The University of Texas at Austin
Cockrell School of Engineering

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USRC: Communications & Sensors

Design Review I

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INTRODUCTION

The USRC project at the University of Texas is called the Drone Estimation Lab (DEL). DEL is tasked with designing a system of generating an error ellipsoids around drones in GPS-denied environments as well as avoiding obstacles in flight. The following is a design review for the communications and sensors team.

Purpose: Flying multirotors autonomously in GPS-denied environments by generating error ellipsoid. [1]

HERITAGE

CONCEPT OF OPERATIONS

The main categories of drone sensors can be classified as accelerometers, gyroscopes, optical cameras, and magnetometers according to [2]. Drones usually use different combinations and configurations of these sensors in order to accurately determine their attitudes and effectively control the crafts.

MEMS IMU

One of the most common sensors on drones is a MEMS IMU which is an inertial measurement unit. The MEMS IMU is a combination of an accelerometer and a gyroscope. ‘Fusing the accelerometer and gyroscope information, the pitch and roll orientation motion of the drone can be estimated’ [2, p. 1]. Only having a gyroscope results in a 3-axis drone. Adding the accelerometer makes it a 6-axis drone

MAGNETOMETER

The previously mentioned MEMS IMU produced a 6-axis drone, but that leaves out heading control according to [2]. This angle control is given by the use of a magnetometer, making it a 9-axis drone.

3D LOCALIZATION

While the sensors described so far help control the attitude of the drones, 3D localization is needed in order to determine where it is in relation to their surroundings. This is where technologies such as LiDAR and RGB-D cameras are used according to [2].

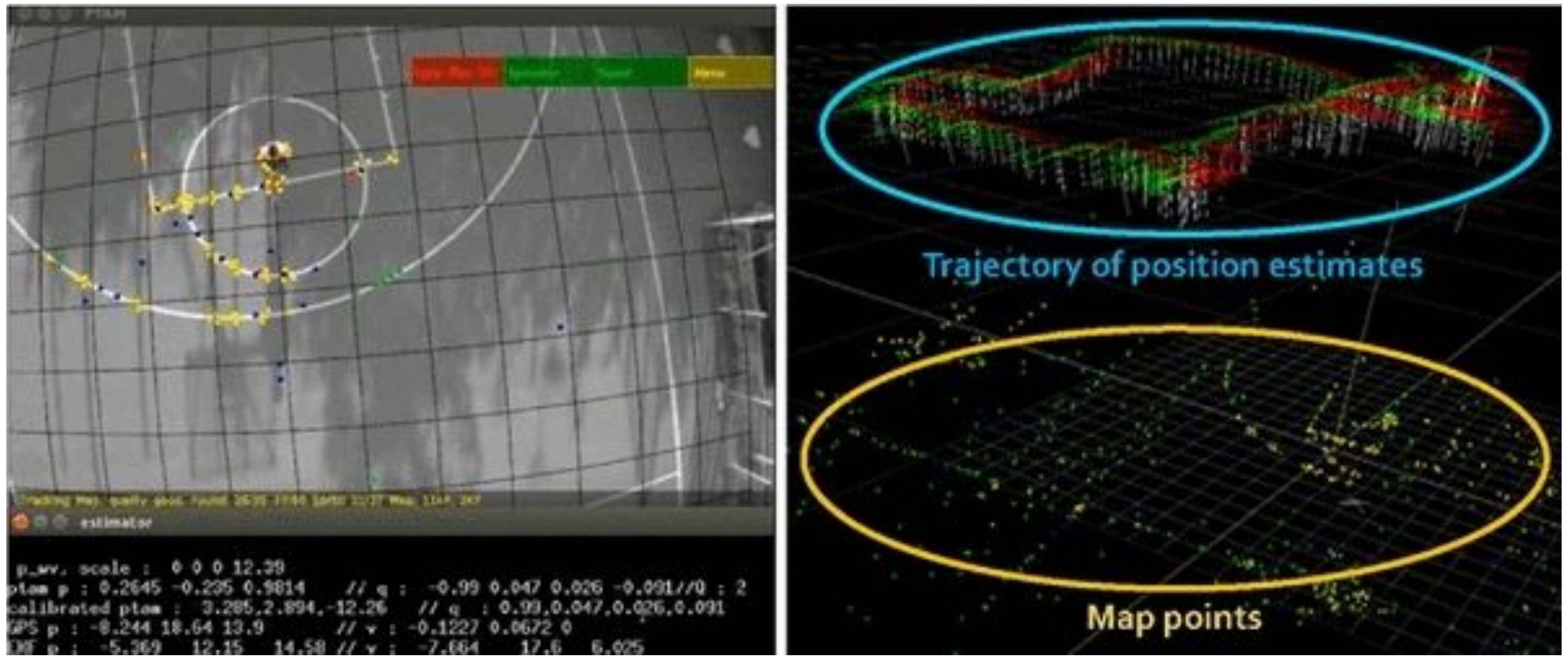

Figure 1: Position estimates in 3D
Source: [2]

VISION-BASED STATE ESTIMATION

GPS is one of the most common methods for determining position of a drone as stated by [2], but there are circumstances where GPS cannot be used. Often times in urban areas have a lot of tall buildings and bridges that can block the GPS signal from reaching the drone, so it has to fly based on its vision.

Figure 2: Drone flying in a GPS-denied environment
Source: [2]

MISSION SCOPING

Need Statement

The overall need of this project is to develop drones capable of sensing and **avoiding obstacles** with a minimized risk of collision or damage to property **in GPS denied environments.**

Goals

1. Create a list of sensor types necessary for autonomous flight without GPS
2. Develop sensor comparison framework to determine which sensors to purchase/test
3. Determine how sensors detect obstacles
4. Understand how to communicate with other drones to avoid each other
5. Optimize sensor placement and positioning for maximum awareness of surroundings and coordination with drone

OBJECTIVES

- Determine how sensors detect obstacles
- Research methods of static obstacle detection
- Research methods of dynamic obstacle detection
- Investigate what types of sensors can detect static and dynamic obstacles
- Understand what type of data is collected by those sensors
- Determine how to implement that data and use it with the estimation team

OBJECTIVES

1. Determine a list of factors that could affect sensor choice (ex: cost, size, etc).
2. Prioritize list of factors from most important to least.
3. Create general range for each factor (ex: What is the most we can spend on a single sensor? What is the maximum space we can allocate for this sensor? etc)
4. Develop comparison framework to proposal pipeline to better share information with Leadership Team.
5. Keep track of sensor budget.

Objectives of Goal #5

1. Ensure the design for the drone can fit all necessary sensors (number of sensors TBD)
2. Find best positions/orientations for each individual sensor to cover more area or more important regions to utilize as much of each of the sensor's functions as possible
3. Find best configuration of all visual sensors for maximum field of vision
4. Find best configuration of all other sensors for maximum sensitivity across drone
5. Discover most ideal sensor(s)/actuator(s) paring and relative distance from one another for most intuitive and sensitive control of drone attitude and movement
6. Optimize objectives 2-5 for most optimum performance and sensitivity

Constraints

The following are constraints on the sensors and communications hardware that could impact the success of the goals:

- Size
- Mass
- Cost
- Utility
- Durability

CONSTRAINT

- *Main constraint:* money
    - Drones can get pretty expensive, and the majority of the cost comes from the sensors. Ideally, one could build a drone with the best (most expensive) sensors that would allow the drone to smoothly and autonomously avoid obstacles and maintain distance from other drones. However, this project does have a cap on how much money we can spend. As a result, our priority is to compare the different features each type of sensor has and how important those features are for our team. Although we are not working with an ideal situation (no budget), we definitely can find the right sensors for our project needs within our budget.

Constraint #1 - Weight

This constraint applies to goals 2 and 5, as it plays a role in sensor comparison and in the optimization of sensors and their placements for maximum performance and sensibility. Looking more into the impact of this constraint on the objectives for goal 5, the maximum weight allowable on the drone affects objective 1. Equally important, the weight distribution across the drone limits the amount and weight of sensors we can have in our design, as well as the configuration of those sensors. This constraint will also limit the total number of sensors and put more emphasis on the individual masses of each sensor when making sensor purchase decisions. With this constraint applied, we may not be able to acquire all the necessary sensors for the maximum performance, as such it will be more important to optimize the sensor selection and their configuration on the drone for the best performance possible given the weight constraint.

Constraint #1 - Weight

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Constraint #2 Monetary Budget

This constraint directly affects goal 2, but also indirectly affects goals 1 and 5. The cost of various sensors and their potential substitutes will be a key consideration when making purchase decisions. Additionally, the monetary budget allowed to our subteam and the USRC team as a whole will limit the maximum size of the drone and the necessary components for both flight and autonomous flight control. As such, the monetary budget will affect goal 1 in that it will potentially limit us from purchasing all of the sensors made in the list. Furthermore, with the max size of the drone limited by the budget and the total number of sensors and their own weight and advancement. The monetary budget would likely force us to buy more medium grade options for trivial sensors and focus most of our budget on higher grade options for the more essential sensors. All things considered, the monetary budget will indirectly have a huge impact on goal 5 and its realization.

Durability

One of the main constraints for this project is the durability of sensors. During the testing phase, drones are likely to crash into objects, so fragile sensors would not be ideal as they may need to be replaced after every crash. There needs to be a balance between the utility of the sensor and the durability to withstand impacts during flights.

Assumptions

- The drone will be close to a 12” drone
- The drone will have retractable legs to allow for bigger sensors underneath

ASSUMPTIONS

- We are unable to access GPS data.
  - The overarching assumption with our goals is that we are unable to access GPS data. Since we know that we can not estimate our location with the use of GPS, we have filtered our research to focus on sensors that may fill in the localization, mapping, and estimation data that we need.

Assumption

- Fanciest/highest-grade option not required for each sensor type
- Maximum drone size will not be so big as to require multiple people to transport
- Assuming the done will be able to fly with X number of sensors minimum, and Y number of additional sensors are optional for improve performance with diminishing returns

“Investigate what types of sensors can detect static and dynamic obstacles”

Implementing this objective is key to the success of understanding how sensors detect obstacles. In the environment, there are plenty of static obstacles such as trees, buildings, light posts, and more. These are objects that can be in the way of the drones, but they will remain in the same position as the drone continues to fly. Dynamic obstacles on the other hand, are objects that will be moving around the field near the drones. These include other drones, cars, people, and more. These are more difficult to track and avoid, so they may require more complicated sensors. Understanding which sensor excel at tracking each type of obstacle is extremely important in meeting the overall goal of understanding obstacle detection.

CONCEPT OF OPERATIONS

The starting assumption is what dictated the general concept of operations. Overall, the assumption provided the overarching goal for the communication and sensors team (provide the sensors necessary for autonomous flight in GPS-denied environments). The constraint affects how quickly we can get through our concept of operations. Since a main concern and constraint for our team is money, we are forced to spend more time on research and comparisons than actual testing and proof-of-concept.

Concept of Operations

Based on the aforementioned objectives, the sensors and their configuration will have an affect on the weight distribution of the drone (as such, affect the flight dynamics of the drone), and on the feedback control system that dictates the autonomous flight. The input data received from the plethora of sensors will enable the software in the flight computer to determine how to orient and maneuver the drone for obstacle avoidance during autonomous flight. The objectives mentioned previously help determine what type of data can be collected by the sensors and what the significance of the data is in relation to the drone as a whole, which affects what the flight computer knows and how it responds to external factors.

REQUIREMENTS

DERIVED REQUIREMENTS

1. The project shall be relevant to the ARMD (Aeronautics Research Mission Directorate) Strategic Implementation Plan.
2. The project shall satisfy one of ARMD's six strategic thrusts as they affect aviation:
   2.1. Safe and efficient growth in global operations
   2.2. Innovation in commercial supersonic aircraft
   2.3. Ultra-efficient subsonic transports
   2.4. Safe and quiet vertical lift air vehicles
   2.5. In-time system-wide safety assurance
   2.6. Assured autonomy for aviation transformation
3. The project shall follow the USRC proposal rules.

HIGH LEVEL REQUIREMENTS

4. The drones shall have sufficient sensors to form and maintain aero-ellipsoid around the drones
5. The sensors shall be able to navigate drones in GPS-denied environments.
6. The drones shall avoid obstacles and other drones autonomously.

TEXAS ENGINEERING

Subsystems

1. Controls - Robert
2. Communications - Ishani
3. Obstacle Avoidance - Ben

Requirements read as high-level/derived requirement number, subsystem number, then requirement number of interest

I.e. 4.1.1. Is read as (high level) requirement 4, controls subsystem, sub-requirement 1 of interest

4. The drones shall have sufficient sensors to form and maintain aero-ellipsoid around The drones
   - 4.1. X
     - 4.1.1. The drones shall be able to track its own dynamics within its aero-ellipsoid
   - 4.2. X
     - 4.2.1. The drones shall be able to transmit individual aero-ellipsoid information to surrounding drones.
     - 4.2.2. The drones shall be able to receive aero-ellipsoid error information from ground stations.
5. Sensors shall be able to navigate the drones in GPS-denied environments.
   - 5.1. X
     - 5.1.1. The drones shall be able to independently control yaw, pitch, roll rotations
     - 5.1.2. The drones shall be able to independently maneuver in xyz directions
     - 5.1.3. The drones shall be able to take feedback from sensors and communicated information from other drones to adjust its own dynamics accordingly to maintain the swarm and remain on course to any arbitrary destination
   - 5.2. X
     - 5.2.1. The drones shall be able to transmit sensor data to ground station
6. The drones shall avoid obstacles and other drones autonomously.
   - 6.1. X
     - 6.1.1. The drones shall be able to perform complex maneuvers by combining multiple commands to both rotate and translate in multiple directions
   - 6.2. X
     - 6.2.1. The drones shall be able to transmit position and velocity data to surrounding drones.
     - 6.2.2. The drones shall be able to receive position and velocity data from surrounding drones.
   - 6.3. X
     - 6.3.1. The sensors shall be able to detect stationary environmental obstacles.
     - 6.3.2. The sensors shall be able to detect dynamic environmental obstacles.
     - 6.3.3. The sensors shall be able to detect other drones.
     - 6.3.4. The sensors shall be able to send obstacle data to the flight controller.

Subsystem 1. Controls - Rationales

4.1.1. This requirement was necessary to ensure that the drone can maintain and track its own flight. Assumed an aero-ellipsoid shape due to Heisenberg Uncertainty Principle regarding position and speed. The design effort to modify and enhance drone functions led to the requirement of swarm drones that could monitor their own aero-ellipsoids and that of the other drones drove the need for requirement 4, which led to the derivation of this requirement of interest. Other data that will be needed to maintain this requirement over time consists of the current velocity of the drone of interest and location/distance information from other drones to approximate aero-ellipsoid for the position of the drone of interest.

5.1.1. This requirement was needed to control the drones' rotations in order to control the attitude of the drone. Assumed isolated drone will be able to control decoupled yaw, pitch, roll rotations without the external influences from local aerodynamics around drone. The design effort to maintain the normal functions of drone flight led to the formulation of this requirement. Other data necessary to maintain this requirement over time will be the current attitude dynamics of the drone of interest.

5.1.2. This requirement was needed to be able to control the flight of the drone. Assumed the drone of interest will be able to move in any linear combination of xyz directions if it was able to independently move in each of those directs. Also assumed that the xyz directions would the xyz axii of the drone, with x being left and right (horizontal), y being forwards and backwards (depth), and z being upwards and downwards (vertical). The design effort to maintain the normal functions of drone flight drove the development of this requirement. Other data necessary to maintain this requirement over time will be the current flight and attitude dynamics of the drone of interest.

5.1.3. This requirement was necessary enable the drone to follow its swarm's flight pattern and reach any arbitrary destination of interest. Assumed that the drone of interest would be able to communicate effectively with other drones from the swarm in its vicinity to help coordinate the drones to achieve the desired swarm effect. The design effort to modify and enhance drone functions led to the requirement of swarm drones that could rely on one another to navigate through GPS denied environments, which came from requirement 5, and which led to the derivation of this requirement of interest. Other data necessary to maintain this requirement over time would be the flight and attitude dynamics of other drones in the vicinity as well as their relative locations and the obstacles they have encountered.

6.1.1. The drones shall be able to perform complex maneuvers by combining multiple commands to both rotate and translate in multiple directions - This requirement was needed to enable the drone to complete the necessary combination of evasive maneuvers to avoid static and dynamic obstacles and other drones that the drones of interest may encounter. Assumed that the obstacle would be small and/or slow enough such that drone(s) of interest would be able to evade any of these obstacles with the right combination of maneuvers. The design effort to maintain the normal functions of autonomous drone obstacle avoidance in flight drove the development of this requirement. Other data needed to maintain this requirement over time would be the sensor data for nearby obstacles, the calculations from the obstacle avoidance subsystem on which combination of maneuvers would be most optimal to avoid the obstacle of interest, and the current attitude and flight dynamics of the drone of interest.

COMMUNICATIONS REQUIREMENTS

4.2.1 The drones shall be able to transmit individual aero-ellipsoid information to surrounding drones

- The ability to transmit individual aero-ellipsoid information to other drones can further improve the drone’s ability to avoid other drones.

4.2.2 The drones shall be able to receive aero-ellipsoid error information from the ground station

- First and foremost, the drone should know if its generated aero-ellipsoid actually fits the simulation-based requirements for an aero-ellipsoid. If not, then it should be able to correct this while flying.

COMMUNICATIONS REQUIREMENTS (cont.)

5.2.1 The drones shall be able to transmit sensor data to ground station

- On a very low level, a drone must be able to ensure that it is collecting a sufficient amount of sensor data (and that the sensor data is accurate). To check this, a ground station may be used to monitor the sensor data that is gathered live.

COMMUNICATIONS REQUIREMENTS (cont.)

6.2.1 The drones shall be able to transmit position and velocity data to surrounding drones.

6.2.2 The drones shall be able to receive position and velocity data from surrounding drones.

- Swarm drones can only operate in a swarm when aware of other drone positions with respect to its own. As a result, an individual drone’s ability to transmit and receive its position and velocity data to other drones is important for efficient and successful swarm operations

6.3.1. The sensors shall be able to detect stationary environmental obstacles.
6.3.2. The sensors shall be able to detect dynamic environmental obstacles.
6.3.3. The sensors shall be able to detect other drones.
6.3.4. The sensors shall be able to send obstacle data to the flight controller.
6.3.5. The flight controller shall be able to compute obstacle avoidance maneuvers with the data gathered from the sensors.

Rationale for 6.3.1, 6.3.2, and 6.3.3

In a typical urban environment, there will be many obstacles surrounding the drones. This project is dividing these obstacles into three main categories: stationary, dynamic, and other drones. This requirement is assuming stationary obstacles are defined as objects in the environment that do not move such as buildings, trees, benches, etc. Dynamic obstacles are defined as objects in the environment that do move outside of the drones' control systems such as cars, people, birds, etc. In order to avoid them, the sensors need to be able to detect and identify them. This is driven by the design effort that states "The drones shall avoid obstacles and other drones autonomously." The Communications and Sensors team will need to work with the Estimations and Simulations team in order for this requirement to succeed.

Rationale for 6.3.4

While flying, the drones will be detecting obstacles based off of 6.3.1-6.3.3, and those sensors need to relay that information to the flight controller in order to avoid the obstacles. This is assuming the information exchange happens fast enough to maneuver out of the way of the obstacle. This is also driven by the design effort that states “The drones shall avoid obstacles and other drones autonomously.” The Communications and Sensors team will need to work with the Estimations and Simulations team in order for this requirement to succeed.

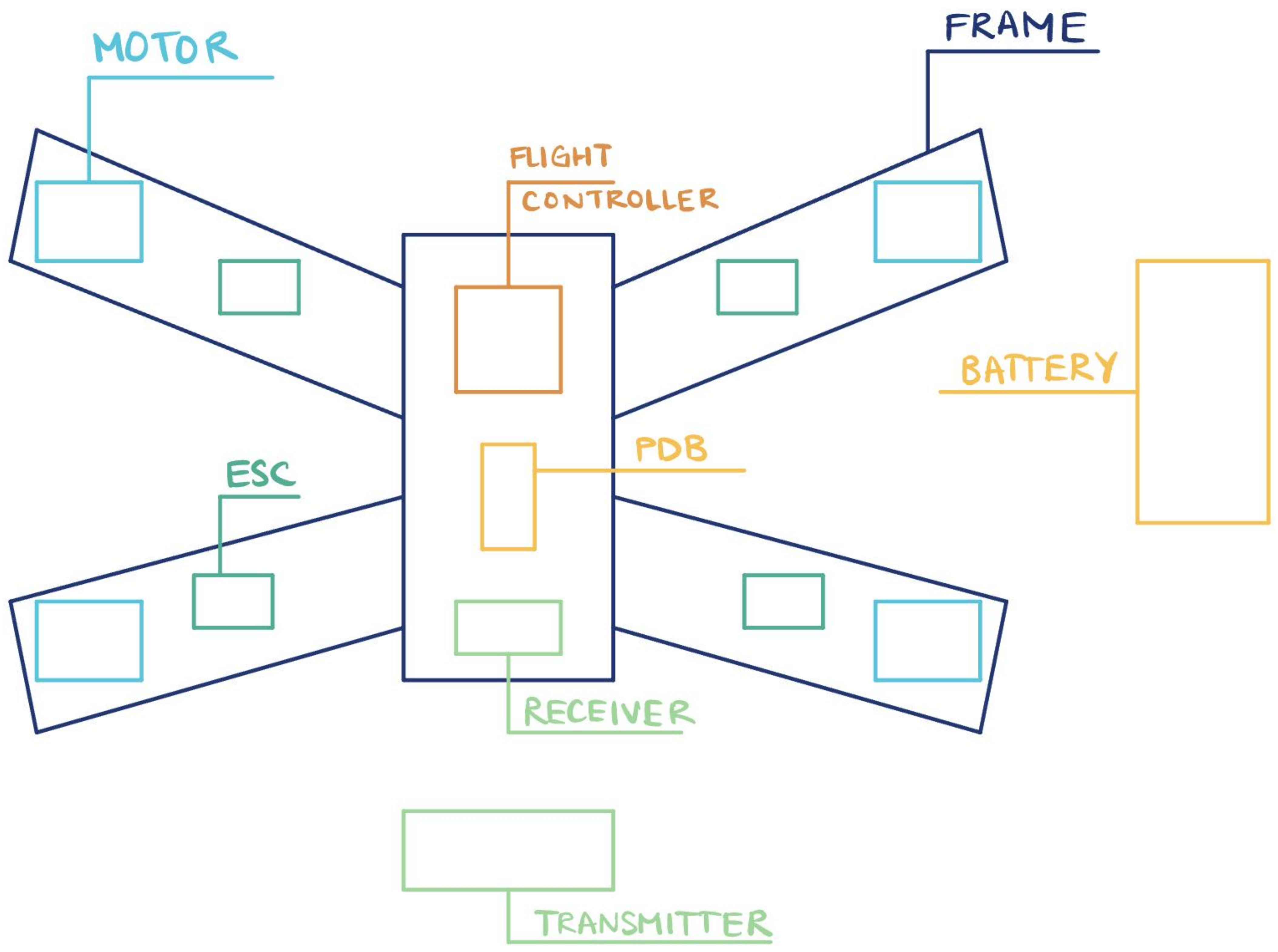
Rationale for 6.3.5

Assuming 6.3.1-6.3.4 succeed, the data will be gathered and sent to the flight controller. This data then will have to be combined in order to compute the maneuver best suited to safely avoiding the obstacles around the drones. Again, this is driven by the design effort that states “The drones shall avoid obstacles and other drones autonomously.” The Communications and Sensors team will need to work with the Estimations and Simulations team in order for this requirement to succeed.

FULL SYSTEM

THE BASIC COMPONENTS

- Frame
- Motors
- Electronic Speed Control (ESC)
- Flight Controller
- Battery
- Power Distribution Board (PDB)
- Receiver
- Transmitter

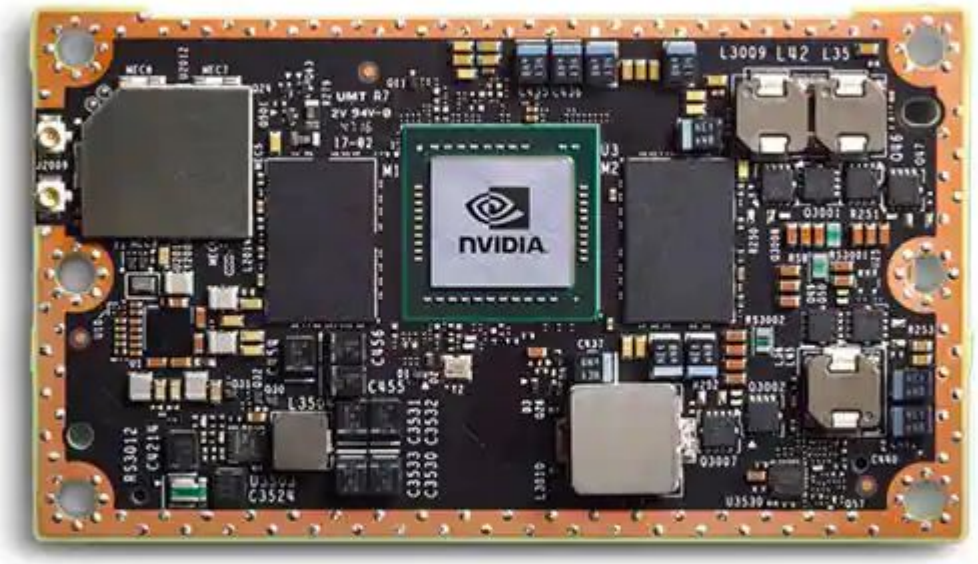


Basic Drone Components Layout

BUILDING A SMART MULTIROTOR

- Onboard Computer: Jetson TX2 This component is what inherently makes the system smart. Unlike the flight controller, an onboard computer has enough processing power and storage to carry out higher level computations.

- Additional Sensors These give our onboarding computer a better perception of the surrounding environment in order to employ computer vision techniques to fly autonomously.



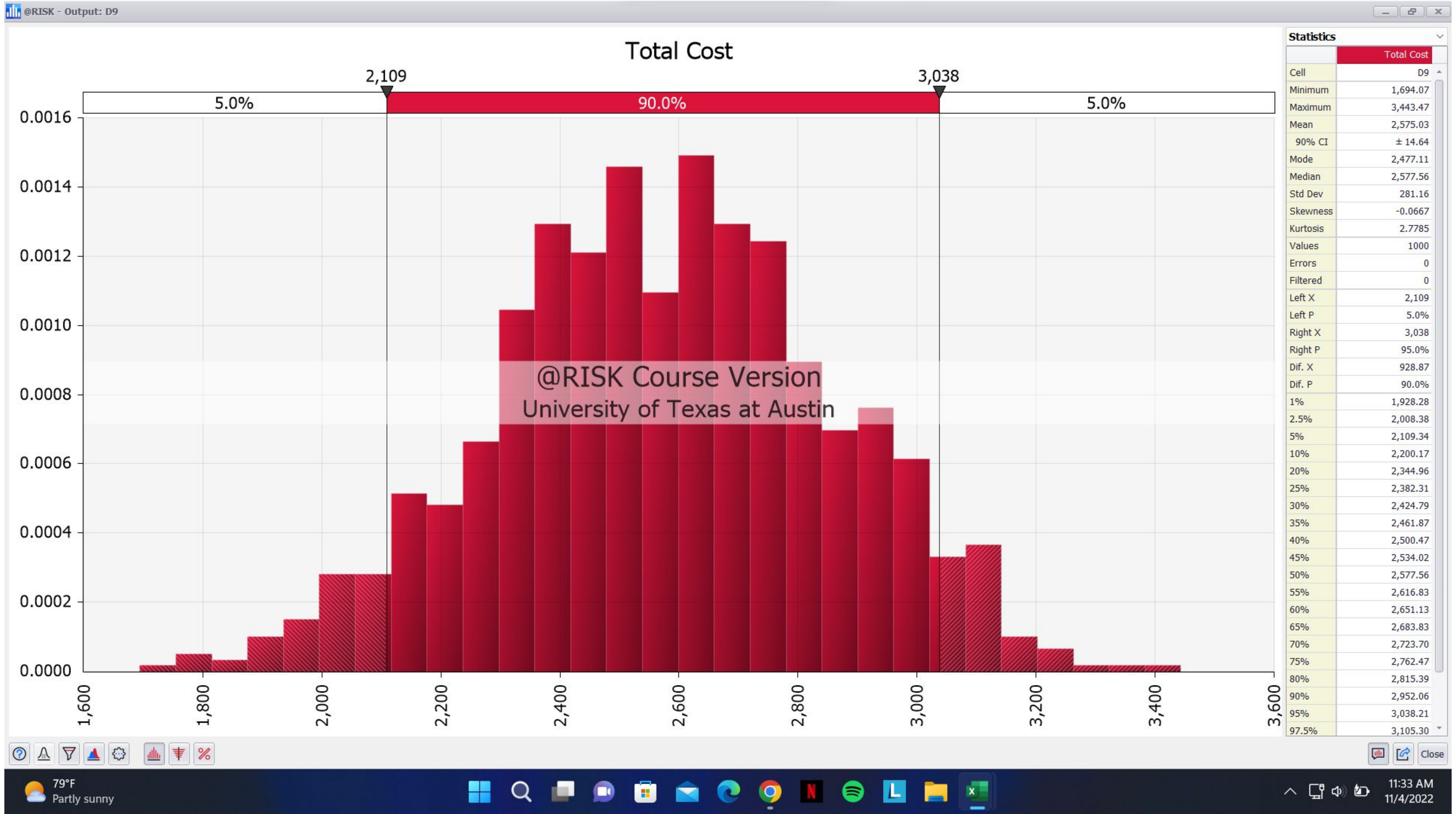
Jetson TX2

COMPONENTS

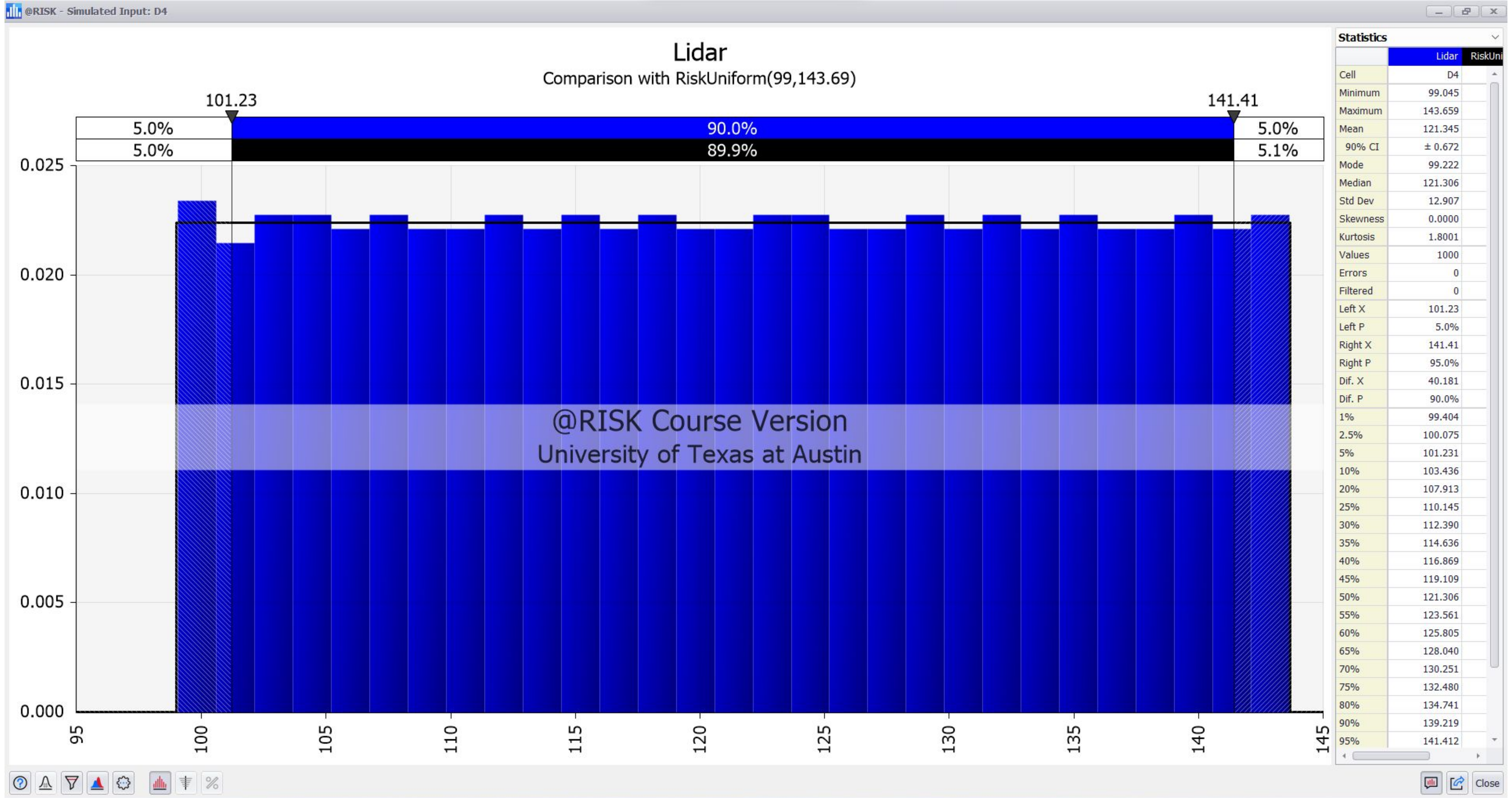
MONTE CARLO ANALYSIS (parts)

- Flight Controller: For low level drone control.
- LIDAR Sensor: For accurate distance ranging and mapping capabilities.
- Cameras: For computer vision and mapping capabilities.
- Transmitter and Receiver: For manual drone control and data transmission.

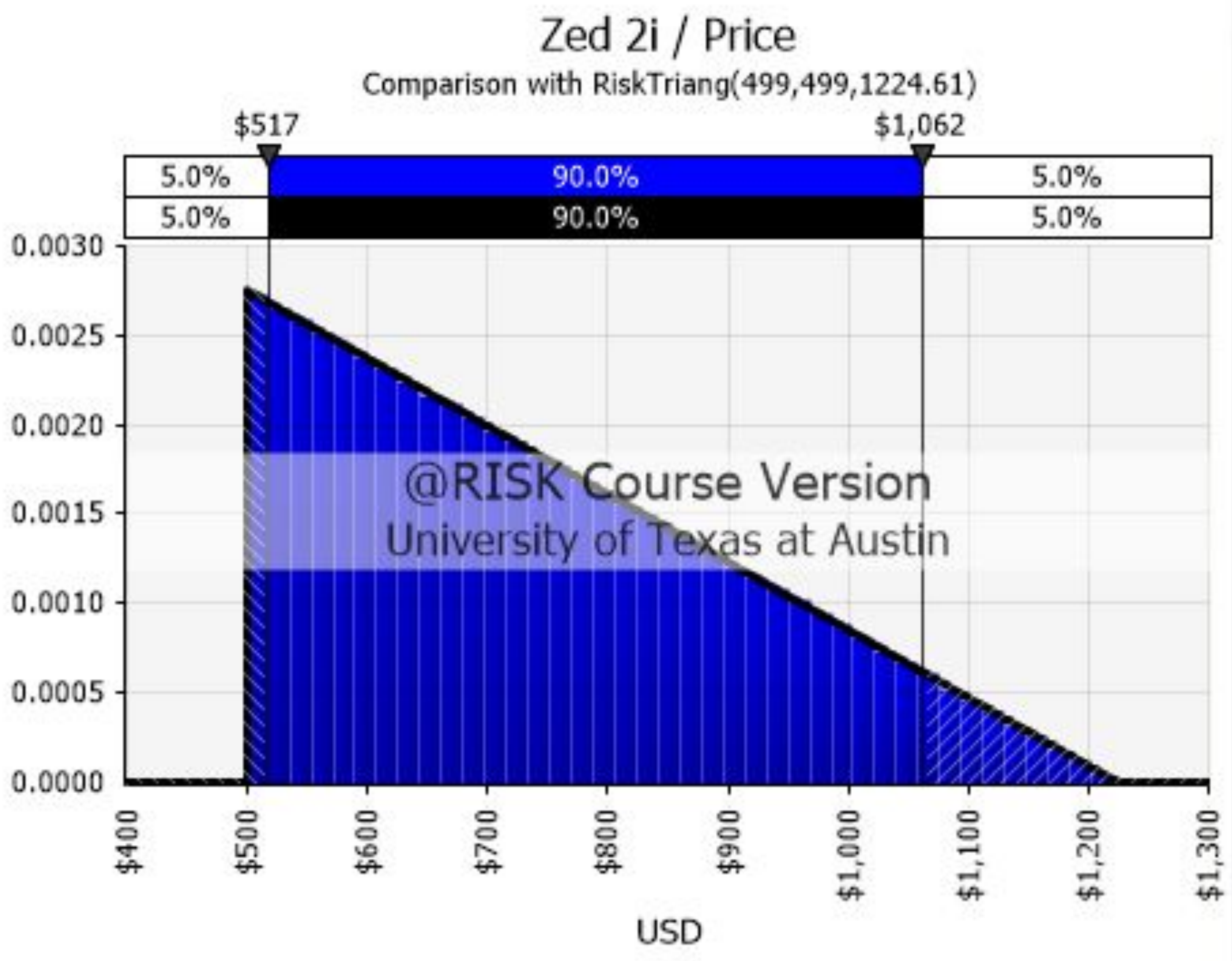
MONTE CARLO ANALYSIS



MONTE CARLO ANALYSIS -Part By Part

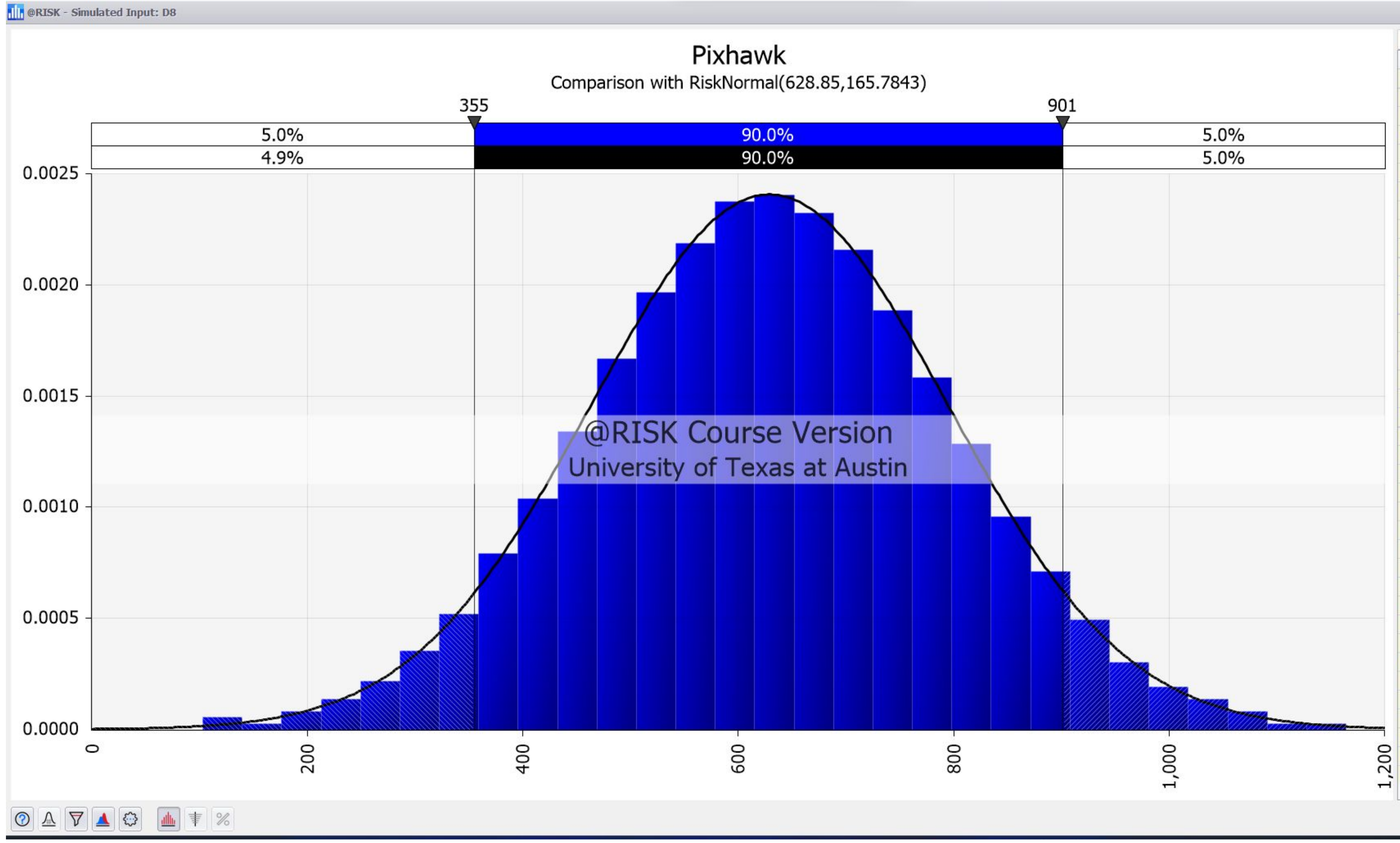


MONTE CARLO ANALYSIS -Part By Part



Statistics

	Zed 2i / Price	RiskTri
Cell	B2	
Minimum	$499.01	
Maximum	$1,220.60	
Mean	$740.87	
90% CI	± $2.81	
Mode	$504.46	
Median	$711.50	
Std Dev	$171.04	
Skewness	0.5658	
Kurtosis	2.4003	
Values	10000	
Errors	0	
Filtered	0	
Left X	$517	
Left P	5.0%	
Right X	$1,062	
Right P	95.0%	

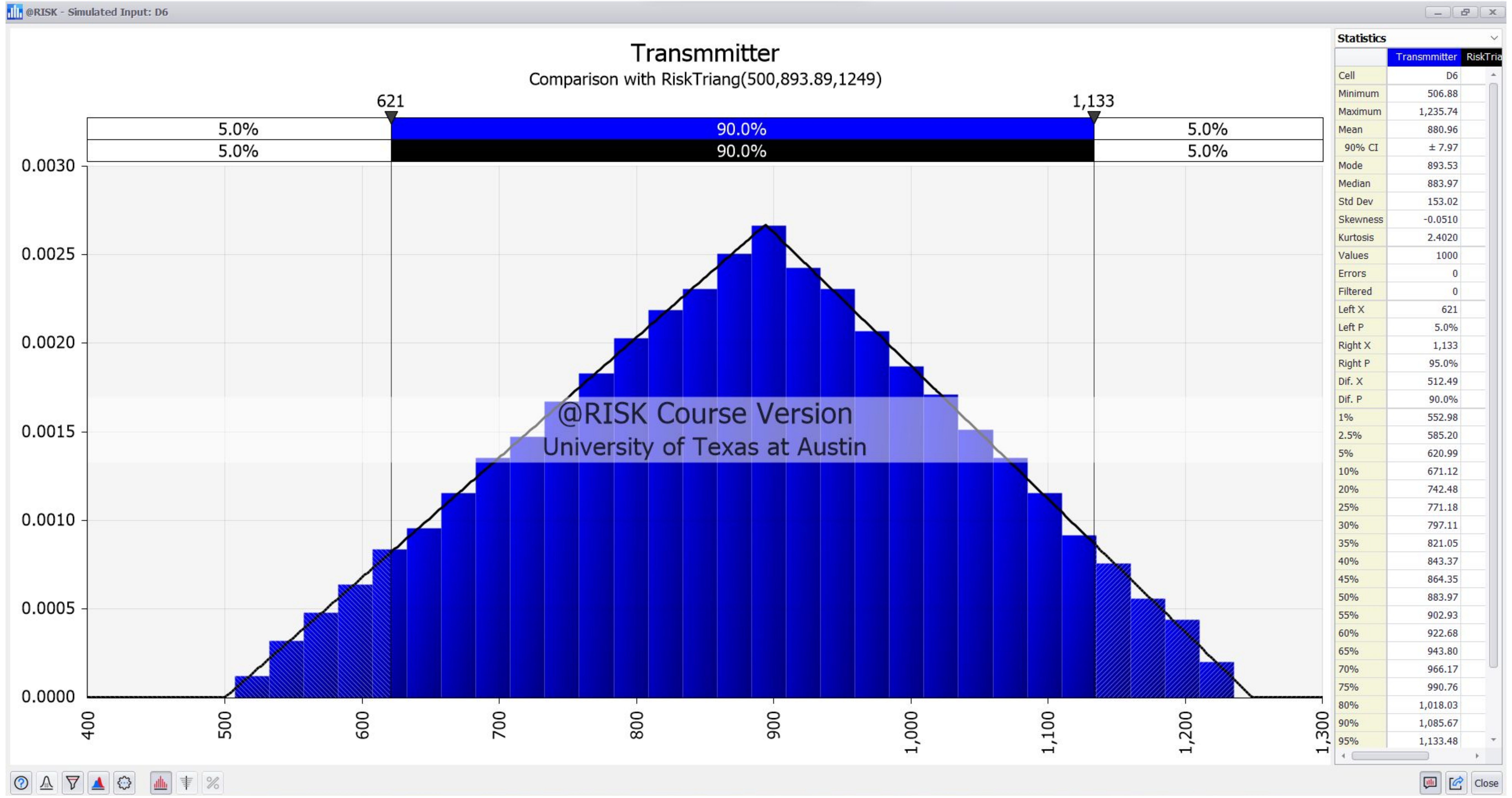


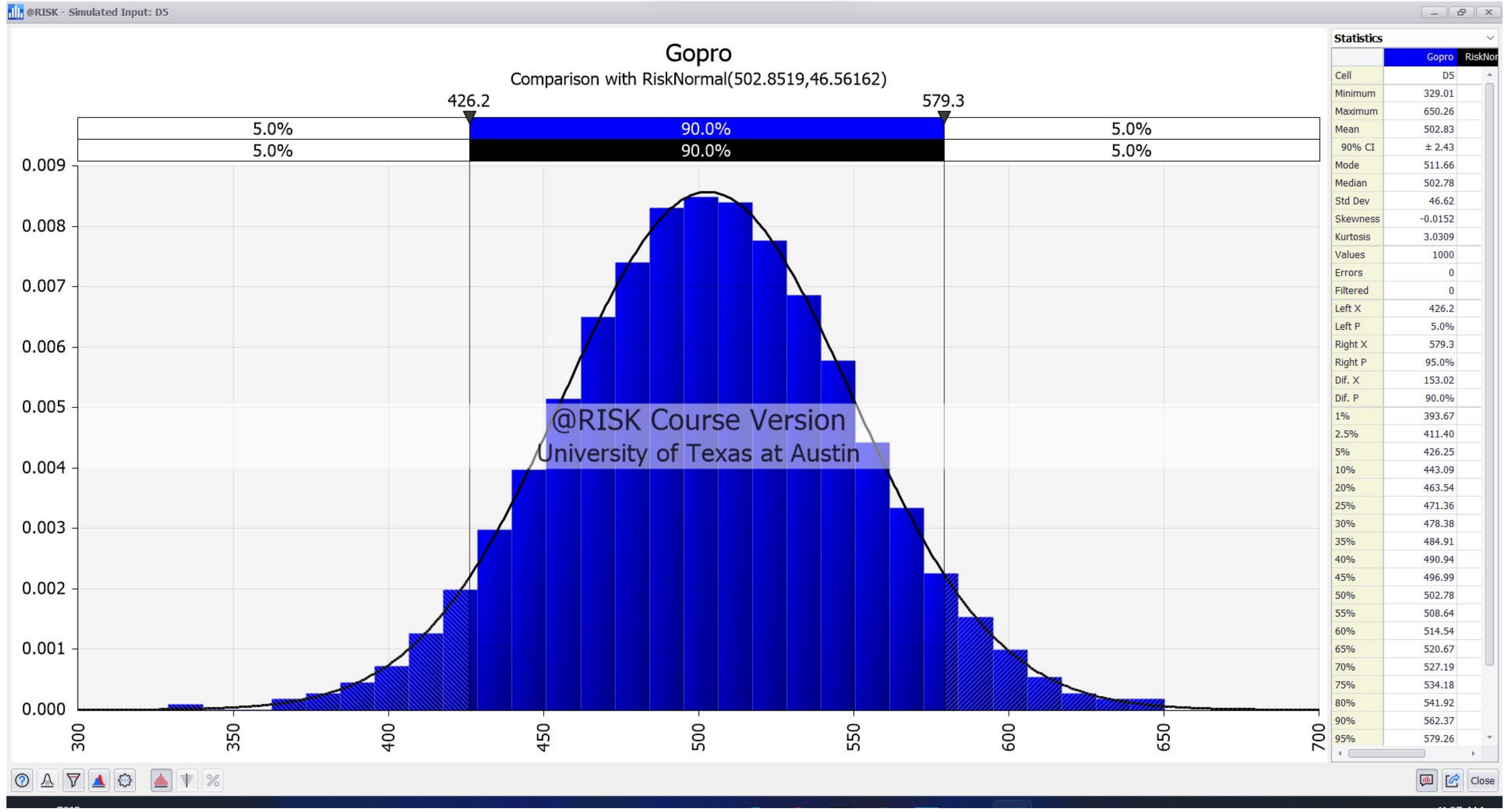
Statistics

	Pixhawk	RiskNor
Cell	D8	
Minimum	102.66	
Maximum	1,164.30	
Mean	628.80	
90% CI	± 8.63	
Mode	601.73	
Median	628.53	
Std Dev	165.78	
Skewness	-0.0042	
Kurtosis	2.9744	
Values	1000	
Errors	0	
Filtered	0	
Left X	355	
Left P	5.0%	
Right X	901	
Right P	95.0%	
Dif. X	545.96	
Dif. P	90.0%	
1%	237.08	
2.5%	303.26	
5%	355.04	
10%	415.59	
20%	489.29	
25%	516.52	
30%	541.68	
35%	564.59	
40%	586.79	
45%	607.71	
50%	628.53	
55%	649.47	
60%	670.49	
65%	692.34	
70%	715.60	
75%	740.61	
80%	768.37	
90%	841.06	
95%	901.00	

Close

MONTE CARLO ANALYSIS -Part By Part





FLIGHT CONTROLLER

(PIXHACK CUBE ORANGE)

- This is the drone’s low-level control brain. It shares the collected sensor data to the Jetson which then in turn tells the flight controller how to move the drone.
- **Link:**

  https://www.amazon.com/dp/B0842XYLGR/ref=sspa_dk_detail_2?psc=1&pd_rd_i=B0842XYLGR&pd_rd_w=tusIL&content-id=amzn1.sym.88097cb9-5064-44ef-891b-abfacbc1c44b&pf_rd_p=88097cb9-5064-44ef-891b-abfacbc1c44b&pf_rd_r=DAQQZ3RCK6P2MHQ6ZGKK&pd_rd_wg=BT04w&pd_rd_r=00ef36c9-3282-4717-be76-5fe798eb9b71&s=toys-and-games&sp_csd=d2lkZ2V0TmFtZT1zcF9kZXRhaWw

360 LIDAR SENSOR

(SLAMTEC)

- The RPLiDAR is a 360° LiDAR sensor that detects obstacles and provides range data within 12 m.
- According to [3], the sensor has a resolution of 0.2 cm as well as an angular resolution of 1°, allowing high resolution in close quarters.
- **Link:**

  https://www.adafruit.com/product/4010?gclid=Cj0KCQjw1vSZBhDuARIsAKZlijRJGCPr-NI66sHwvrmAN_BH4kUPQlu9TdgbXvqyOP_JtgFS84REUCgaAmD5EALw_wcB

STEREO CAMERA

(ZED 2)

- Computer Vision and Obstacle Avoidance
- This is the drone's primary computer vision sensor. It will not only improve our drone's obstacle avoidance capabilities, but also facilitate any environment mapping.
- **Link:**

https://store.stereolabs.com/products/zed-2

TRANSMITTER/RECEIVER

(HERELINK)

- Manual drone control and general drone communications

- This is the primary drone communication sensor. It will allow us to take manual control of the drone in any emergency situations. Most importantly, it will give us the ability to receive a live feed of sensor data from the drone.

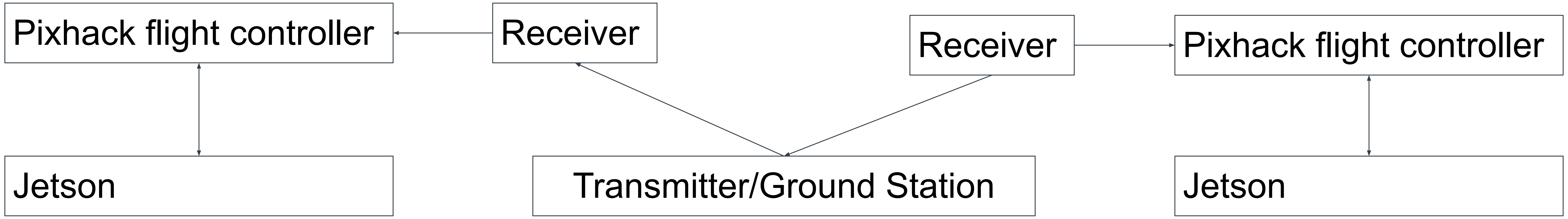
- **Link:**

  https://www.getfpv.com/herelink-2-4ghz-long-range-hd-video-transmission-system-v1-1.html?gclid=Cj0KCQjw1vSZBhDuARIsAKZlijTOmhJdul-PviFPLJCU9ibncwF7VjhD8oZPh9MeyWjFY5AOKbgmJnQaAhuyEALw_wcB

Swarm Drone Communication Theory

Position/Locational and Dynamic information relative to one another and absolute values

The drones will communicate dynamic information about themselves to one another. Using information about the absolute and relative position, velocity, acceleration, altitude, and distance from one another the drones will be able to adjust their flight dynamics accordingly to achieve the visual swarm flock flight pattern



CAMERA AND SENSOR BLOCK DIAGRAM

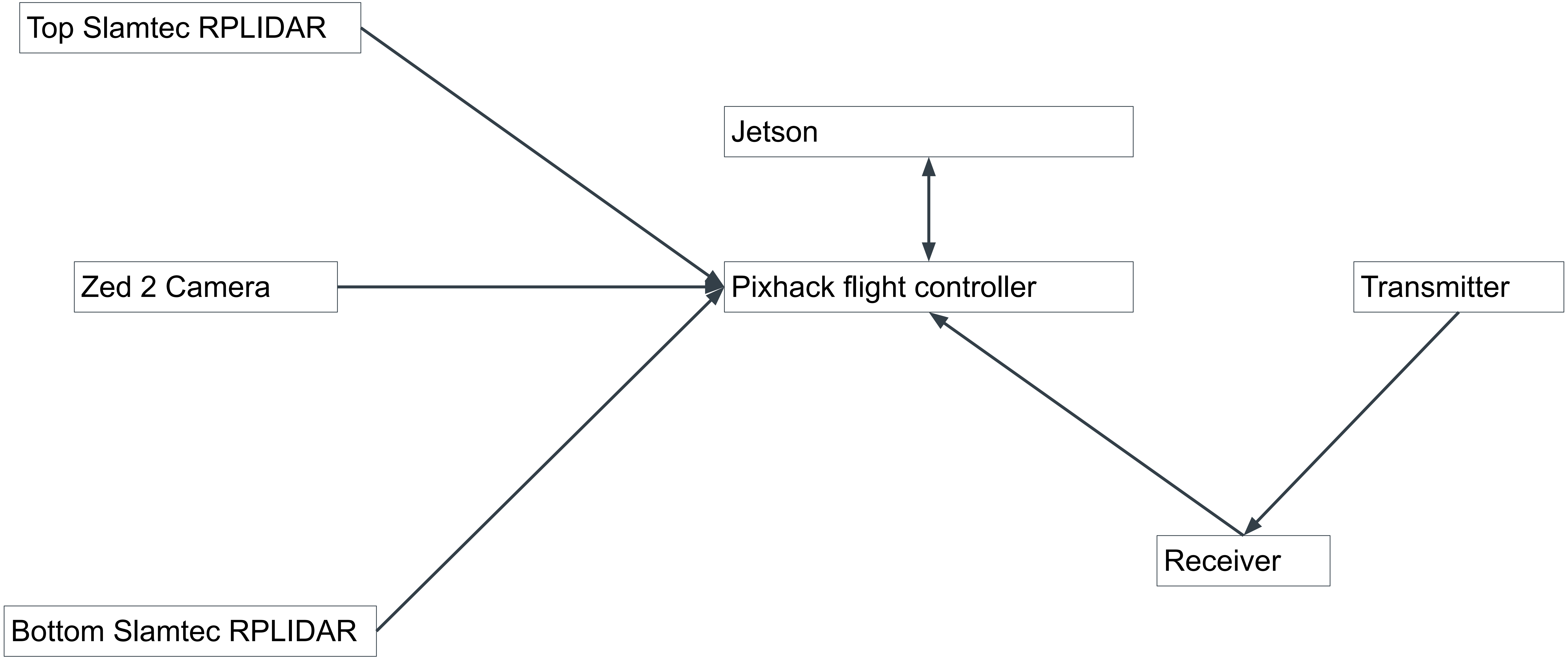
(communication)

- Sensor Input: Sensor input and data collection are extremely significant for the system to understand and track its environment. The two most important sensors for localization and path-planning are the ZED 2 camera and the Slamtec RPLidar.

- ZED 2: This stereo camera gives our system real-time depth perception (that we don’t need to calculate ourselves). Depth perception allows for a better assessment of the environment enabling more accurate positioning and localization.

- Slamtec RPLidar: This sensor supplements the ZED2 data with environment data that escapes the visibility line of the forward-facing camera. This sensor is most likely to pick up obstacles that may be heading towards the drone while it is flying (environmental factors that may include: branches, birds, buildings, stray pieces of trash, etc.)

CAMERA AND SENSOR BLOCK DIAGRAM

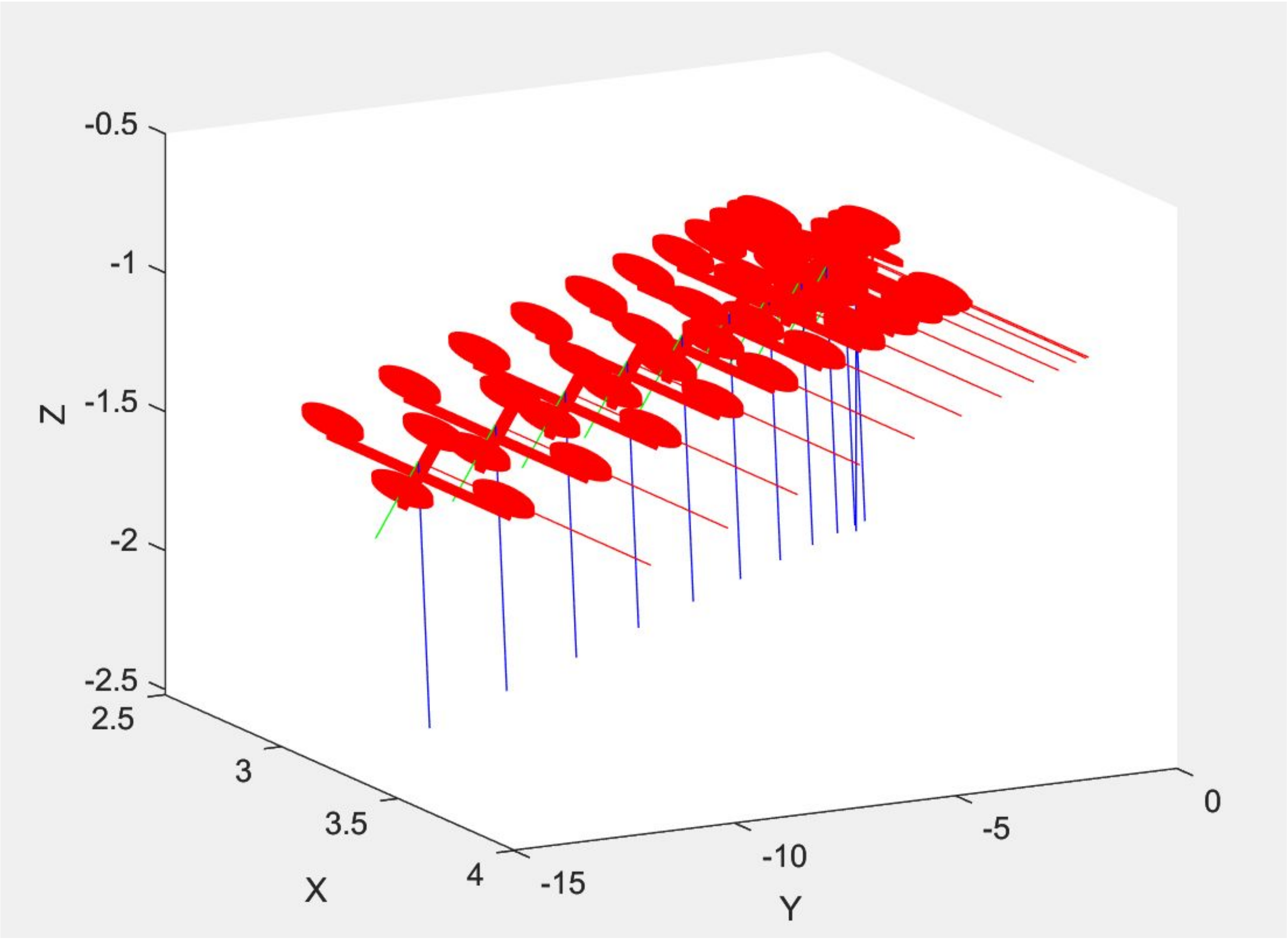


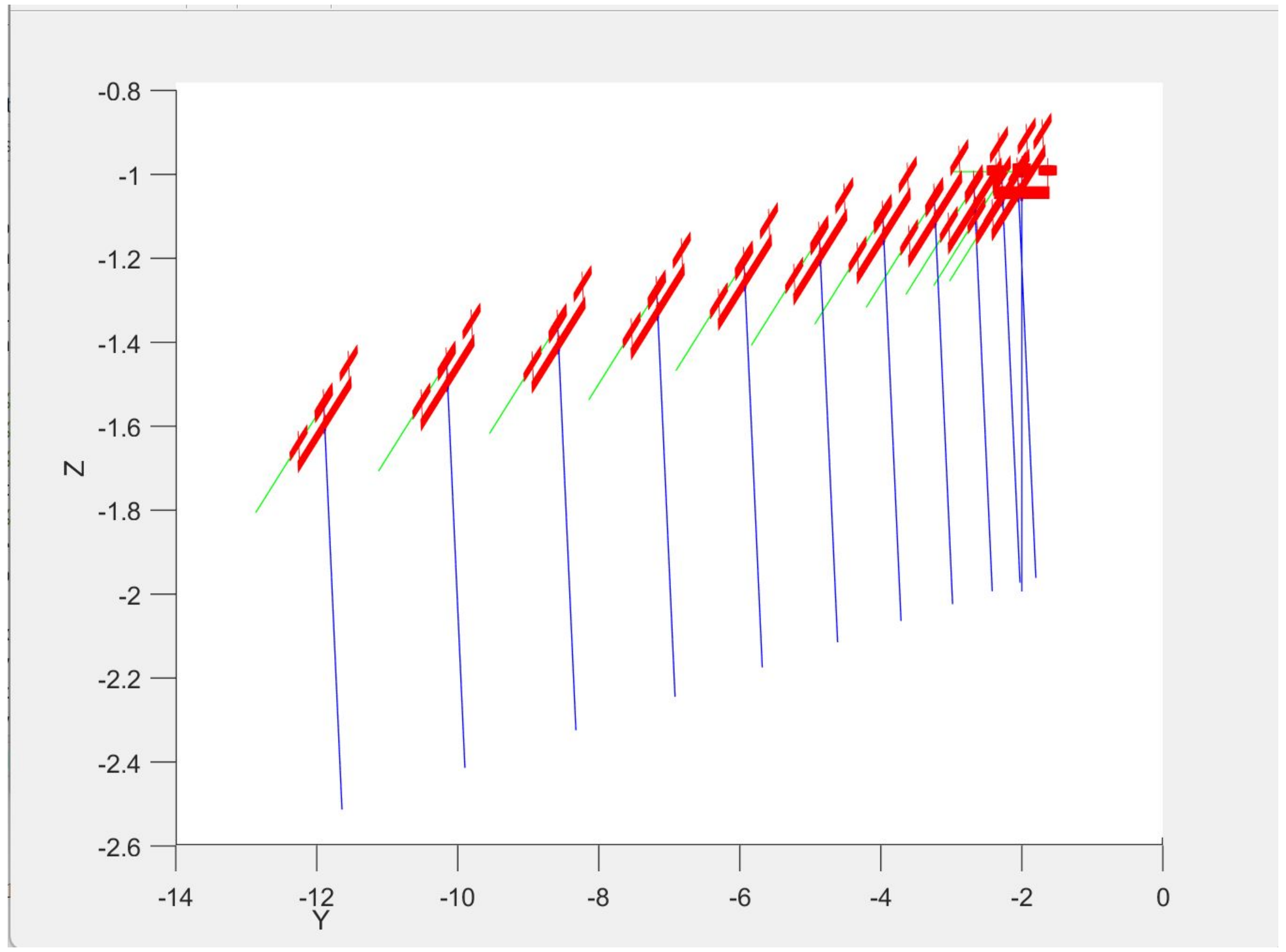
Environmental Analysis

UAV SIMULATION PSEUDO CODE

- Purpose: The purpose of running this simulation is to understand how the environment (gravity, wind, etc.) may impact our UAVs ability to fulfill control commands. The source code came from [5] and [6].
- Inputs: This simulation takes in two inputs: control commands and environmental inputs. For the purpose of this simulation and to understand whether the resulting graph makes sense, we kept the control command fairly basic (a simple roll to the left). We were particularly curious about gravity's effect on the planned drone control. As a result, we ran the simulation solely with the intent to understand how the most standard environmental input (gravity) affects the system.
- Output: The output of the simulation is a graph that represents the UAVs state after a few seconds of being in the simulation with the two different inputs.

UAV SIMULATION UNDER WITH ENVIRONMENTAL INPUTS RESULTS





The graph showcases the UAV translating to the left in the negative Y-direction and slightly downwards towards the end. This downward motion at the end of the graph makes sense with the presence of gravity. It also makes sense that the UAV is translating to the left (negative Y-direction) since our command input is a roll to the left. Note: the UAV is moving from the right to the left of the graph. The red, green, and blue lines represent the X, Y, and Z-axes of the drone respectively over time.

UAV SIMULATION UNDER WITH ENVIRONMENTAL INPUTS

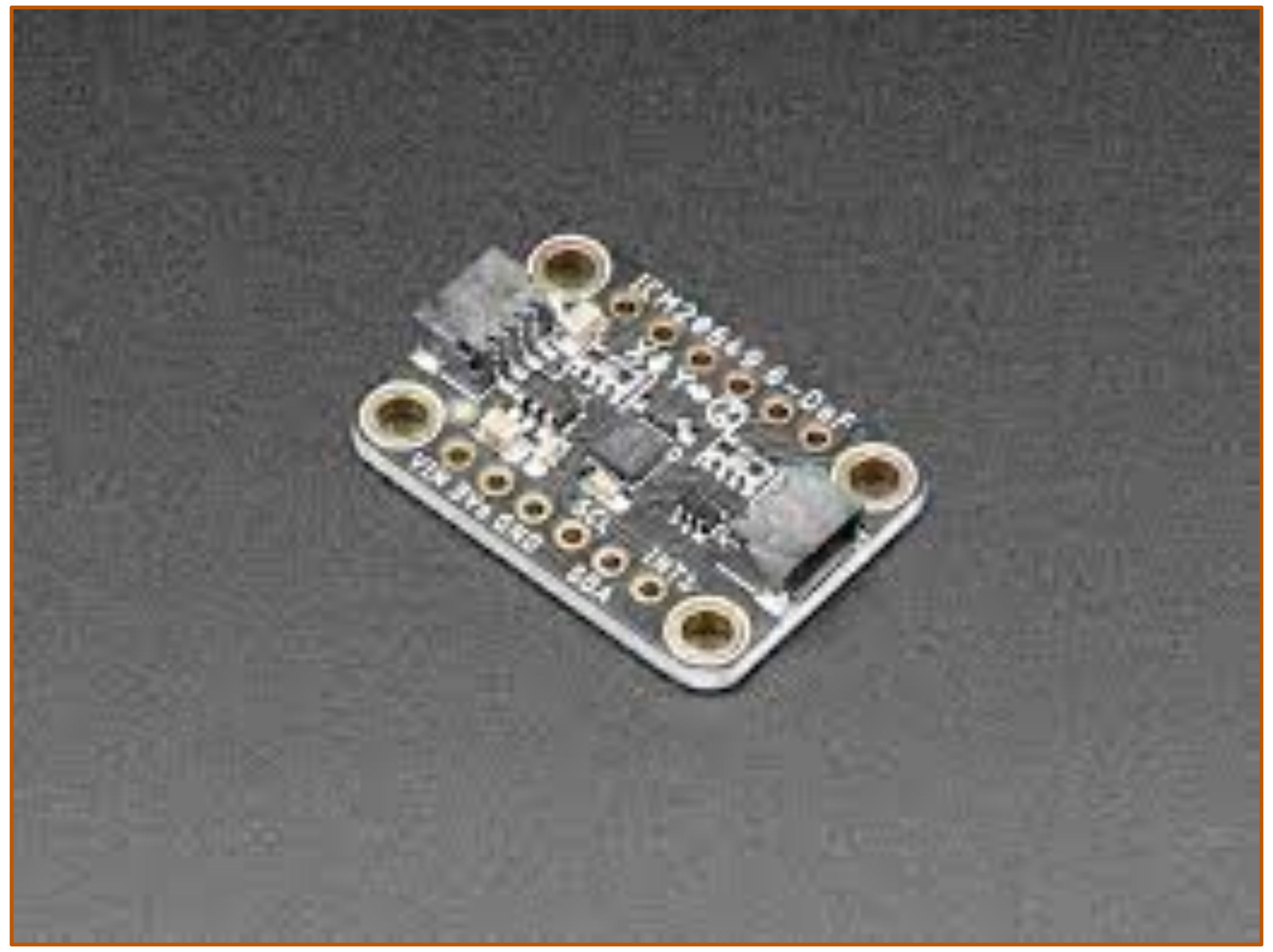
```
model = multirotor;

s = state(model);
s(1:3) = [3;2;1];

u = control(model);
u.Roll = pi/12;
u.Thrust = 1;
% default environment without wind
e = environment(model);
% time derivative
sdot = derivative(model,s,u,e);
% simulate the UAV state using ode45 --> 13-by-n matrix
simOut = ode45(@(~,x)derivative(model,x,u,e), [0 3], s);
size(simOut.y)
% plot change in roll angle based on simulation output
plot(simOut.y(9,:))
```

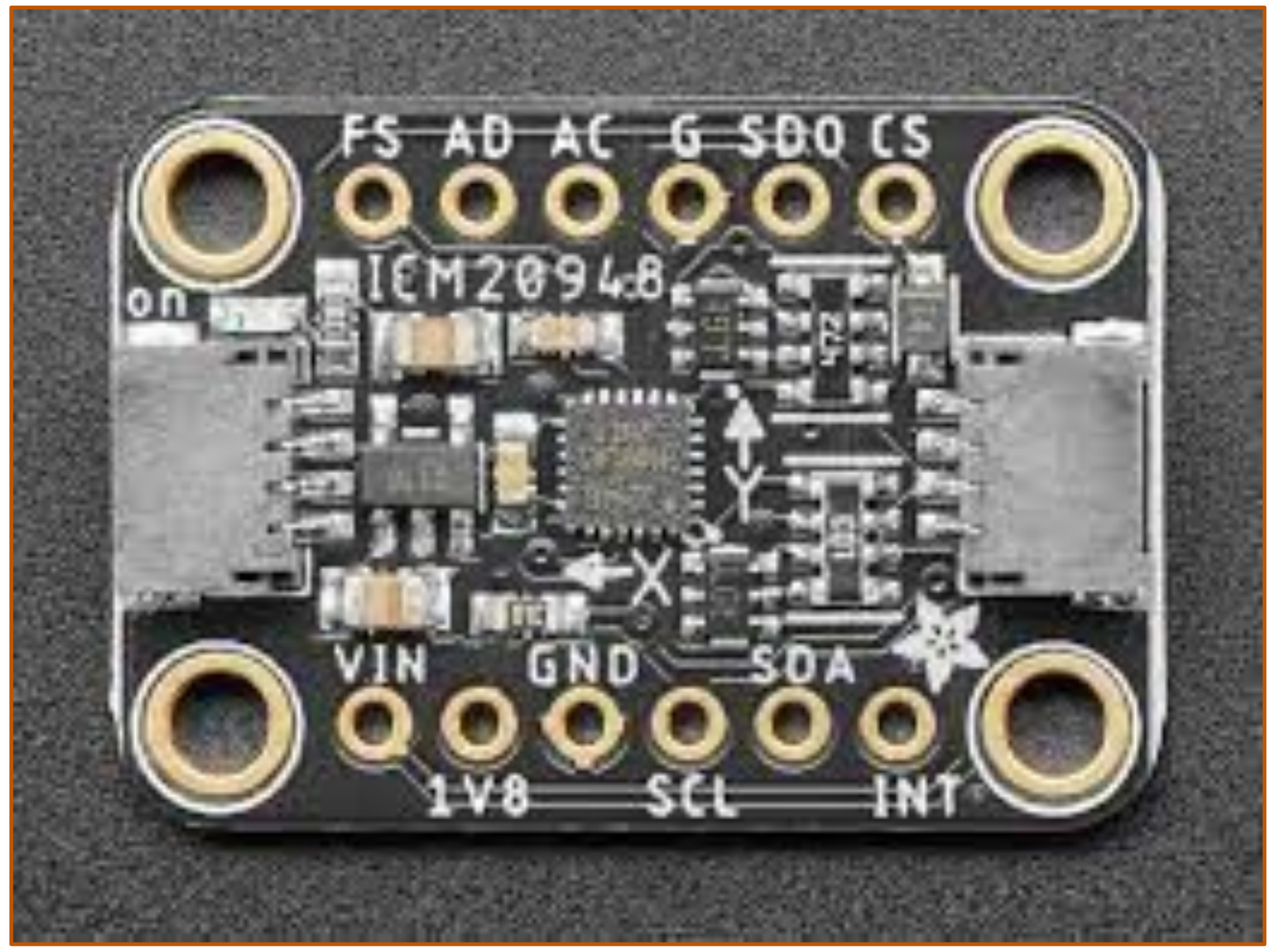
```
% plot the chane in Y and Z positions. with the specified thrust and roll
% angle, the multirotor should fly over and lose some altitude. A positive
% Z value is expected as positive Z is down.
figure
plot(simOut.y(2,:));
hold on
plot(simOut.y(3,:));
legend('Y-position','Z-position')
hold off

% Multirotor trajectory this shows the UAV translating in the Y-direction
% and losing altitude
% xyz position
translations = simOut.y(1:3,1:300:end)';
% ZYX Euler
rotations = eul2quat(simOut.y(7:9,1:300:end)');
plotTransforms(translations,rotations,...
    'MeshFilePath','multirotor.stl','InertialZDirection','down')
xlabel('X');
ylabel('Y');
zlabel('Z');
view([90.00 -0.60])
```

STABILIZING DRONE USING IMU SENSORS

- Purpose: Our flight controller includes two IMU sensors that are the first line of defense against basic destabilizing environmental factors like wind and gravity.
- Accelerometer: This sensor is primarily responsible for determining the position and orientation of a flying multirotor. We can think of this sensor as one that simply gathers information about the state of the drone.
- Gyroscope: This sensor measures the multirotor's rate of rotation and keeps it balanced by sending information to the motors to counteract unwanted forces. Using the accelerometers information, the gyroscope is the sensor that is actually supplying additional information to counteract environmental effects like gusts, gravity, etc.

IMU Sensors





Pixhawk Cube Orange

IMU 206049 Accelerometer/Gyroscope

IMU 20948 Accelerometer

Pixhawk has 3 built-in accelerometers, the IMU 206049 has integrated gyroscope as well whereas the IMU 20948 and IMU 20602 are both designated accelerometers

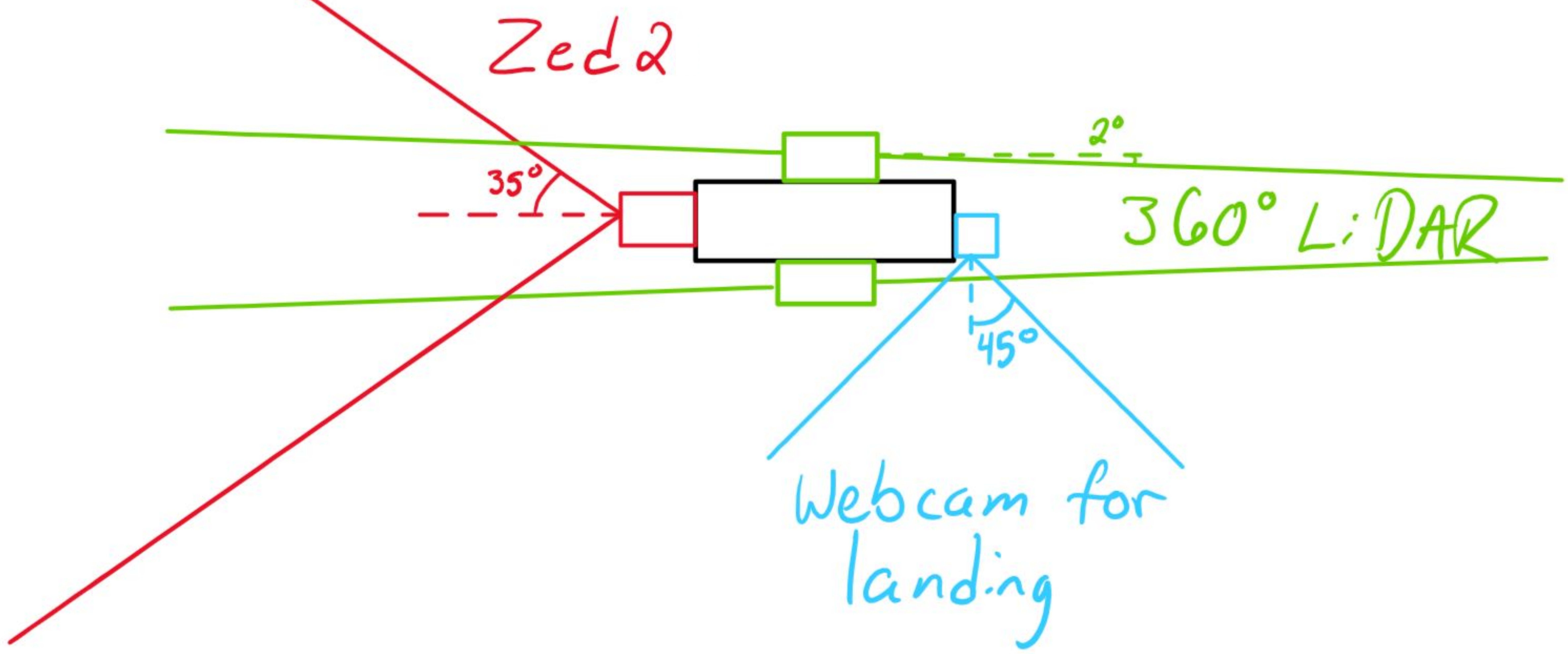
VISIBILITY

CAMERA & SENSOR CONFIGURATIONS

- Zed 2: The Zed 2 camera will be the drones' main vision system. It will be placed at the front of the drone facing forwards. It has a field of view of 110 x 70 degrees in the horizontal and vertical directions respectively according to [4].
- Slamtec LiDAR: The drones will each have two Slamtec 360 degree LiDAR systems. One will be placed on top of the drone while the other will be placed underneath the drone. They will be placed at a slight angle, around 2 degrees from the horizontal, so that they intersect behind the drone. This prevents missing objects that approach from behind.
- Webcam: There will be a simple webcam facing down from the drone for landing purposes.

CAMERA AND SENSOR CONFIGURATION

(for obstacle avoidance - diagram)



CAMERA AND SENSOR CONFIGURATION

(for obstacle avoidance)

- Autonomy and Visibility: The entire system relies on our ability to perceive the environment and make decisions based off of live environmental factors. In order, to ensure our ability to successfully fly autonomously, we must also ensure proper visibility. The diagram in the previous slide, showcases the camera and sensor configuration necessary for enough visibility to employ obstacle avoidance.

- Obstacle Avoidance: Since our drone is flying forward (turning to ensure that most movement is done forward, to the right, or to the left), our main concern is ensuring full visibility in the front. Our stereo ZED camera, allows for 70 degrees of visibility on the vertical and 110 degrees of visibility on the horizontal. This gives us more than enough visibility in the forward direction (the most important direction as the drone is flying forward). When tilted slightly the 360 LIDAR module allows enough visibility in the planes above and below the drone and also for sufficient visibility behind the drone.

FUTURE WORK

- Visualizing an ellipsoid with collected sensor data
  - Types of sensors needed and optimal configurations
- Potential implementation of sensors that take into account and adjust for the effects of wind on the drone flight
  - Types of sensors needed and optimal configurations
  - Connection(s) with pixhawk and jetson needed to adjust flight

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THANK YOU.

QUESTIONS?

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Innovation starts here