project. While this testing takes place will be sure to wear the appropriate equipment and gear needed such as safety googles and hardhats if necessary.

VIII. Design Verification and Validation Plan

To validate the first PSSC, the AirSim software will be used to thoroughly test the flight path algorithm before we test it using the actual drone. Then we will begin testing the actual drone itself in the designated drone room. Once the quality of the algorithm can be ensured, we will test the drone outside in both daytime and nighttime conditions.

The validation and verification plan for the second PSSC is to test the landing feature on while the drone is flying. We will create tests where non ideal conditions are purposely enforced. This includes making the camera lens blurry, draining the drone's battery, and adding extra weight to the drone. This will ensure that the landing feature will be called and executed when needed.

PSSC 3 will have designed a test where will be put the drone through a maze where it must detect multiple waypoints and receive instructions from each waypoint to finish the maze. This will ensure that the drone can properly detect waypoints, receive instructions from waypoints, and execute instructions given by waypoints.

The fourth PSSC will be tested indoors first in various lighting conditions. We will examine if the hazard and flood lights are turning on when the room gets darker. When the quality of the lighting system is ensured, we will test the drone outdoors at nighttime.

The fifth PSSC will be verified and validated by examining the PCBs after they are soldered to make sure they are sturdy. Also, we will ensure that if the drone drops then the hardware will be protected by testing the strength of the 3D printed case.

IX. PCB Design

The PCB was designed to have 6 diodes spread across the board (as seen in figure 3). The design is to incorporate the lights necessary, a step-down converter, as well as future integration of the flood light that we plan on incorporating in the improved design of the PCB.

The diodes function at 85% capacity with the converter and the integration of photoresistors on the Arduino itself makes the whole design turn on at night where necessary. The flood light (although not shown in the picture) can operate from 10% to 100% brightness intervals with up to 30V of activation on the device. Below is the 80% complete design of the first PCB.

When the PCB is done, we will verify and validate the PCB by testing it indoors in dark settings. Then we will test it on the drone while it is flying at night as well.

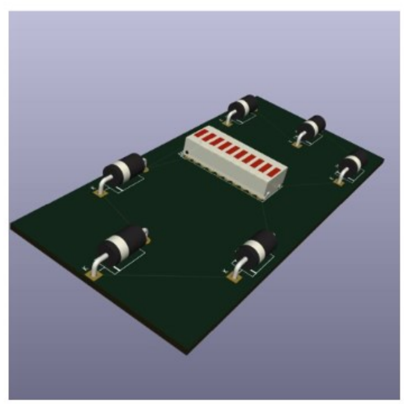


Fig.4 PCB design of the 6 diodes and step-down converter from and Arduino (or Jetson) to the components. 80% complete design with easy integration of other components where necessary.

X. CAD Files

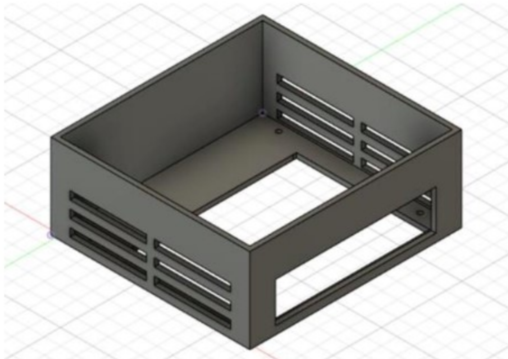


Fig.5 Showcased above is the protective case to house the hardware and ensure it is protected in case of a collision.

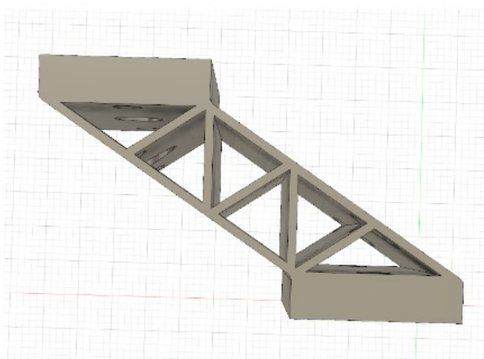


Fig.6 Displayed above is the Zed 2 camera mount to allow for the camera to be positioned at an optimal angle.

XI. Sensor Calibration, Data, ML Progress

The sensors in question are the stereoscopic camera that we have shown off in the demo as well as the LIDAR camera. The smaller sensors were the photoresistors on the PCB which already work at 100% capacity.

From figure 5 we tested the calibration of the stereoscopic camera with the idea of catching the people that are in the way of the camera. The camera would come back with data on where the people are in the room and how far away, they are from the camera, which is vital for the project's integrity. From the testing we have done, the camera comfortably accounts for 5-6 people as well as how close they are to the camera and their location in the space provided with 90% accuracy. The camera had little to no trouble running this software we developed, and the main functionality came from the computer that we ran the system from.

The other major sensor to test was the LIDAR camera which bounced signals off the walls and people around the camera. This device would spin continuously and give the software a solid idea of the surroundings of its space. From the live demo we were able to comfortably find edges to walls in a 12 m diameter to safely find the area to work with around the camera. The accuracy of the camera was about 70% to start and moved to about 80% as we tested the software more and more. This is passable for the moment, but we can improve this accuracy by increasing the power given to the camera without compromising the rest of the power shared on the drone as well (figure 6).

The ML component of the project can be seen in figure 5 where the camera could learn how close or far objects are over time just by taking many samples of the same people around different objects in the room. The idea is for the camera(s) to learn more about their surroundings to not only make the process of navigation faster but to also map out and navigate areas a lot more efficiently. Also, we are currently using pretrained vision networks in our flight path algorithm to detect waypoints. The next steps of our ML component of the project is to train the vision networks ourselves.

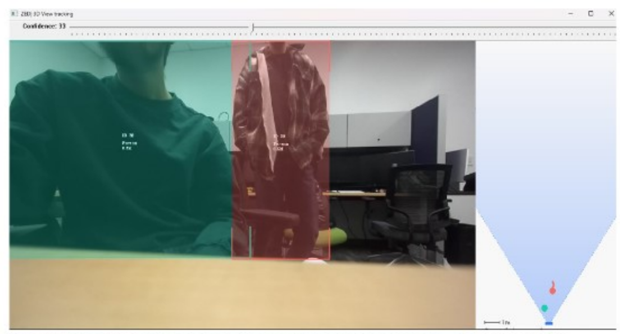


Fig.7 The figure above shows the stereoscopic camera feed and how the system finds the people in the room and tells us where they are in accordance with where the camera is located.

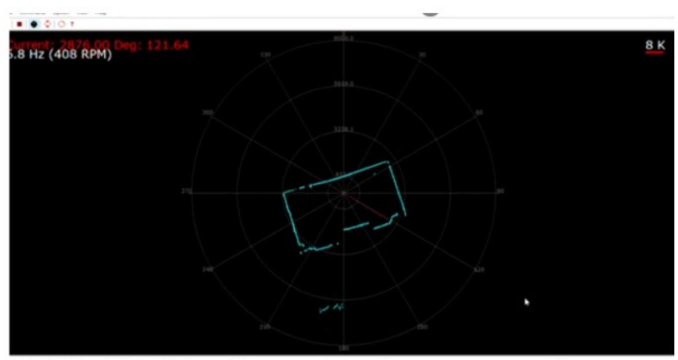


Fig.8 The LIDAR in action mapping out a square room with not many objects in it. A sort of backup to the stereoscopic camera to work in tandem with as the drone moves around a room.

XII. Images and Videos

Below is a link to one of our simulation videos. The video was made using the AirSim software. It is a simulation of how a drone would behave when controlled by our software. In the video the drone flies along a wall and then turns when it encounters an obstacle. Below the link to the video is a picture of our PCB circuit breadboarded. It is currently controlled using an Arduino and works very efficiently.

https://youtube.com/shorts/-XnSur4_YzA?feature=share

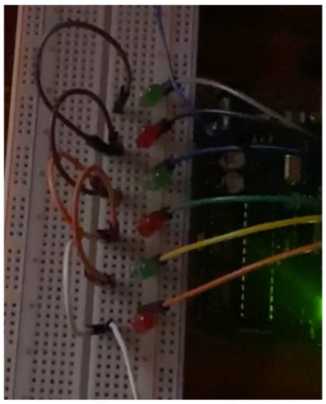
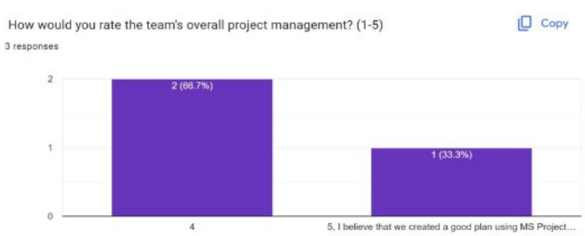


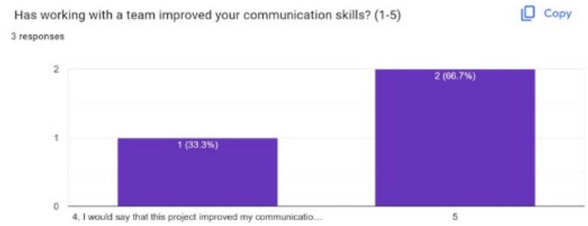
Fig.9 The image above showcases our PCB circuit on a breadboard. The circuit currently utilizes 6 LEDs, 6 Photoresistors, and an Arduino Uno.

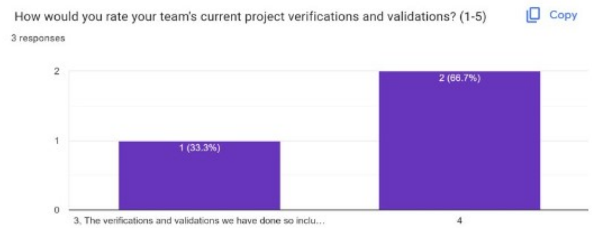
XIII. Team Self-Assessment

The results of the team survey indicate that all team members are satisfied and agree that we are making good progress. The team also agreed that communication is efficient along with project management. A few suggestions that Professor Materdey had for us in the CM/TM survey was to the MS teams folder more, work on task more in parallel, and finish tasks such as the drone training.

Survey results







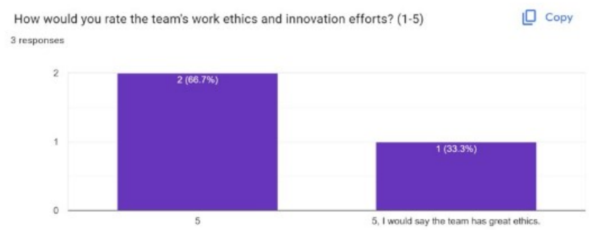


Fig.10 The results above show that all team members are generally satisfied with the progress of the project. It shows that the team has demonstrated excellent communication, management, and consistent progress.

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