The University of Texas at Austin
Aerospace Engineering
and Engineering Mechanics
Cockrell School of Engineering

December 2022

DESIGN REVIEW #2

USRC - Simulation / Estimation

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PROJECT OVERVIEW

OUR PROJECT

- 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.
    - Construct a system that is able to take real time inputs from actively flying drones and output a state estimation with 3-D error ellipsoid visualization using an Extended Kalman Filter (EKF)
    - Avoid collisions with other drones and environmental obstacles
- The application of this system would be for the increase of commercial drone delivery operations

ESTIMATION & SIMULATION

TEAM STRUCTURE

- Meeting Times:
  - Monday 2-3 PM
  - Friday 2-5 PM
  - More time if needed
- Informal Split of responsibilities
  - Nick is person of contact
  - Expertise distributed among us

GOALS

- Implement an extended Kalman filter (EKF) on drone positions
- Develop flight software to control drones precisely
- Visualize drones and drone behavior using simulation software
- Develop drones' ability to successfully avoid obstacles
- Develop architecture for communication between drones
- Design system for software-software and software-hardware integration

PROFESSIONAL RESPONSIBILITY

- Collision Avoidance: Need a nearly guaranteed success rate of avoiding obstacles, inanimate and animate alike, to minimize injury and/or damage to property
- This affects certain aspects of our drone operation:
  - Maximum velocity
  - Altitude
  - Avoidance trajectories
- More factors will be considered in the future
  - Acoustics
  - Drone end of life

PROJECT UPDATES

PROJECT UPDATES

- 3D Error Ellipsoid
  - Created a dynamic 3D error ellipsoid model using a Potential Flow Field
- Gazebo Investigation
  - Researching ROS integration with simulation
  - Researching creation of model and error ellipsoid visualization
- Ardupilot/QGroundControl Integration
  - Software is available and ready to be uploaded to drone
  - Research integration of Ardupilot with simulation

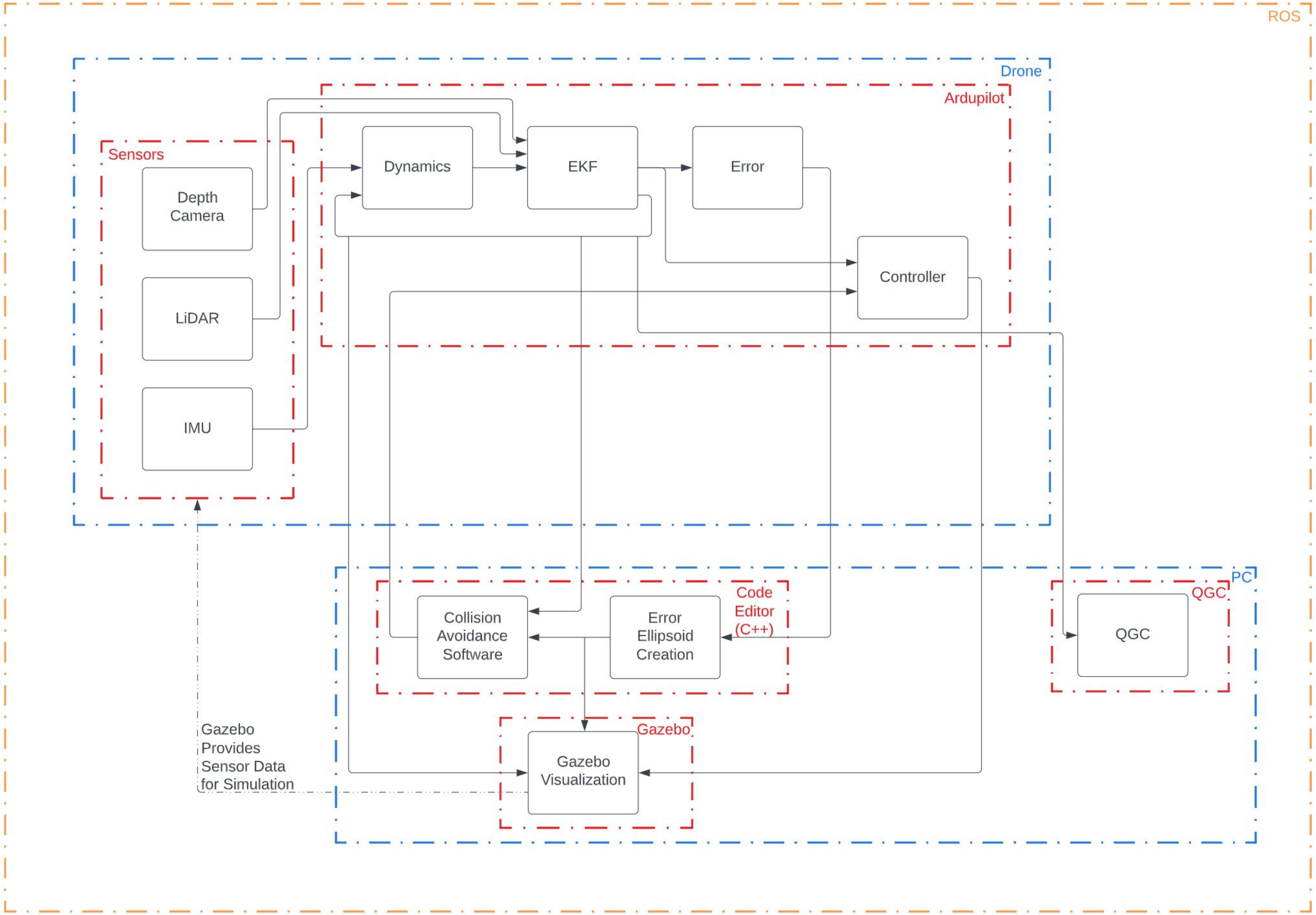
SOFTWARE & BLOCK DIAGRAM

OVERALL OPERATING SYSTEM (OS)

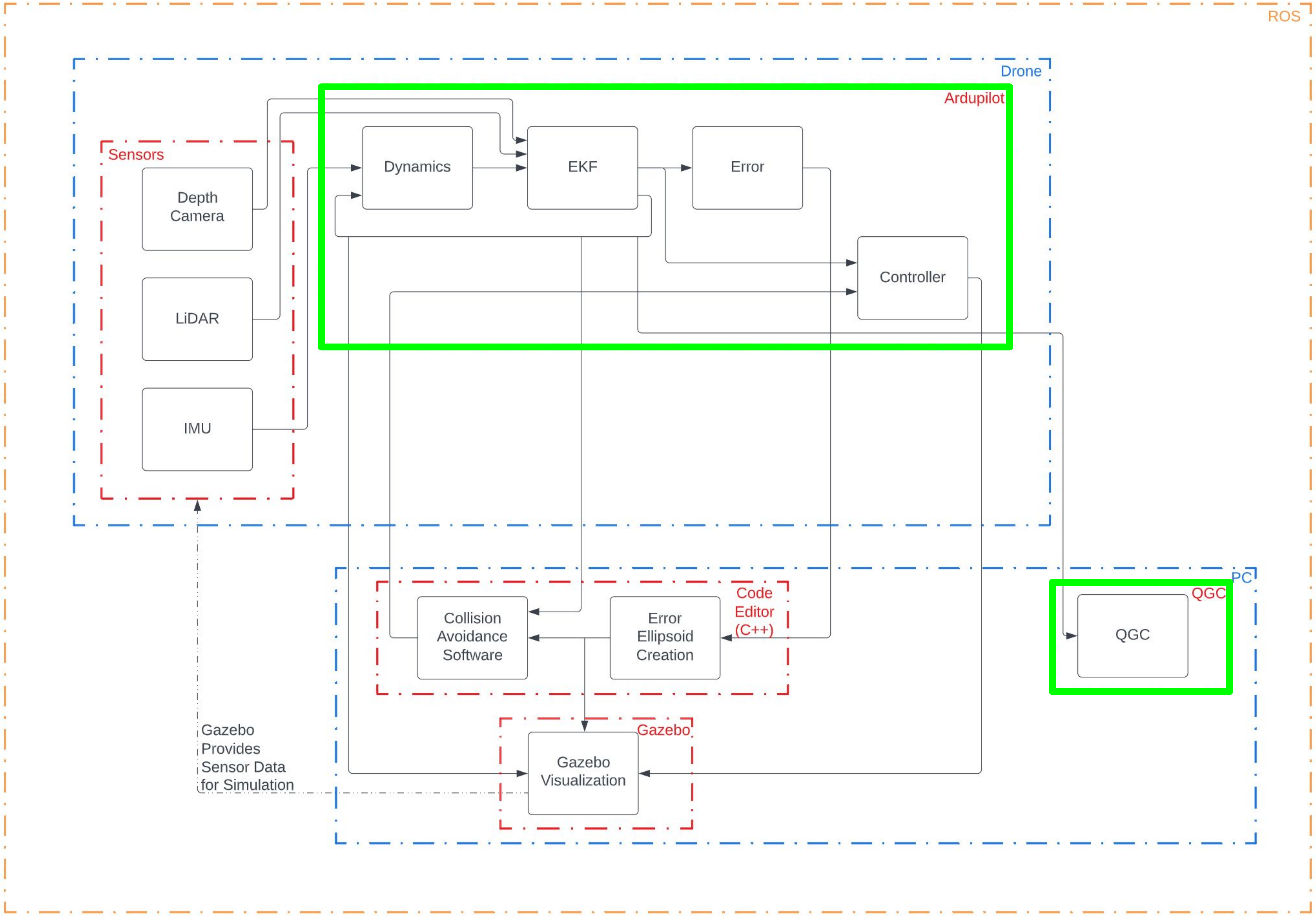
- For developmental purposes, we will be using Linux/Ubuntu. This will allow for more freedom and control when developing software. Certain software like the Robot Operating System (ROS) are developed specifically for operation on a Linux OS.

SOFTWARE LIST

- ArduPilot
- Code Editor (MATLAB, VSCode, Visual Studio, Eclipse, etc.)
- Gazebo/Simulink
- QGroundControl (QGC)
- Robot Operating System (ROS) / MAVLink ("MAVROS")
- Sensor Software (LiDAR, Depth Camera, etc.)



ROS
Drone
Ardupilot
Sensors
Depth Camera
LiDAR
IMU
Dynamics
EKF
Error
Controller
PC
Code Editor (C++)
Collision Avoidance Software
Error Ellipsoid Creation
QGC
QGC
Gazebo
Gazebo Visualization
Gazebo Provides Sensor Data for Simulation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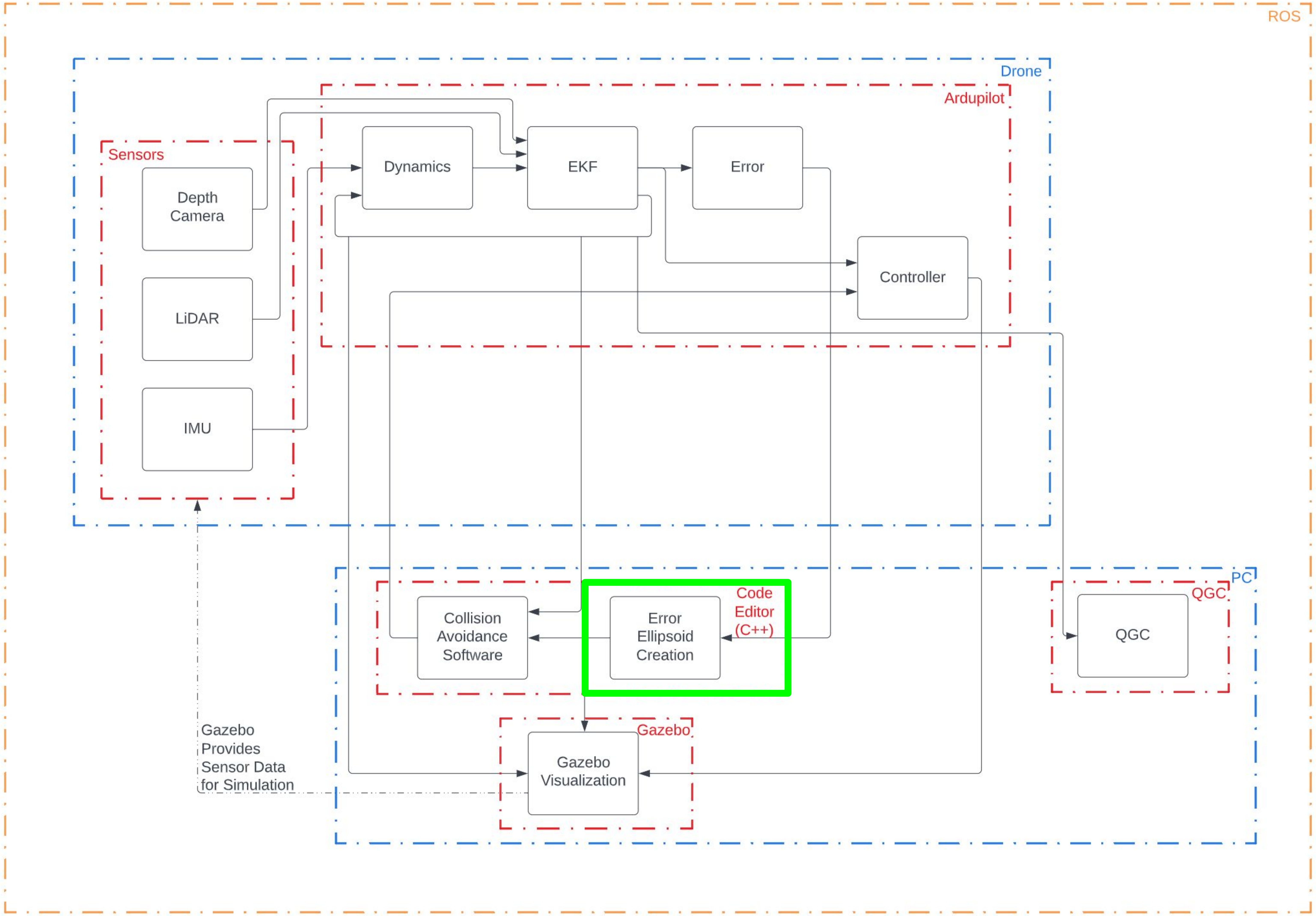
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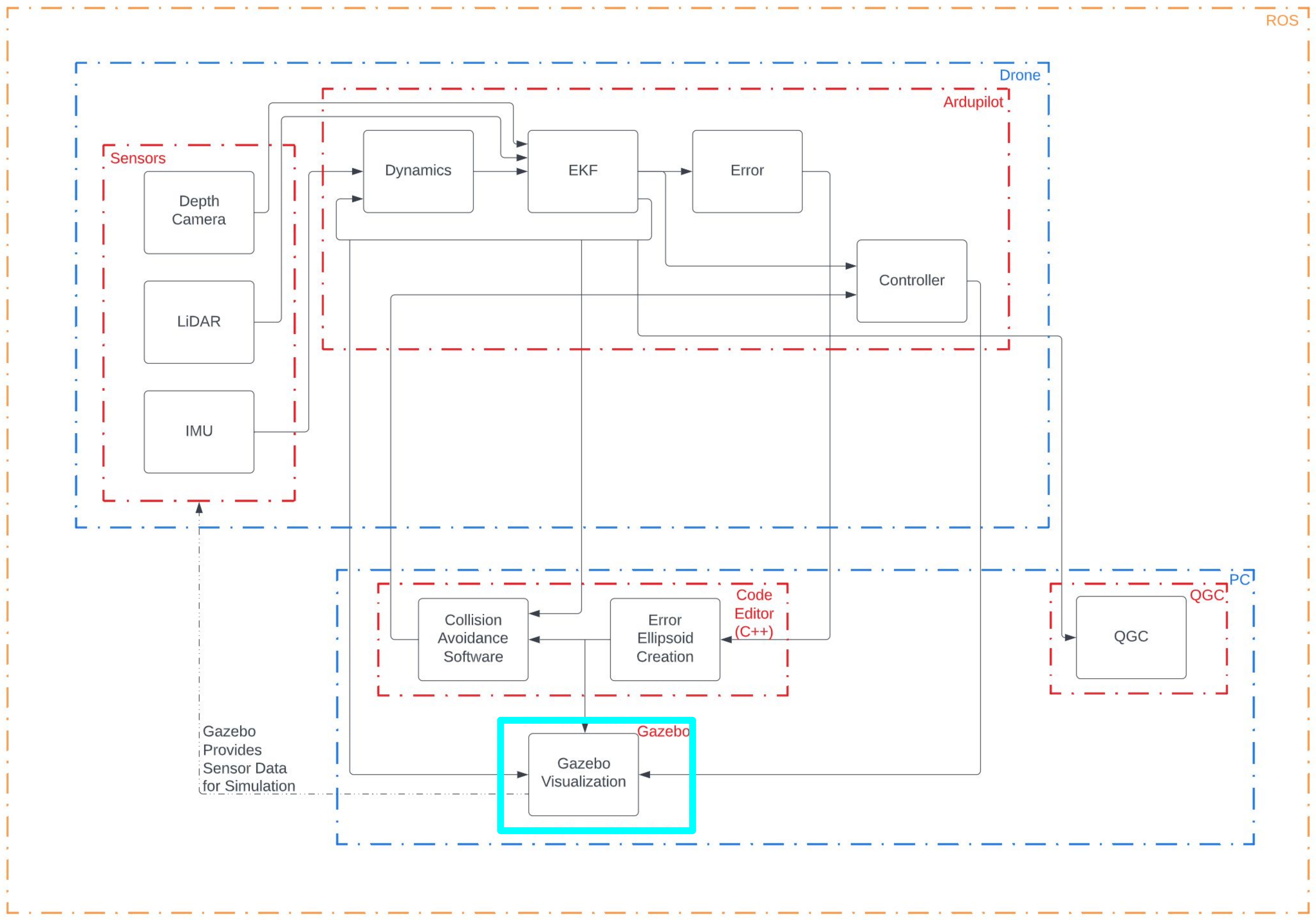
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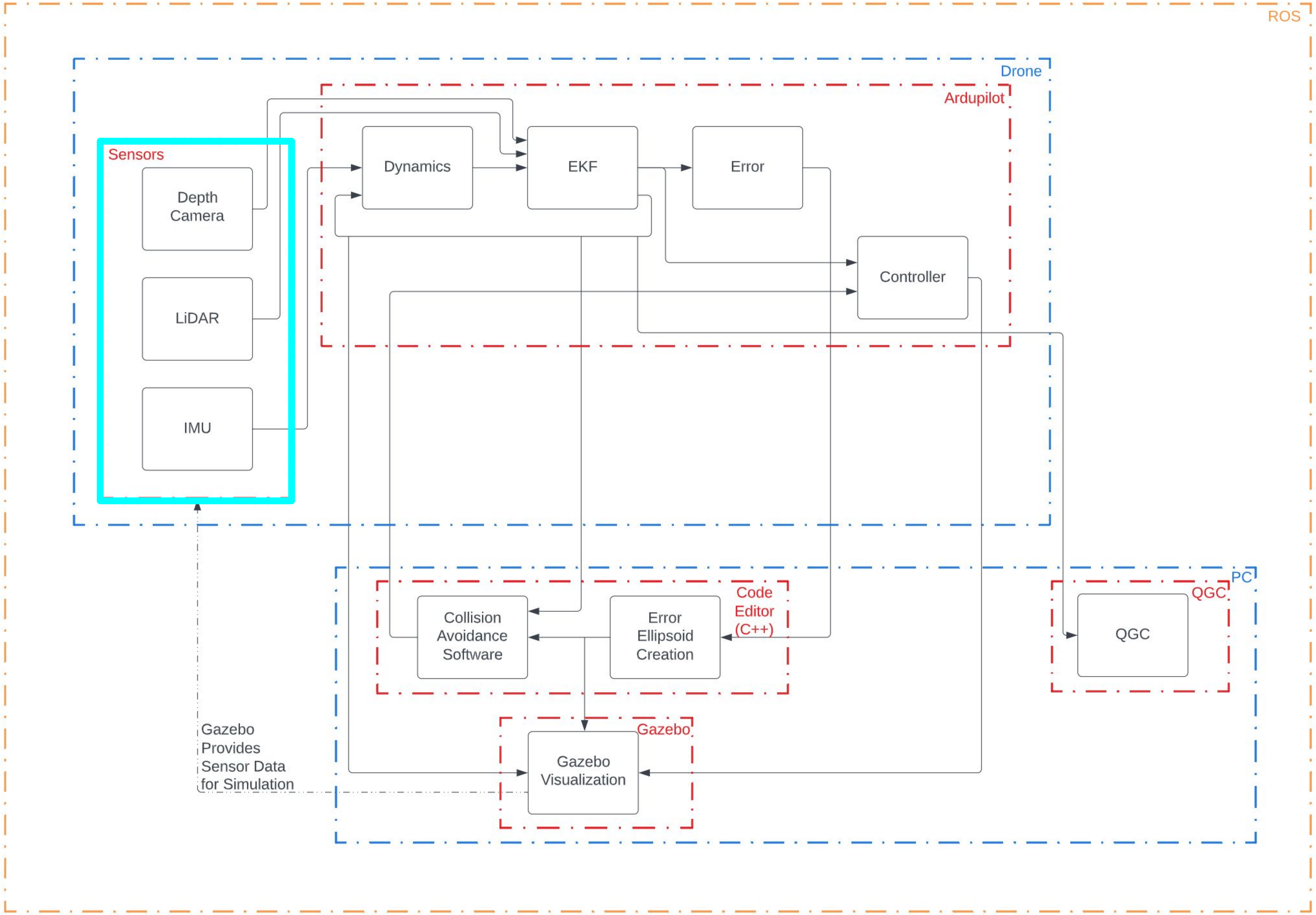
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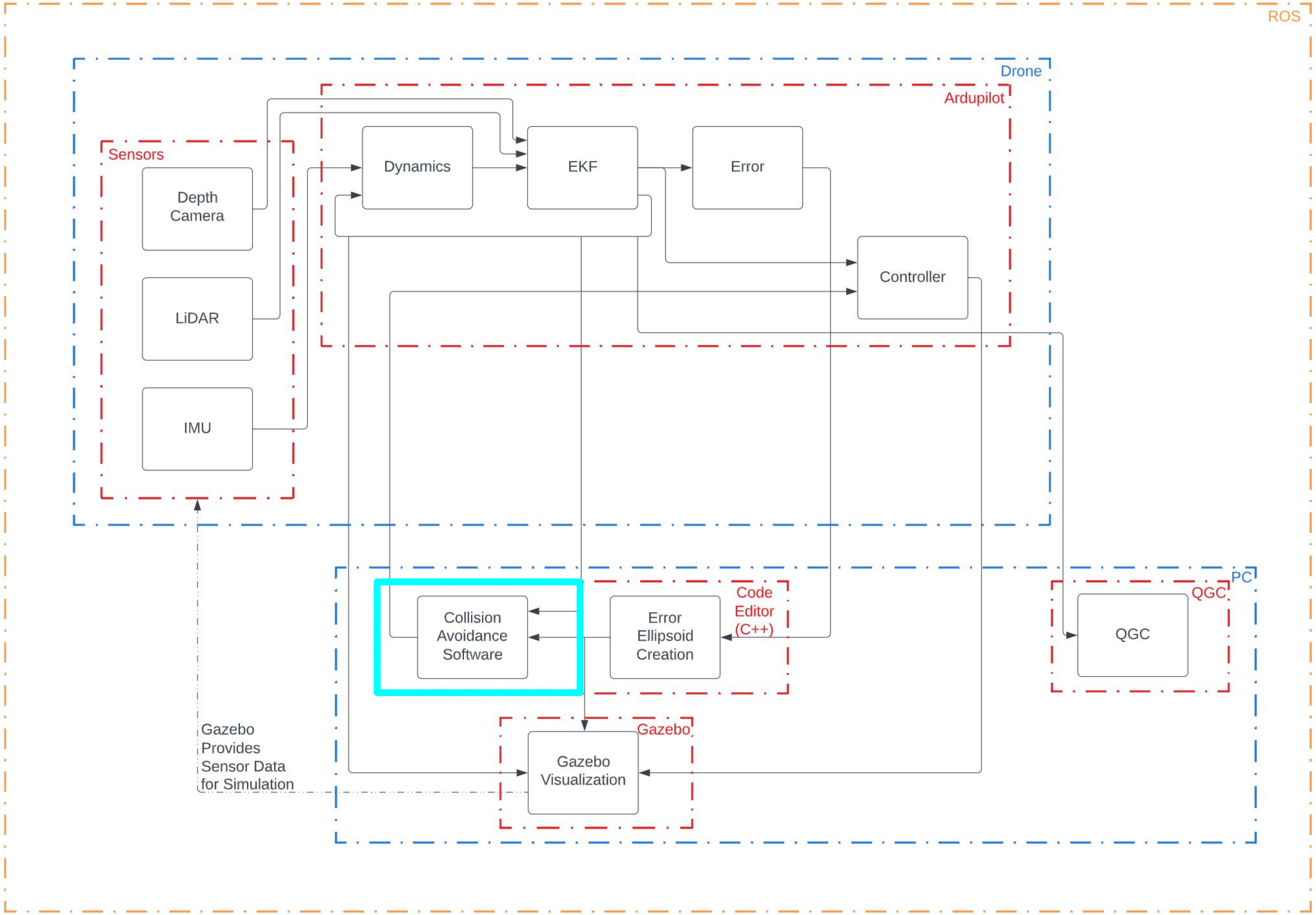
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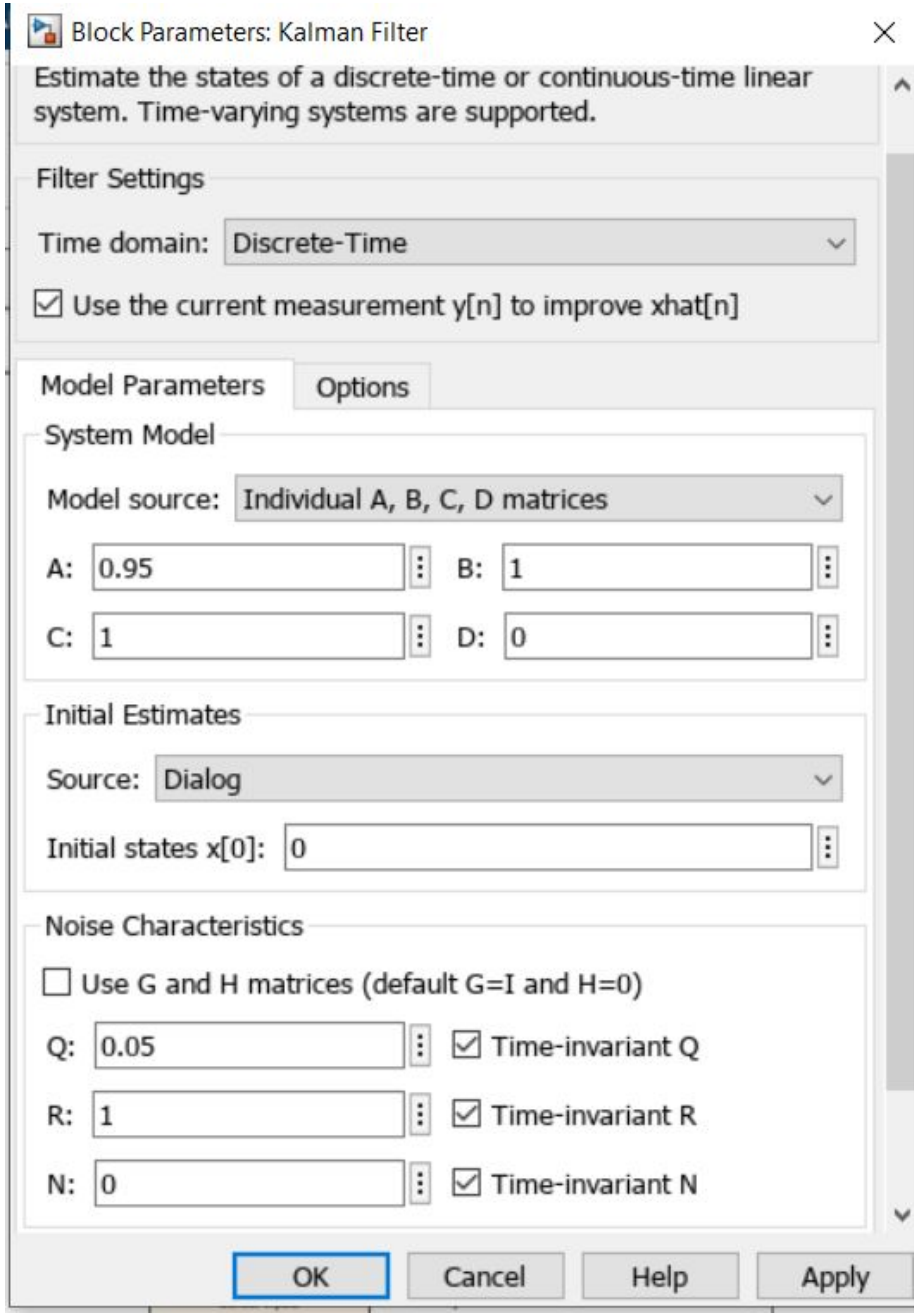
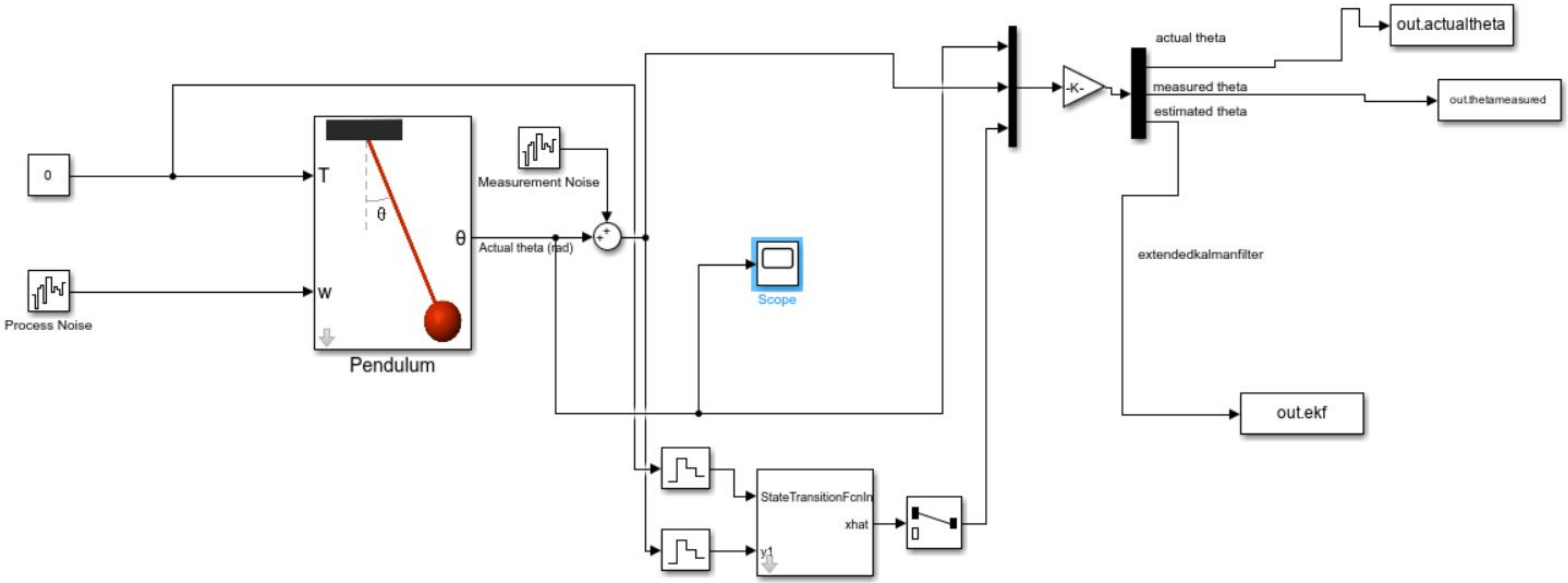
PENDULUM SIMULATION

Extended Kalman Filter (EKF)

- A Kalman Filter is a filter that takes a less than perfect dynamic model and noisy measurements to provide very accurate state estimations for a system. This filter only works for linear systems.
- Two covariance matrices: Q and R (process and measurement noise respectively)
- An EKF can be used in non-linear systems but requires more computation. The general concept is the same, and the Q and R covariance matrices are still very important.

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θ
Pendulum
Process Noise
Measurement Noise
Actual theta (rad)
Scope
StateTransitionFcnIn
xhat
y1
-K-
actual theta
measured theta
estimated theta
extendedkalmanfilter
out.actualtheta
out.thetameasured
out.ekf

POTENTIAL FIELD 3D SIMULATION

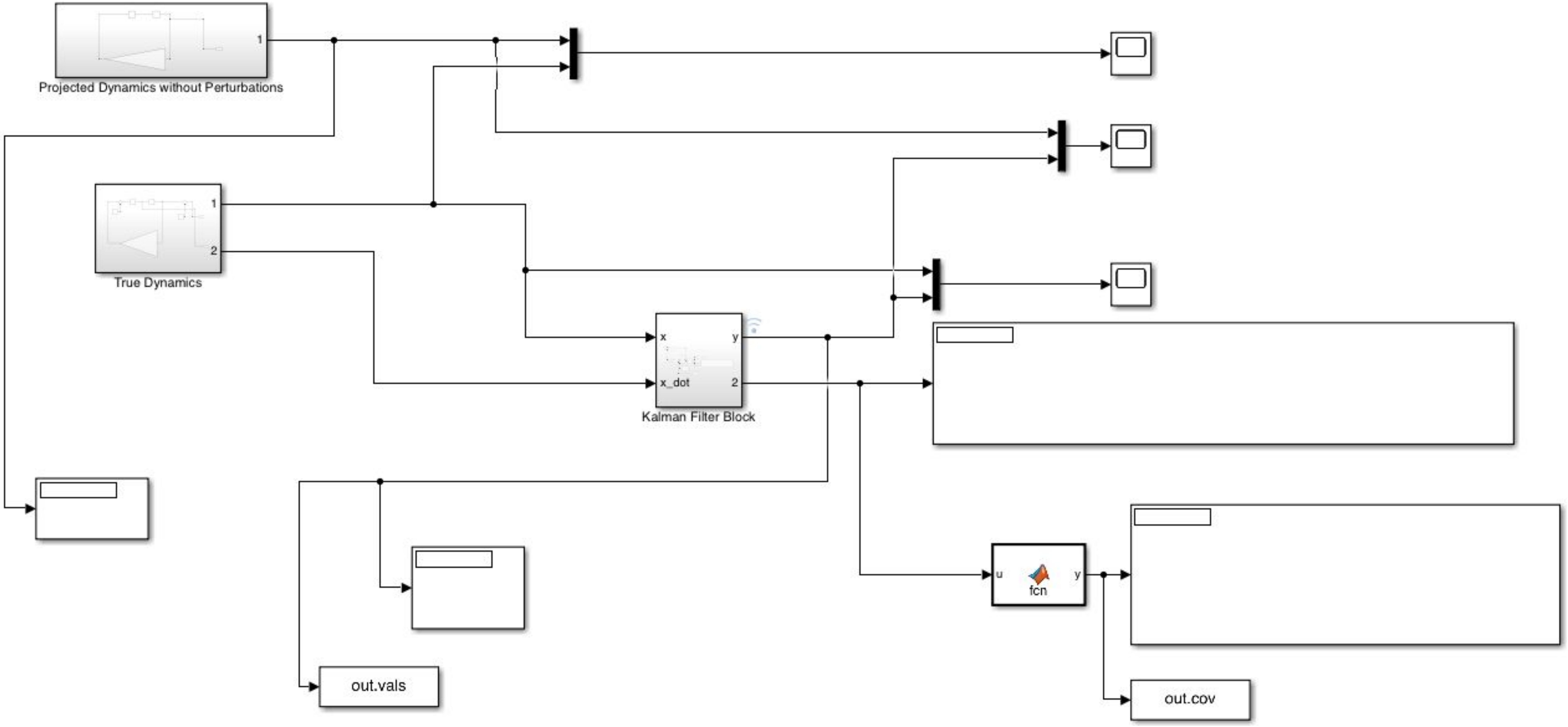
Potential Field Dynamics:

- The main motivation in creating a potential field model was to have a three dimensional model that a Kalman filter could be applied to.

- The potential field was designed to impart an acceleration in the x direction, the y direction, and the z direction based on the location of the particle in 3D space.

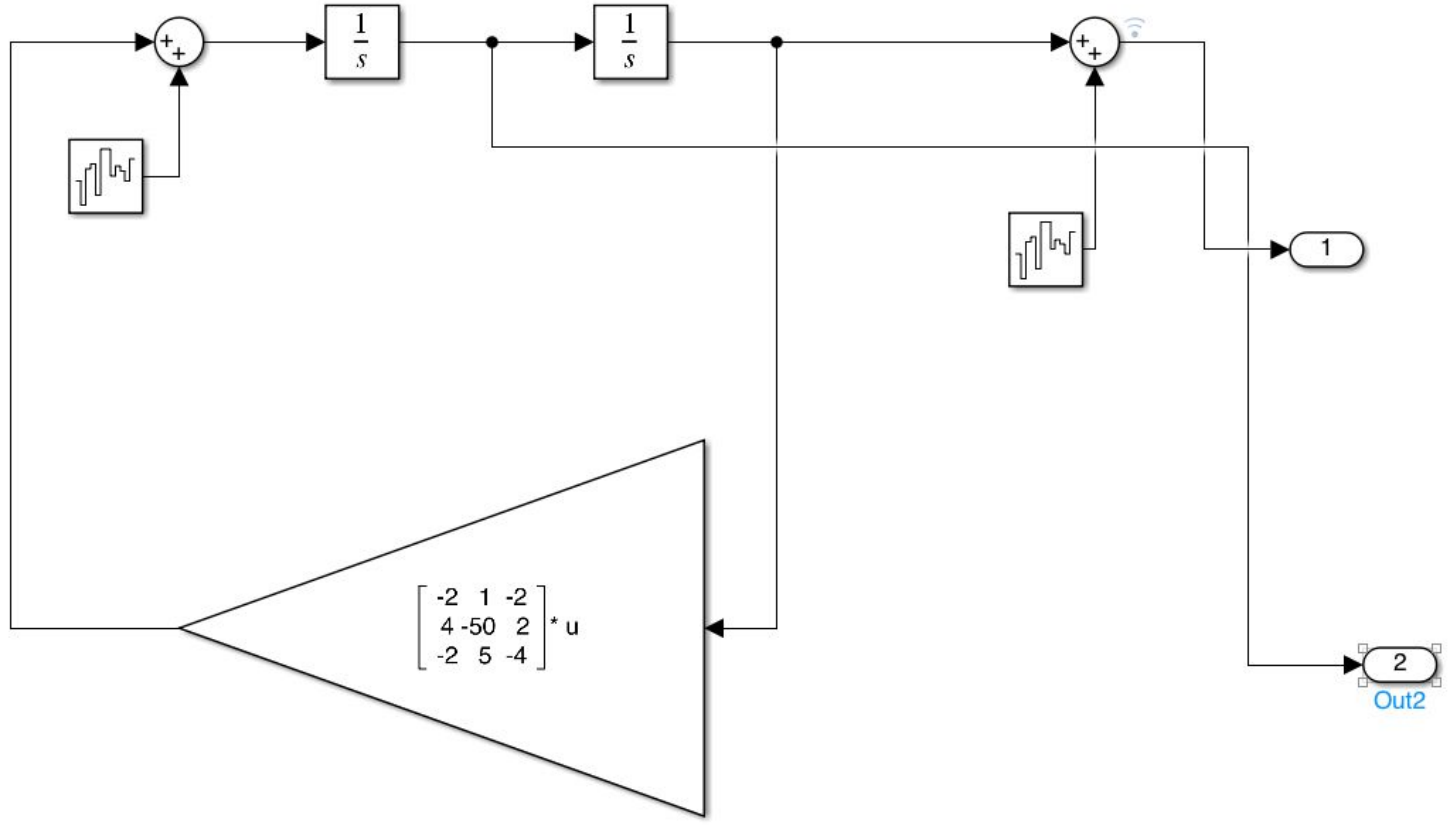
- The accelerations were chosen to be:
  X_Acceleration= -2x+1y-2z
  Y_Acceleration= 4x-50y+2z
  Z_Acceleration= -2x-5y-4z
  This created a coupled system.

Potential Field Block Diagram:



Potential Field Block Diagram:

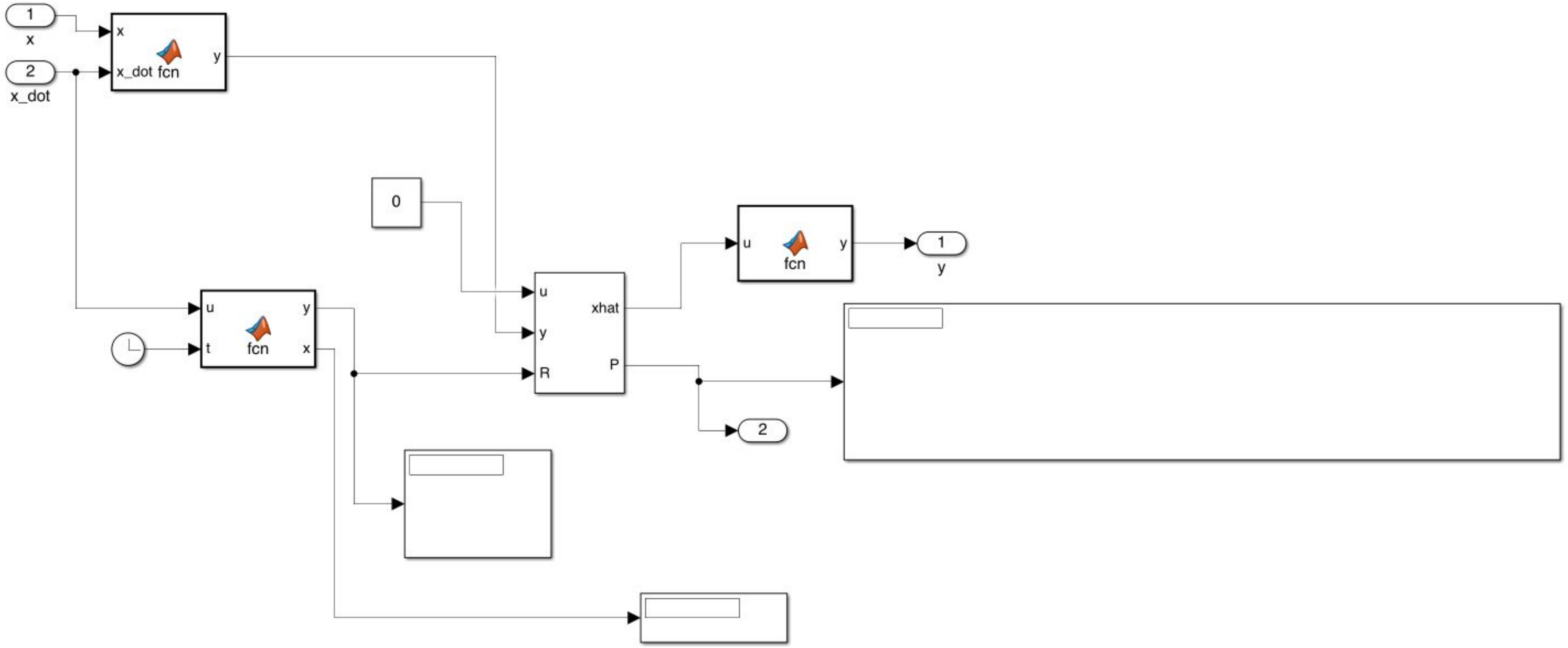
True Dynamics Block:



- The true dynamics were calculated by integrating the differential equations and adding measurement and process noise (chosen at this stage to give a noisy output that still approximately matched the output of the dynamics without noise)

Potential Field Block Diagram:

Kalman Filter Block:



- The Kalman filter requires an input of the projected dynamics within the block. The input was done in state space model form.
- The Kalman filter also requires the input for the actual dynamics found on the previous slide.
- Kalman filter outputs a covariance matrix, which in this case is 6 x 6 because there are 6 states: x, x_dot, y, y_dot,z,z_dot

Potential Field Covariance and Error Ellipsoid:

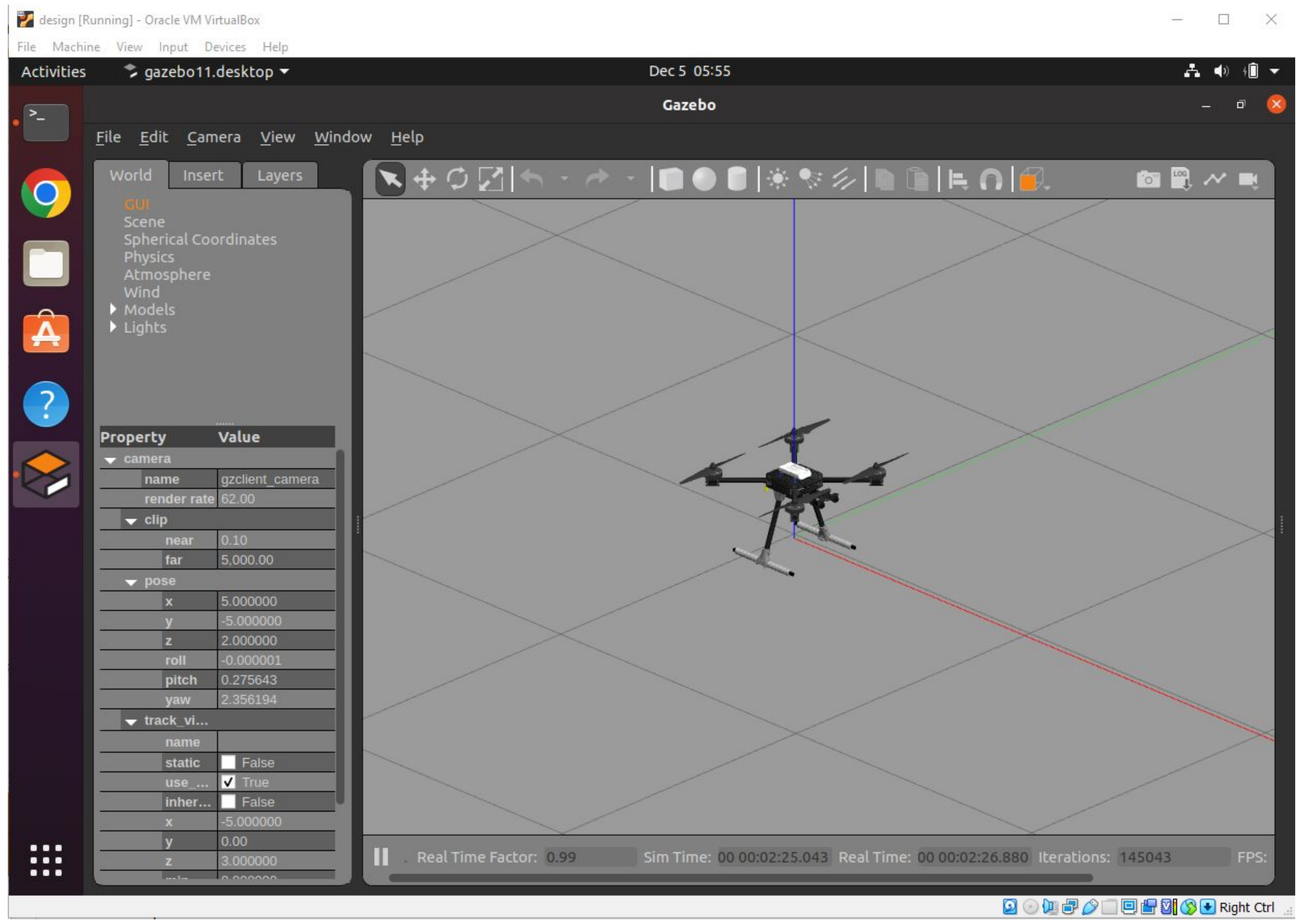
- The noise is chosen to vary with velocity so the covariance matrix error increases with velocity
- This creates a bigger error ellipse when the drone is moving faster
- The values for the covariance matrix that applied to the x and y error were isolated and extracted to create a 3 x 3 matrix. This matrix was then used in a MATLAB script to find the error ellipsoid.
- Using this 3 x 3 matrix, the error ellipsoid could be created by implementing an algorithm created for this purpose [1].
- The values of the state for x and y were also outputted to MATLAB for use in the script.
- The error ellipsoid was then plotted for every point by using the x and y of the state as the center. The visualization was done via a for loop and the drawnow functionality.
- The error ellipsoid was visualized using the surfl MATLAB plotting tool.

VISUALIZATION

3D SIMULATION

GAZEBO

- Develop a 3D model simulation with a time-varying error ellipse to account for the more realistic conditions of variable noise
- Research how to apply the extended kalman filter to a 3D system
- Develop a functional simulation that can estimate the drone state and visualize the error ellipsoid based on flight and sensor inputs



NEXT STEPS

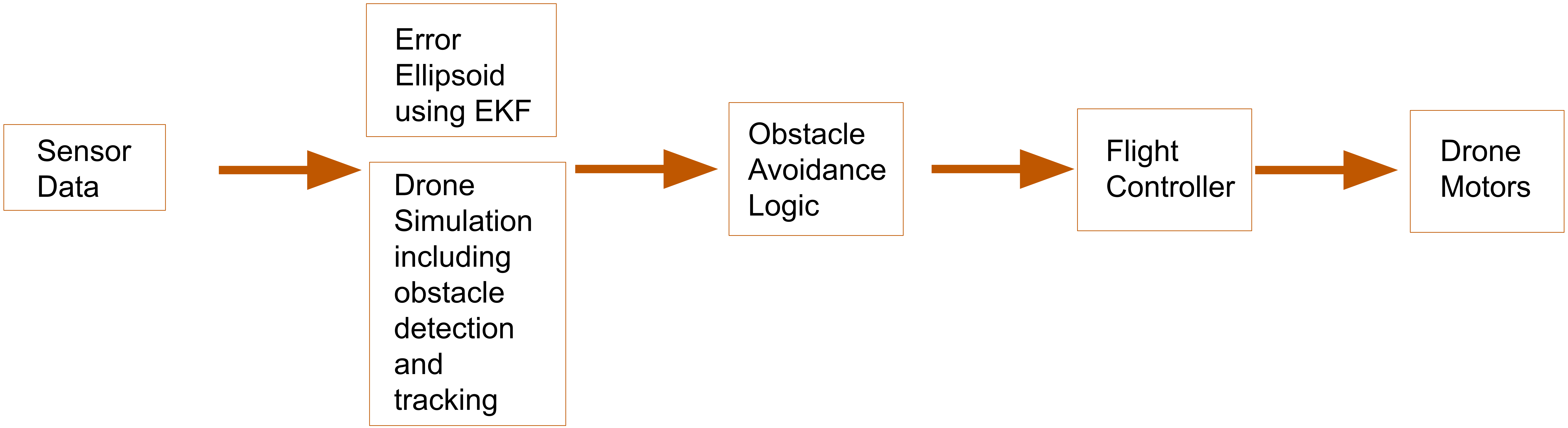
GANTT CHART FOR NEXT SEMESTER

TASK TITLE	START ESTIMATION	TENTATIVE DUE DATE	COMPLETE (?)	1/9	1/16	1/23	1/30	2/6	2/13	2/20	2/27	3/6	3/20	3/27	4/3	4/10	4/17	4/24
Simulation																		
Dynamic Model	1/9/2022	2/6/2022																
Upload specs to model parameters	1/30/2022	2/6/2022																
Kalman Filter for Dynamic Model	1/30/2022	2/20/2022																
Sensor Models	2/6/2022	2/20/2022																
Simulink Flight	2/20/2022	3/20/2022																
Gazebo Simulation	3/13/2022	4/24/2022																
Estimation																		
Research Error Ellipsoid Methods	1/9/22	1/30/22																
Implement Relevant Error Ellipsoid to Model	2/13/22	3/6/22																
Implement Error Ellipsoid in Gazebo	3/27/22	4/24/22																
Flight Software																		
Manual Flight ArduPilot Installation	1/9/22	2/6/22																
QGroundControl Setup	1/30/22	2/20/22																
Acquire Computer Vision Software	2/27/22	3/20/22																
Research Obstacle Avoidance Algorithms	3/20/22	4/24/22																

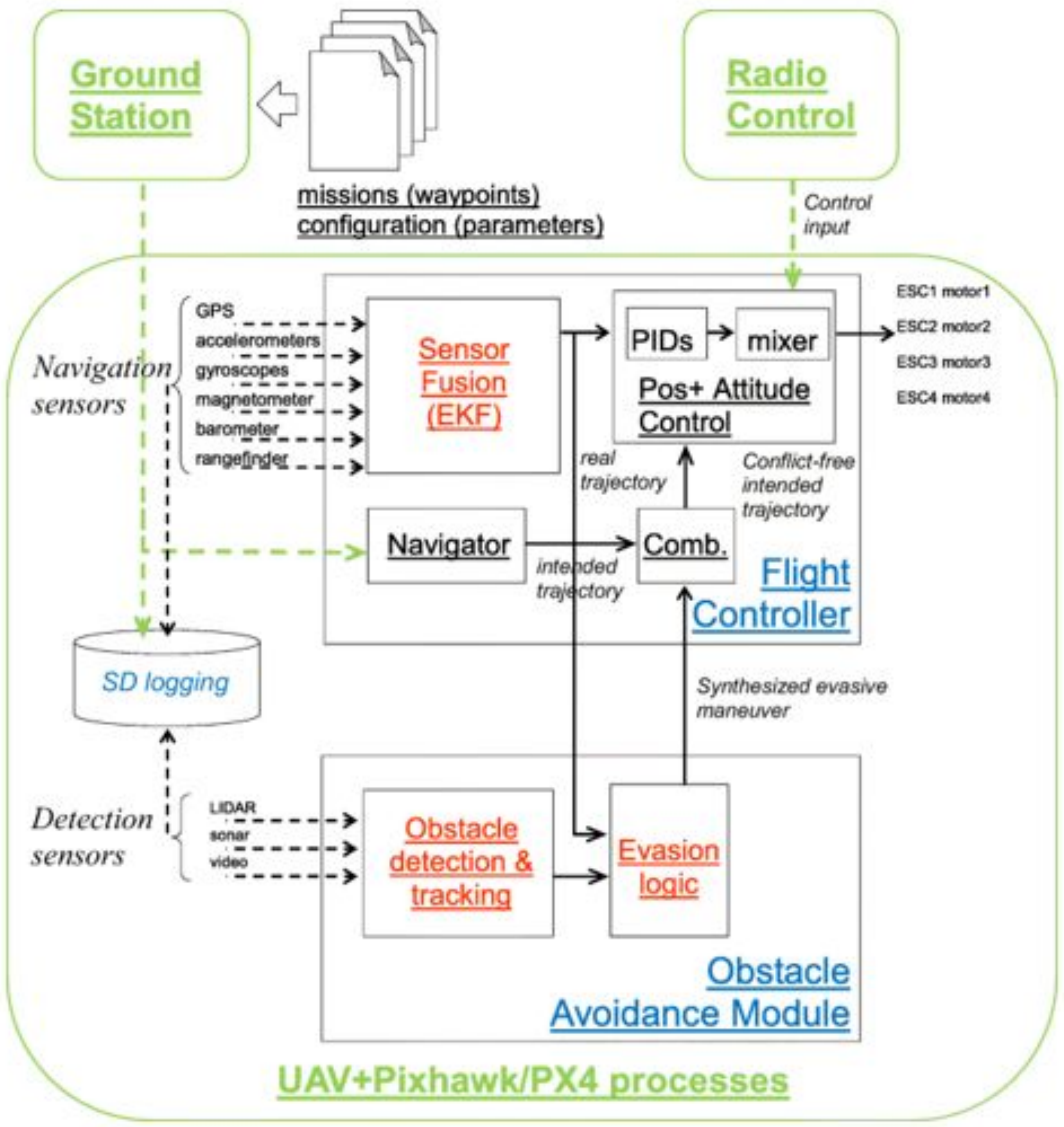
FUTURE WORK

- Develop a 3D model simulation with a time-varying error ellipse to account for the more realistic conditions of variable noise
- Develop a functional Gazebo simulation that can estimate the drone state and visualize the error ellipsoid based on flight and sensor inputs
- Implement code onto physical drone
  - Flight Software
  - Drone Dynamics
  - Error Ellipsoid Generation

DRONE SYSTEM PIPELINE



FULLY INTEGRATED SOLUTION



THANK YOU.

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References:

[1] “Plot 3D Error Ellipsoid,” https://kittipatkampa.wordpress.com. https://kittipatkampa.wordpress.com/2011/08/04/plot-3d-ellipsoid/