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

November 2022

DESIGN REVIEW #1

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.
- Obtain a system that is able to take real time inputs from actively flying drones and output a state estimation with three dimensional error ellipsoid visualization
- Collision avoidance concerning other drones and environmental obstacles
- The application of this system would be for the increase of commercial drone delivery operations

PROJECT OVERVIEW

- Using an Extended Kalman Filter (EKF) to turn error into ellipsoid visualization
- Physical data taken from the sensors on board the drone will be used in tandem with a powerful simulation through Gazebo
- The collision avoidance system will make sure that no two error ellipsoids around their respective drones will intersect

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

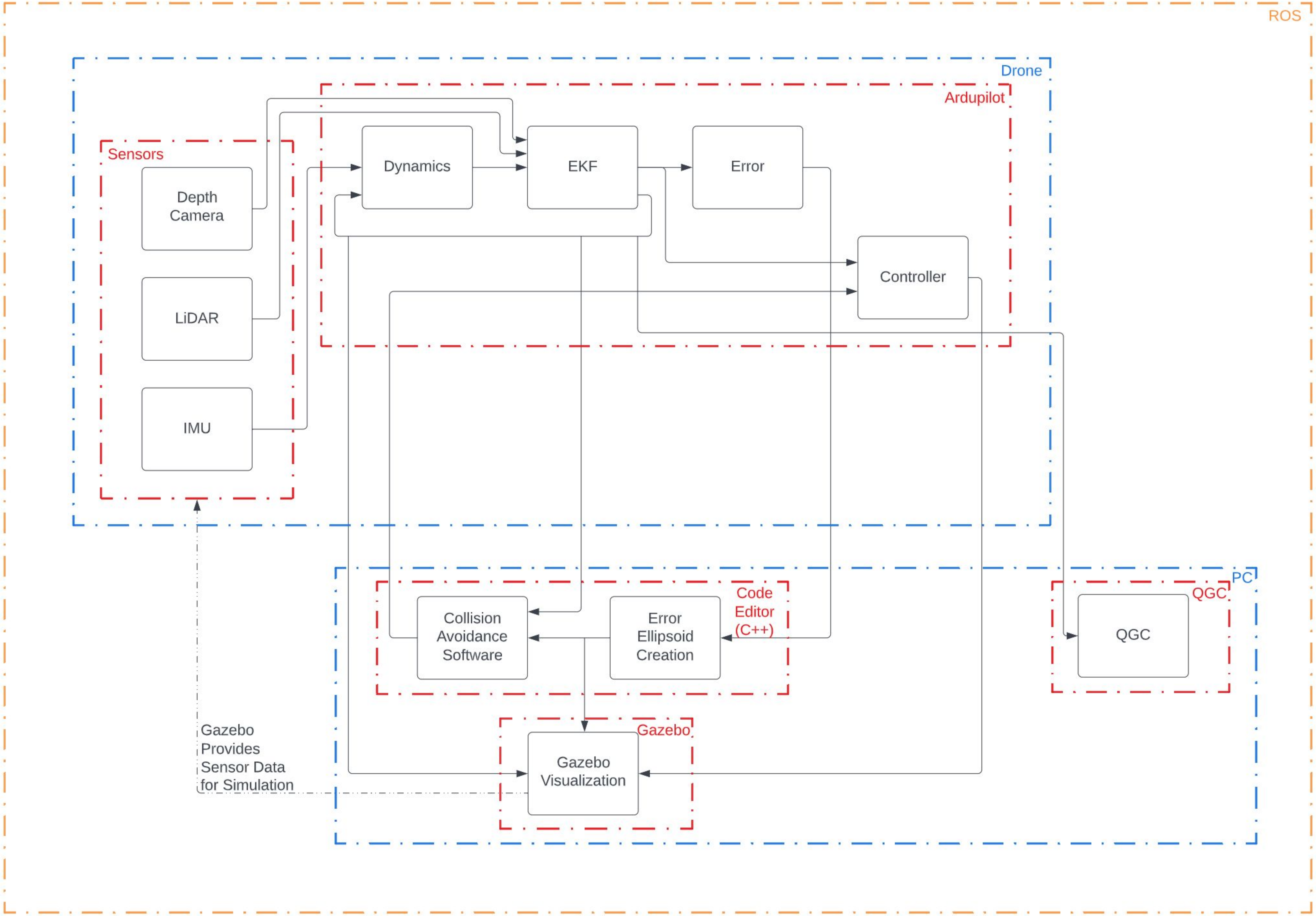
SOFTWARE & BLOCK DIAGRAM

OVERALL OPERATING SYSTEM (OS)

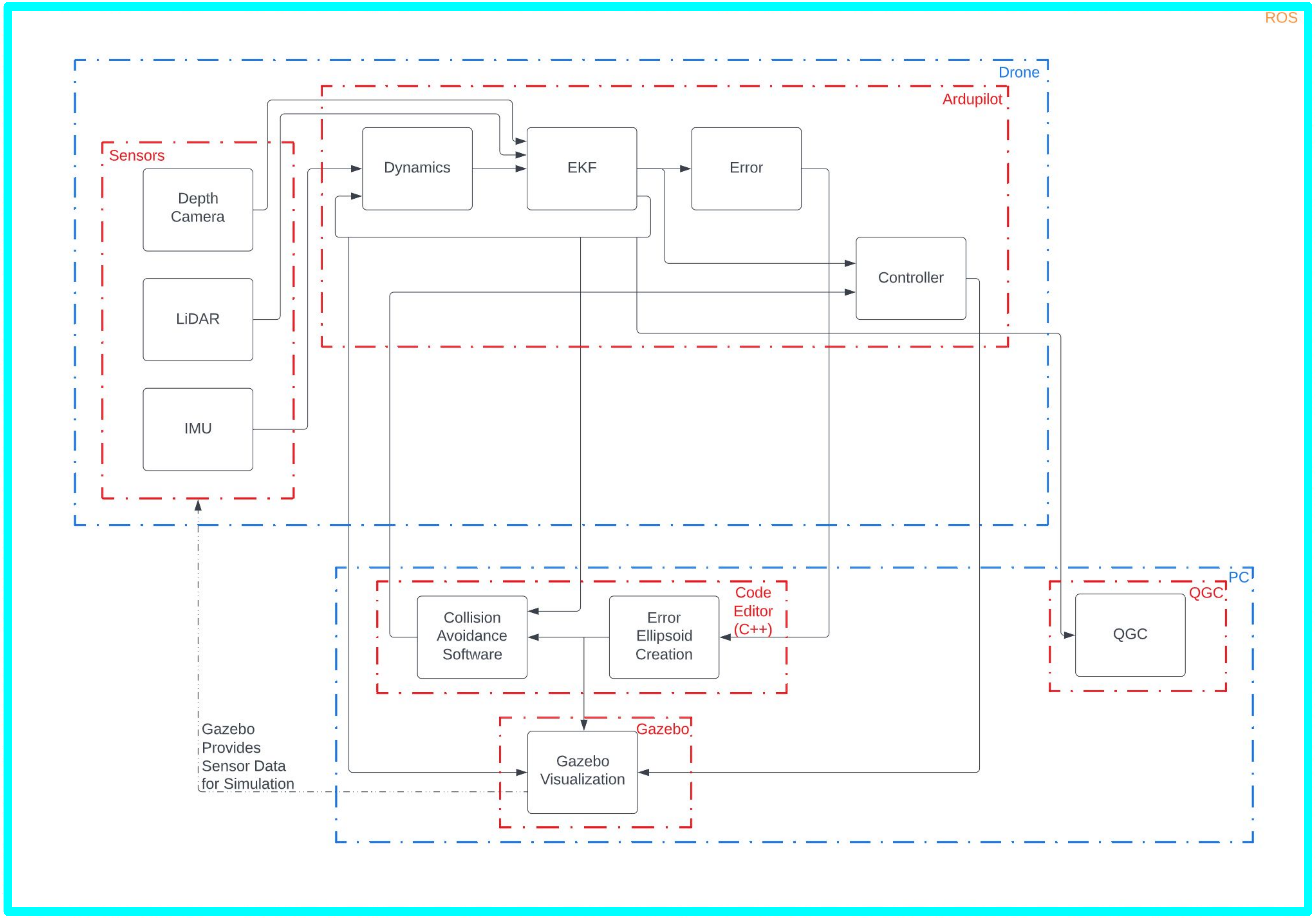
- For developmental purposes, we will be using Linux/Ubuntu. This will allow for more freedom and control when developing software. Certain software like the Robot Operating System (ROS) are developed specifically for operation on a Linux OS.

SOFTWARE LIST

- ArduPilot
- Code Editor (MATLAB,VSCode, Visual Studio, Eclipse, etc.)
- Gazebo/Simulink
- QGroundControl (QGC)
- Robot Operating System (ROS)
- 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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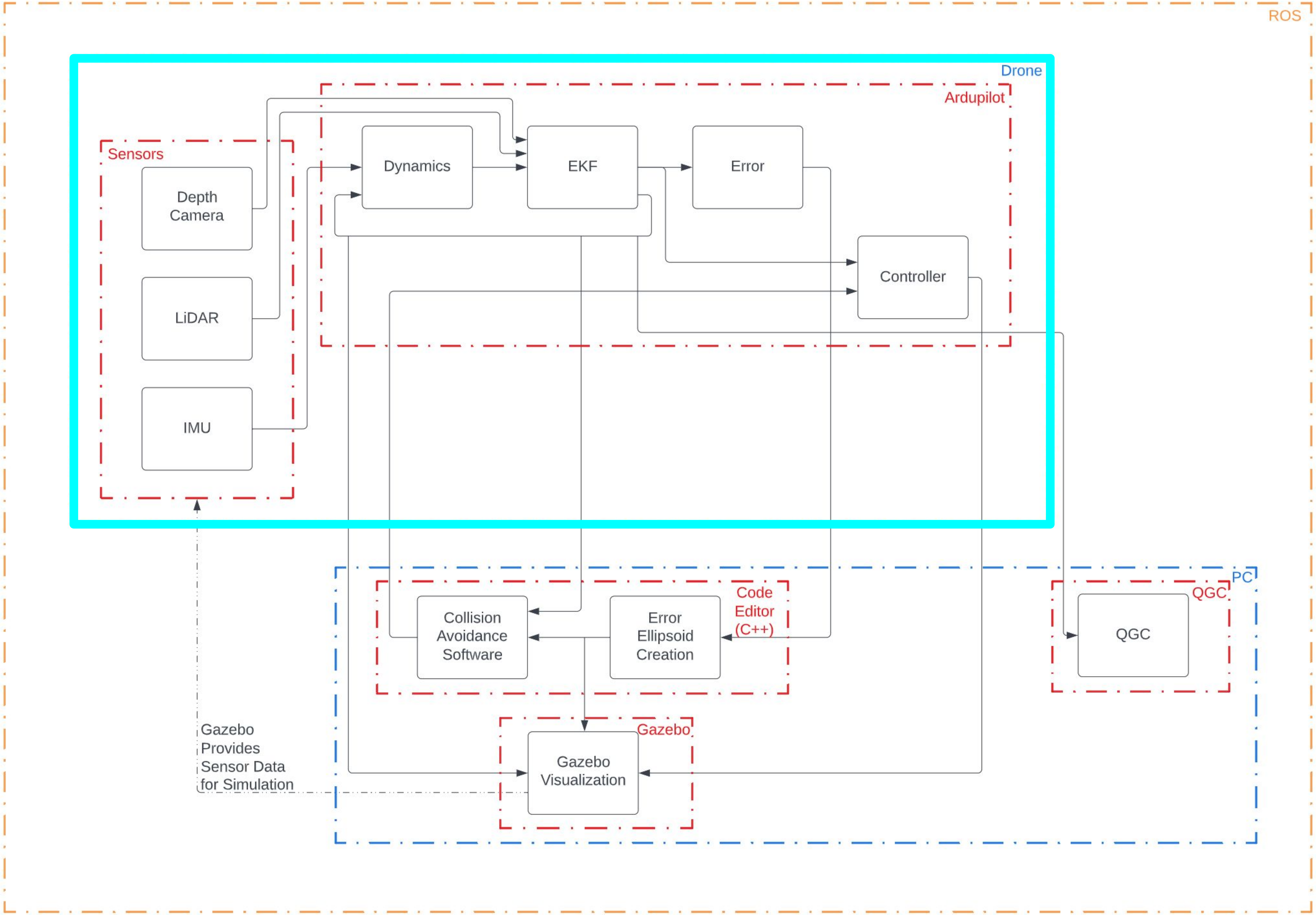
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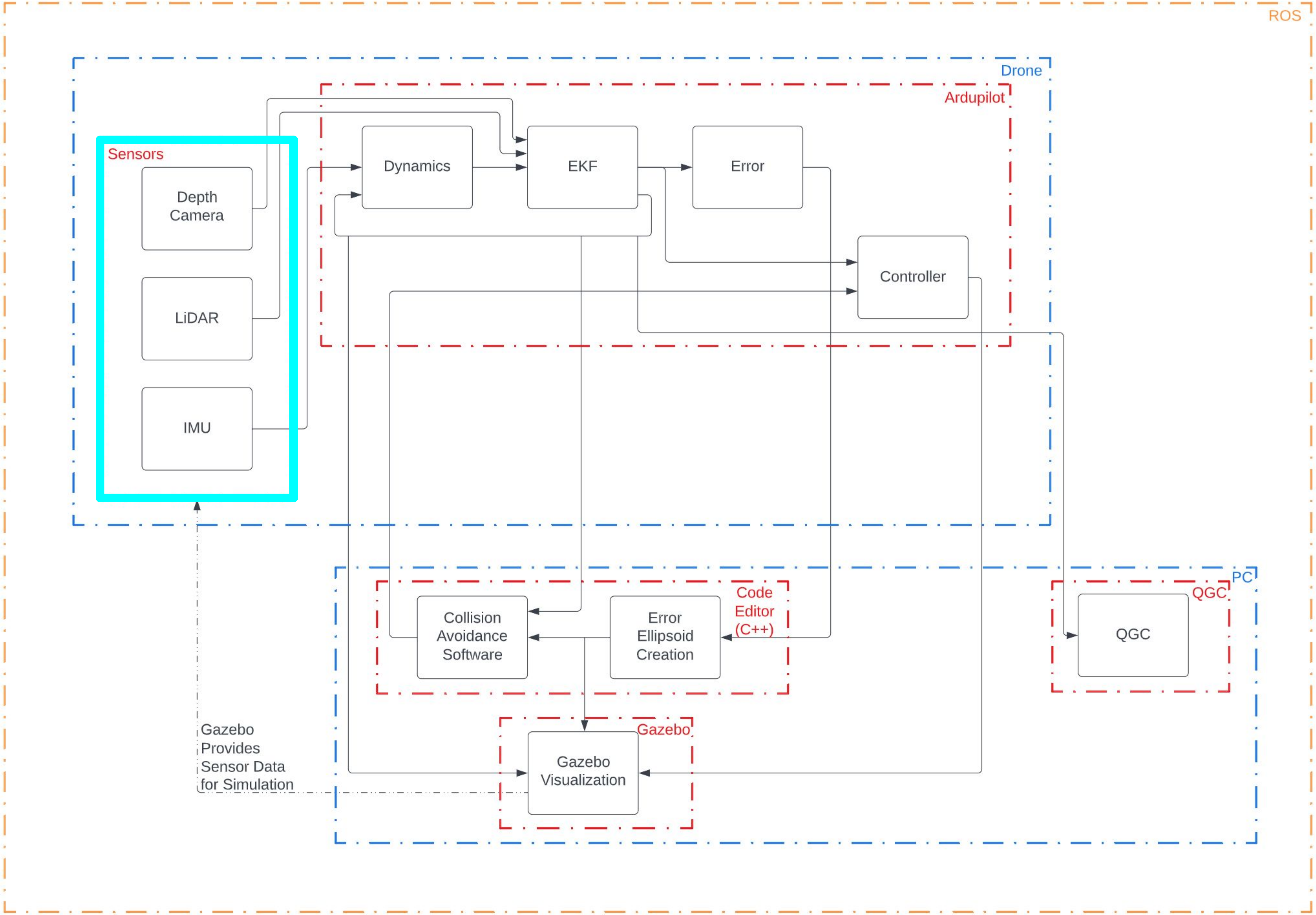

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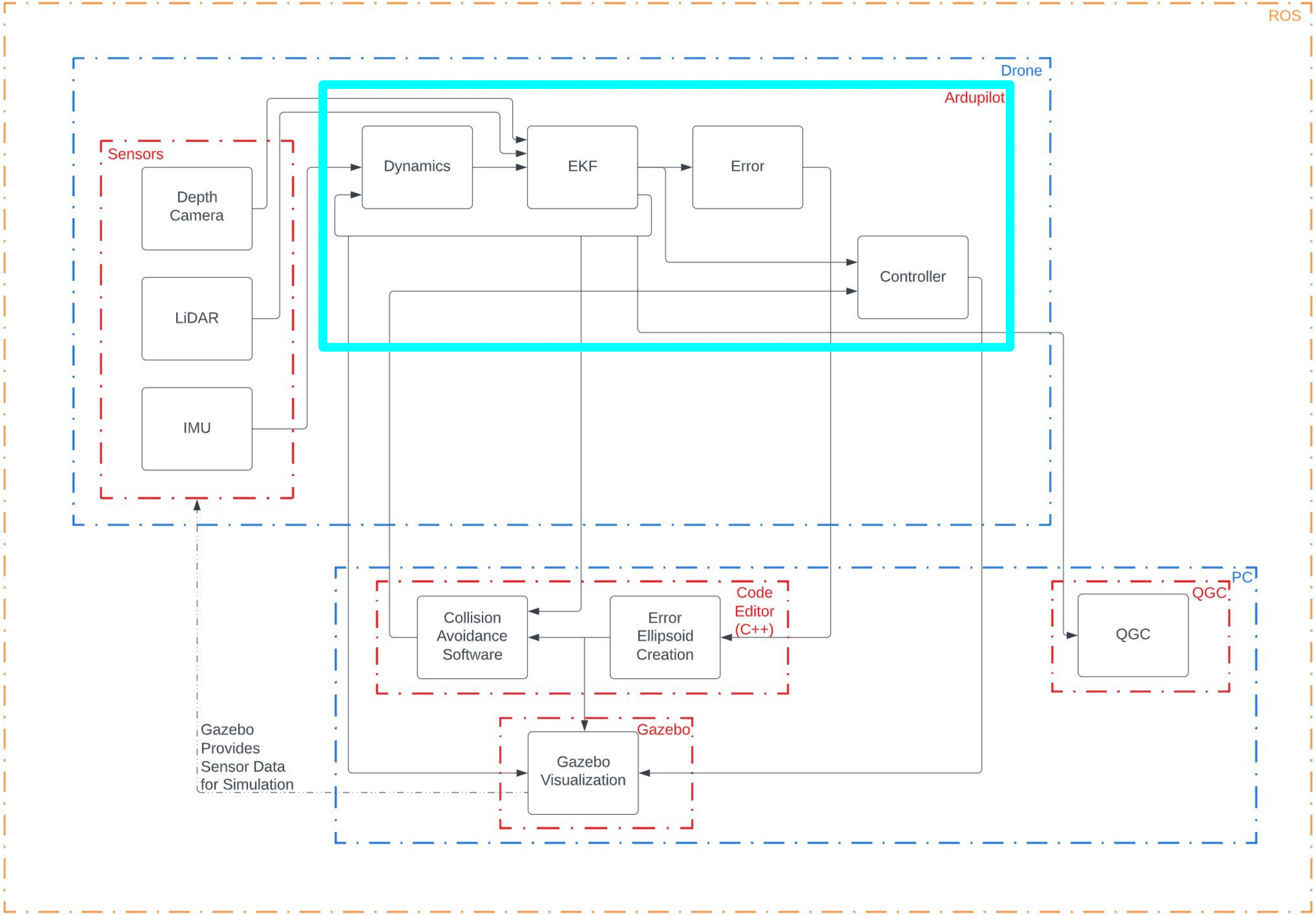

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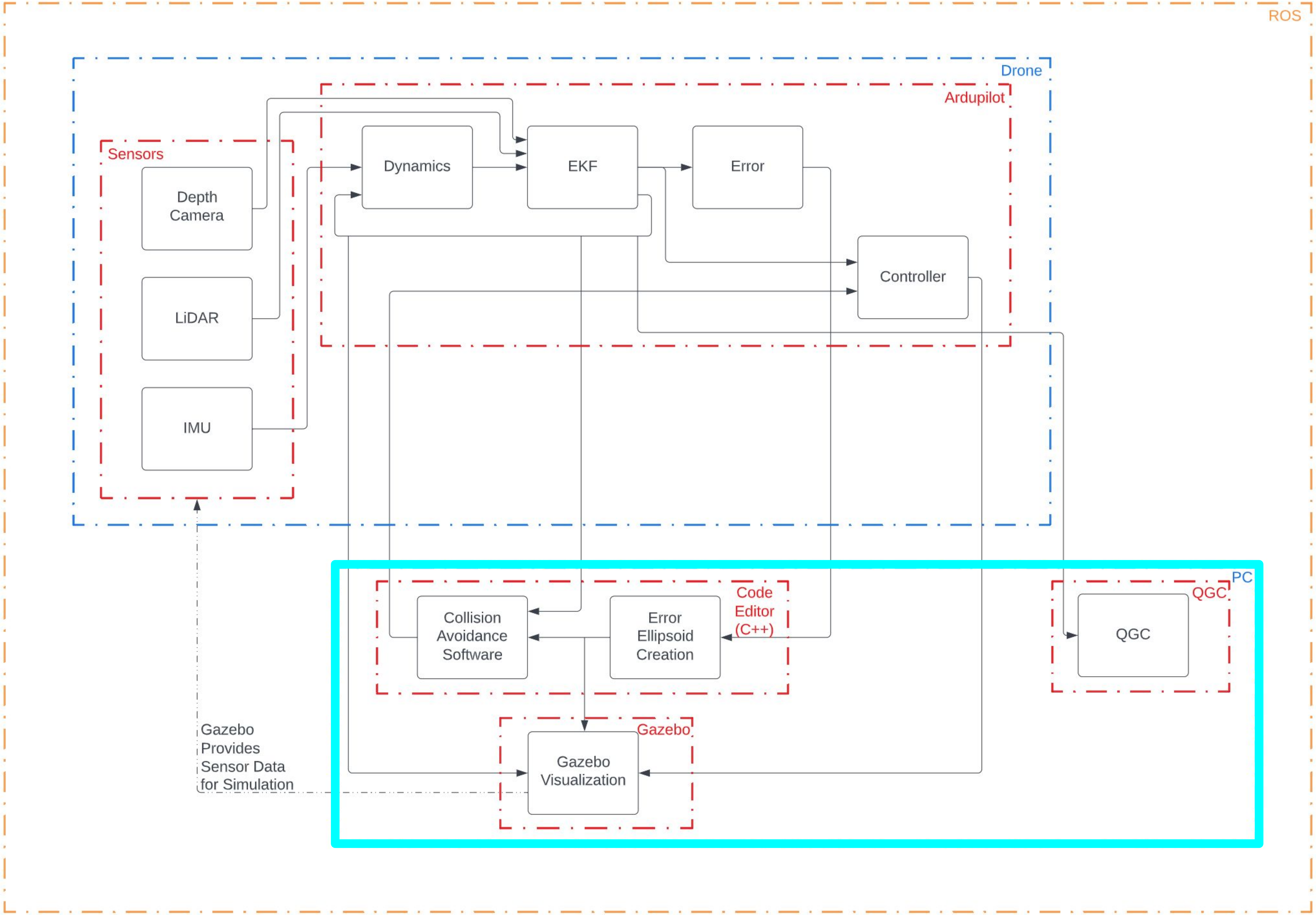

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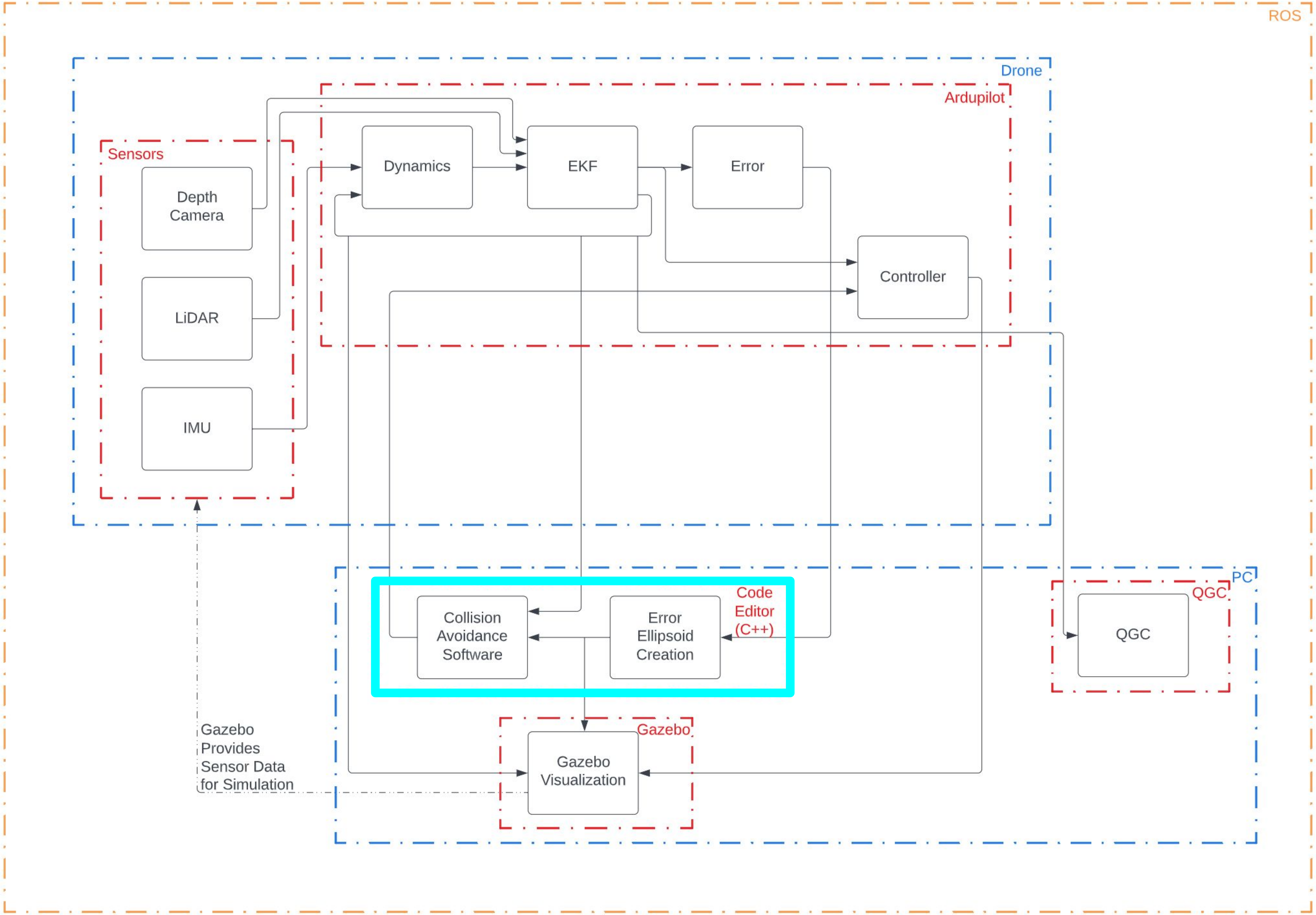
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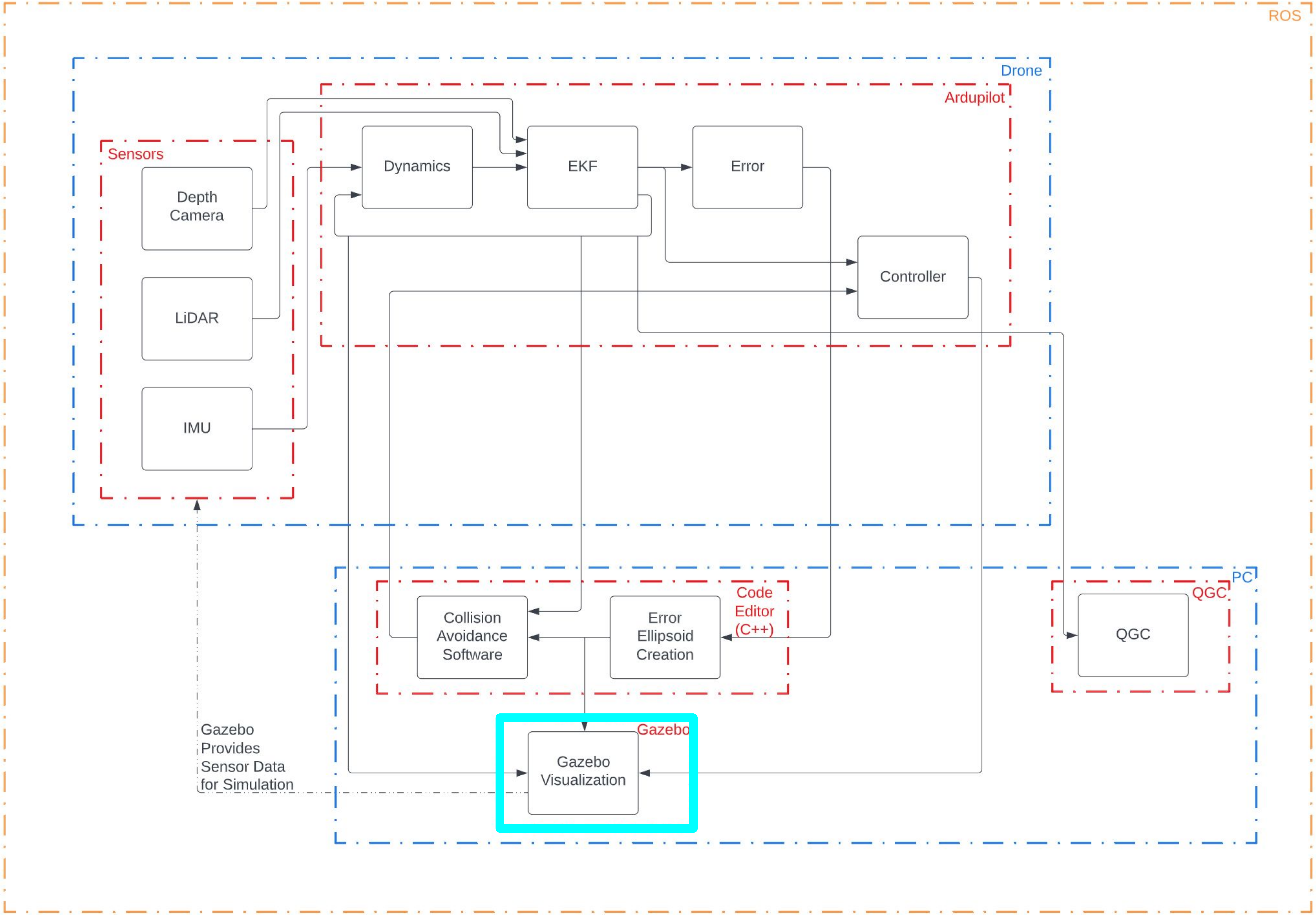
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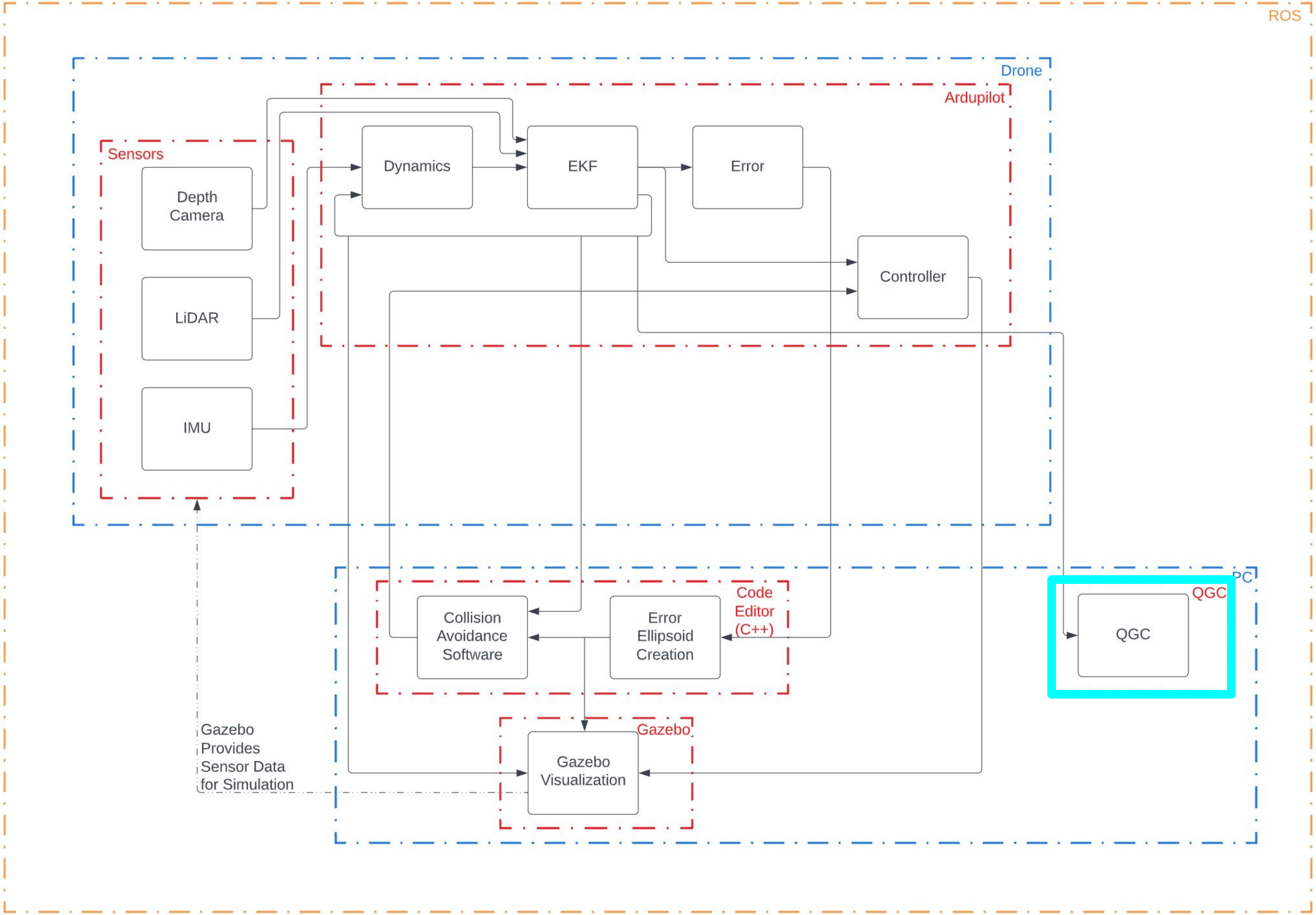
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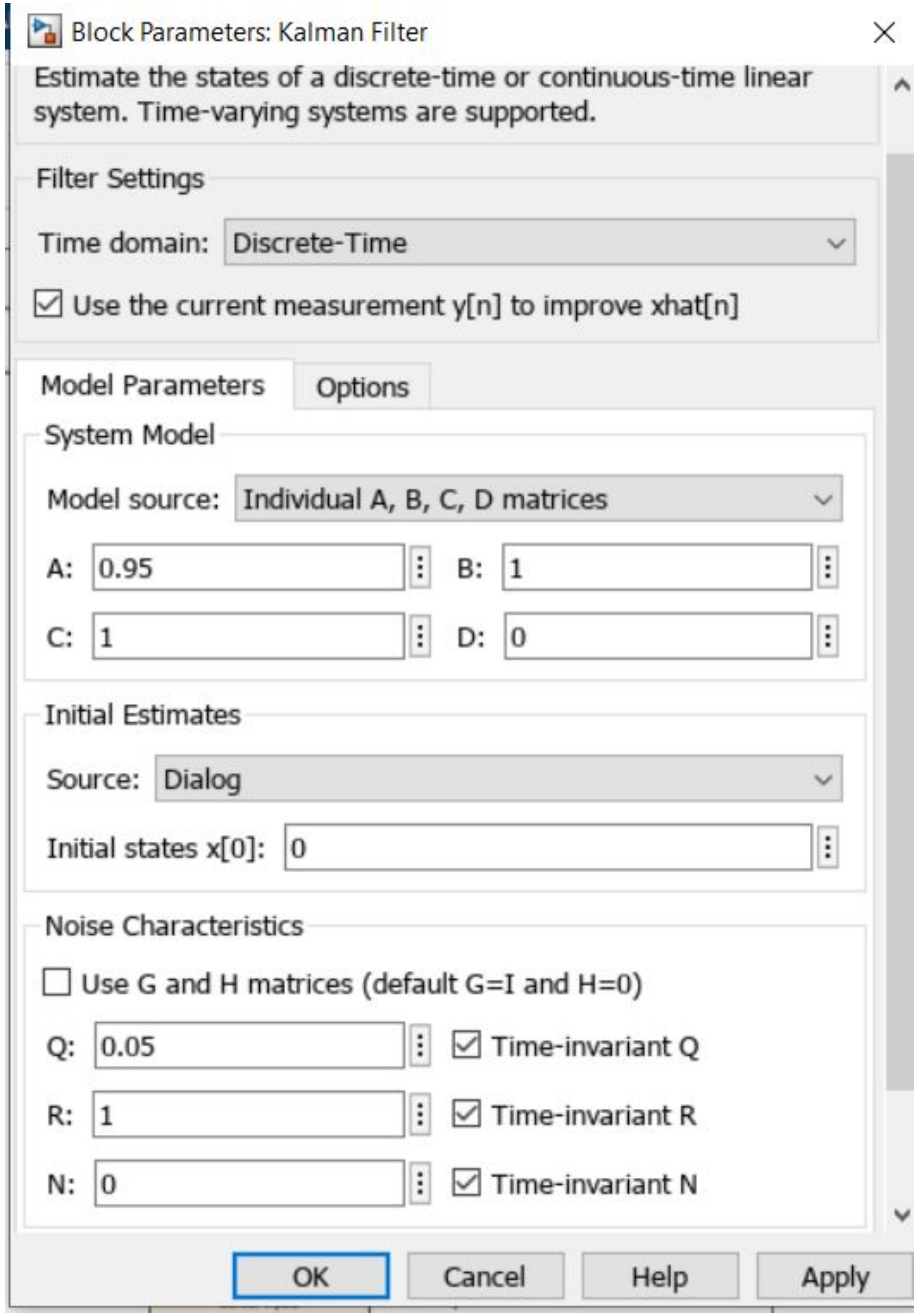
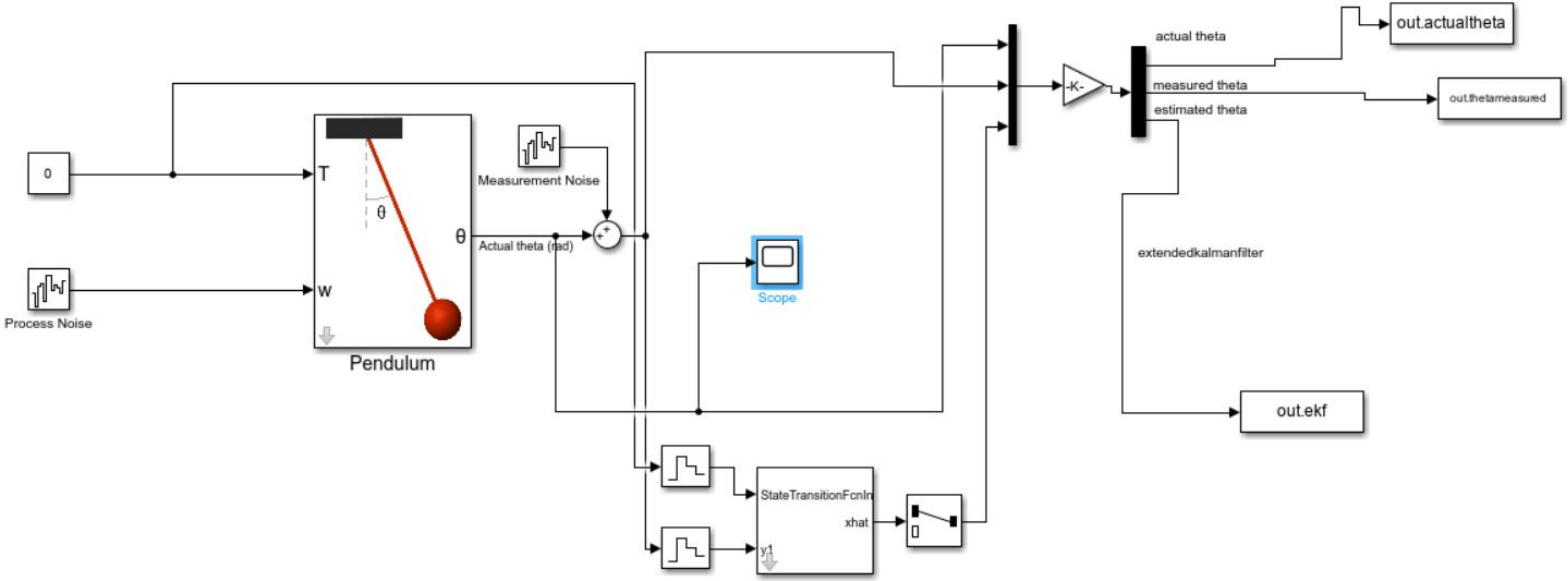
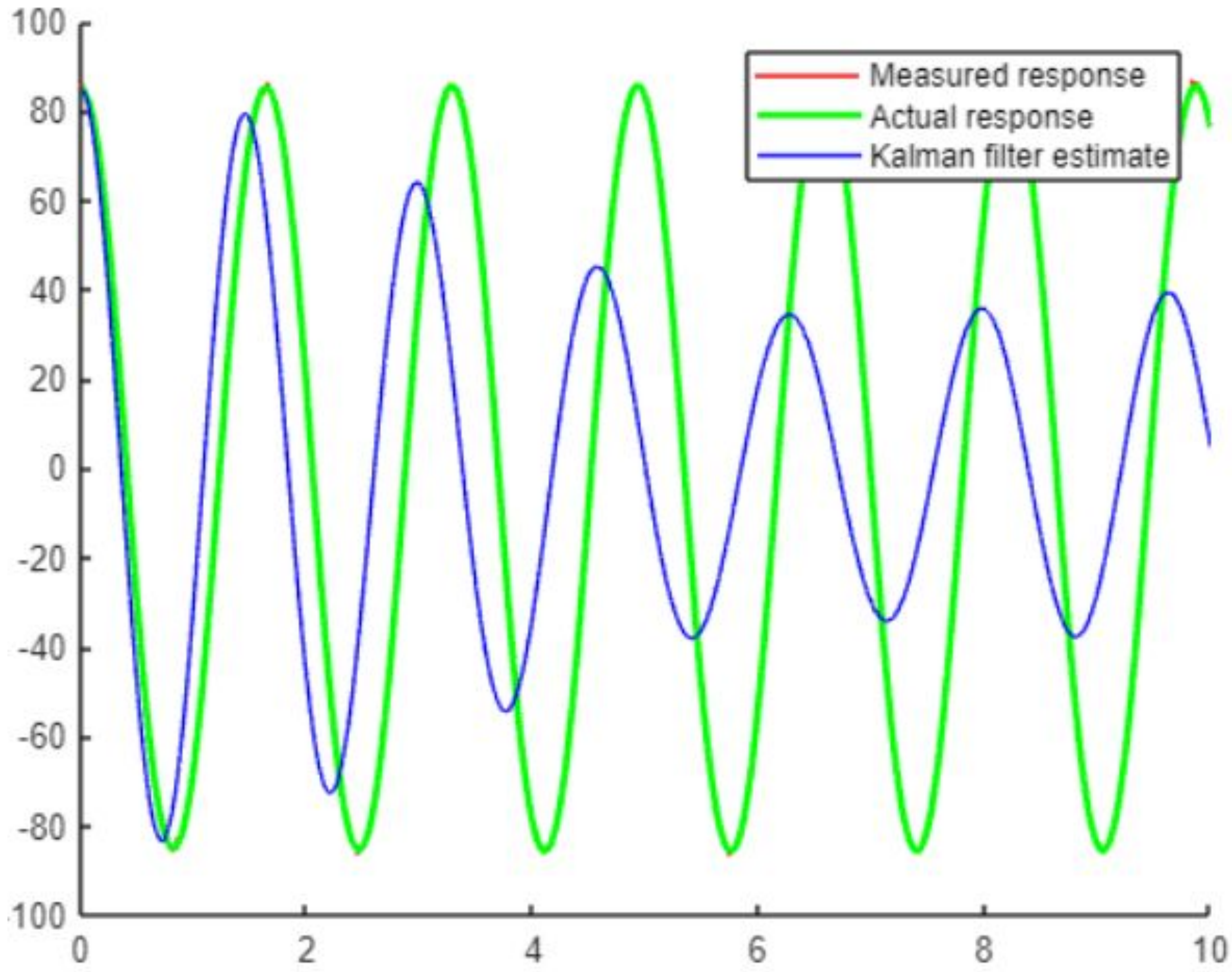
PENDULUM SIMULATION

Extended Kalman Filter (EKF)

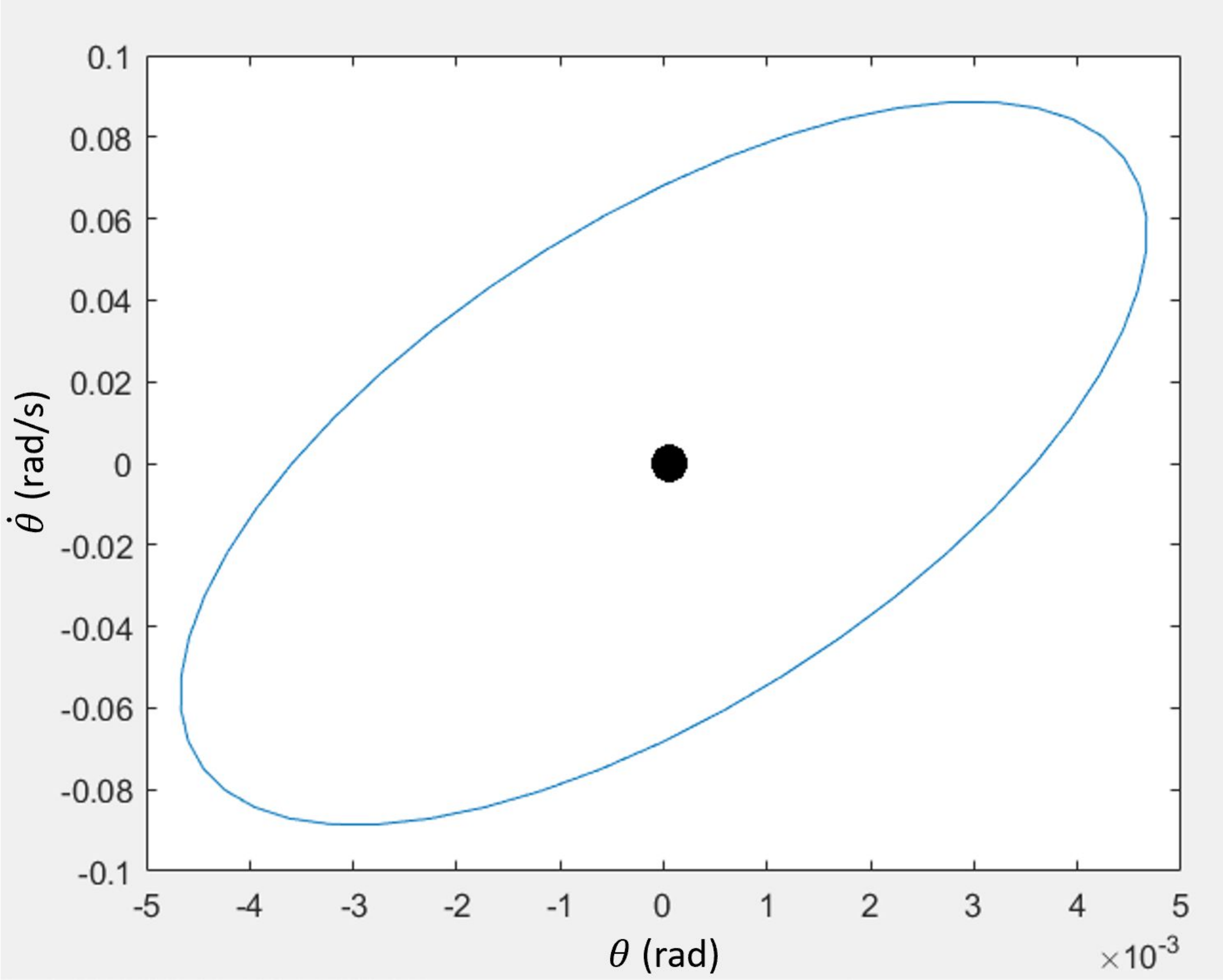
- A Kalman Filter is a filter that takes a less than perfect dynamic model and noisy measurements to provide very accurate state estimations for a system. This filter only works for linear systems.
- Two covariance matrices: Q and R (process and measurement noise respectively)
- An EKF can be used in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




0
Process Noise
T
w
θ
θ
Pendulum
Measurement Noise
Actual theta (rad)
Scope
StateTransitionFcnIn
xhat
y1
-K-
actual theta
measured theta
estimated theta
out.actualtheta
out.thetameasured
extendedkalmanfilter
out.ekf


Measured response
Actual response
Kalman filter estimate
100
80
60
40
20
0
-20
-40
-60
-80
-100
0
2
4
6
8
10

Error Ellipsoid Visualization



- Error ellipsoid constructed from the final 2 x 2 covariance matrix of angle and angular rate
- Covariance matrix remained constant after the initial change, meaning the error ellipsoid visualization was steady after a short period
- From ellipsoid, the difference between maximum and minimum possible angular position is 0.5°, meaning that predicted angular position had uncertainty of ± 0.25°.

POTENTIAL FIELD SIMULATION

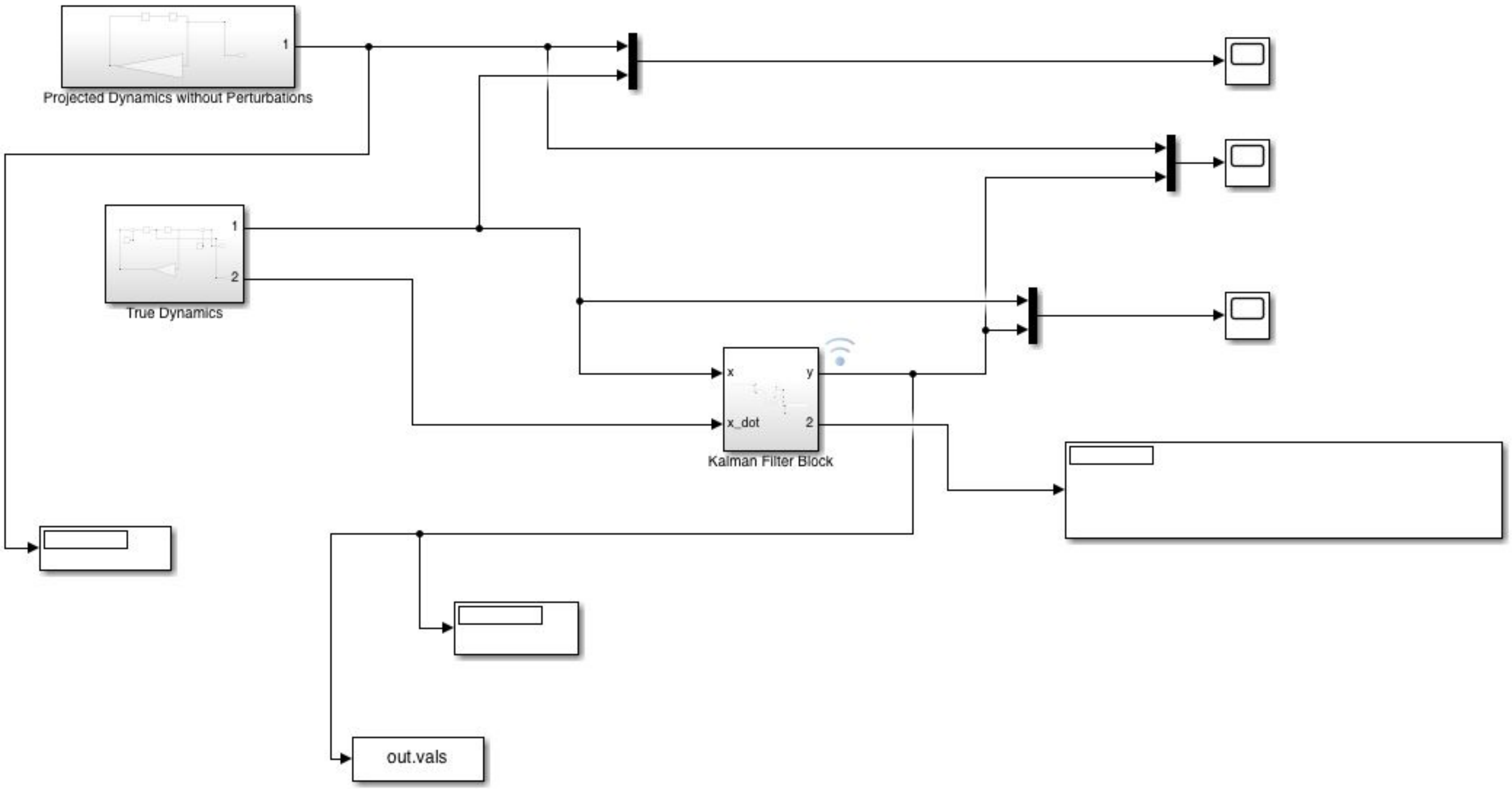
Potential Field Dynamics:

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

- The potential field was designed to impart an acceleration in the x direction and the y direction based on the location of the particle in the X-Y plane.

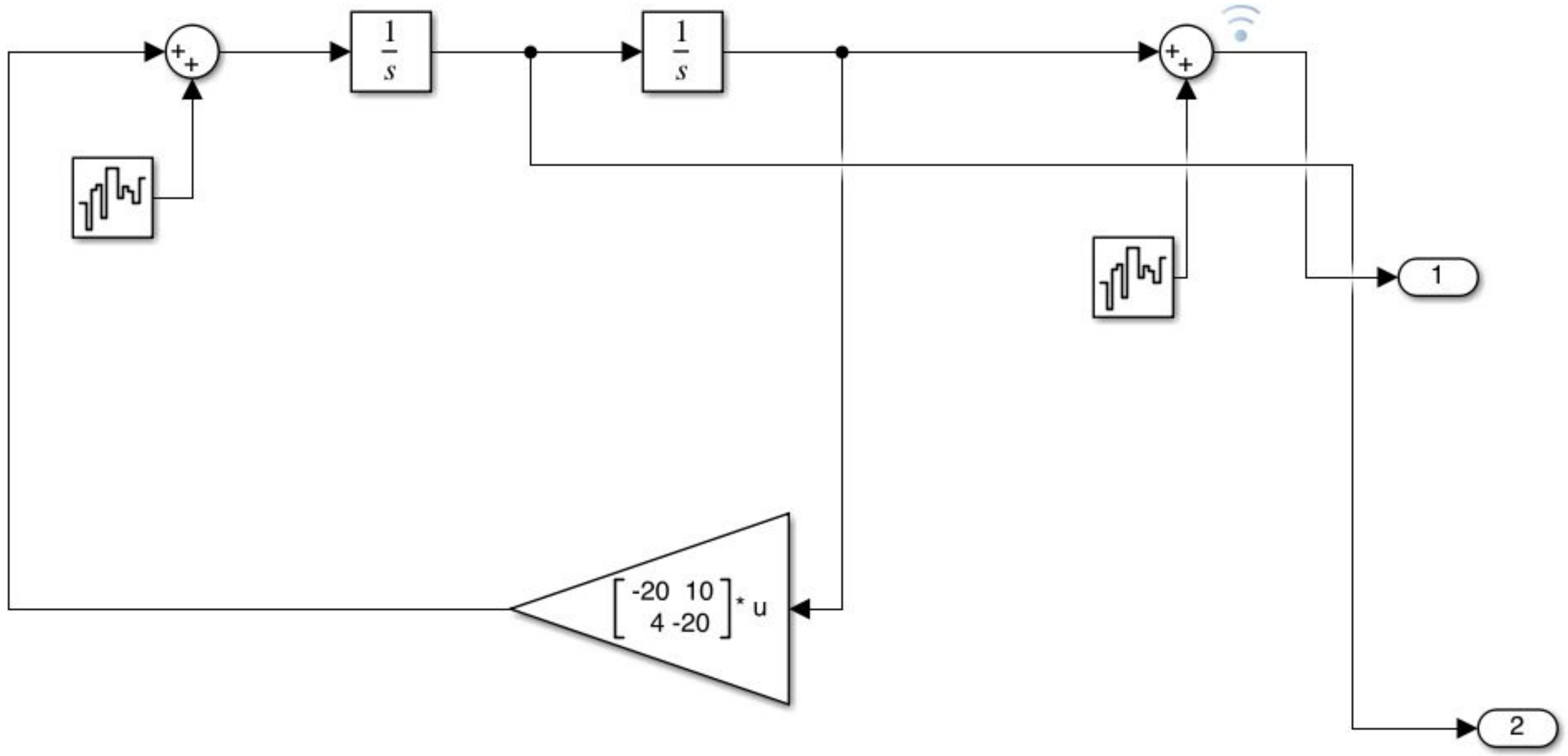
- The accelerations were chosen to be:
  X_Acceleration= -20x+10y
  Y_Acceleration= 4x+ -20y
  This created a coupled system.

Potential Field Block Diagram:



Potential Field Block Diagram:

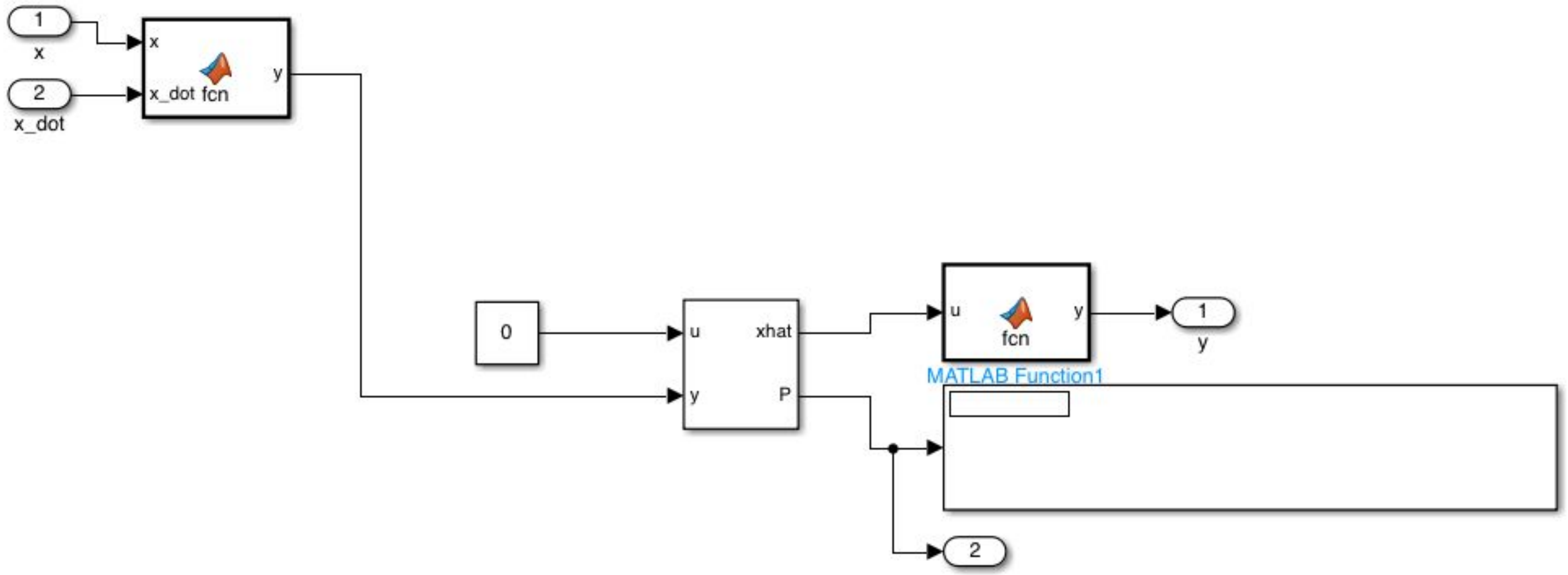
True Dynamics Block:



- 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 4 x 4 because there are 4 states: x, x_dot, y, y_dot

Potential Field Covariance and Error Ellipse:

- The noise is kept constant so the covariance matrix is constant as well
- The values for the covariance matrix that applied to the x and y error were isolated and extracted to create a 2 x 2 matrix. This matrix was then used in a MATLAB script to find the error ellipse.
- Using this 2 x 2 matrix, the error ellipse could be created by implementing an algorithm created for this purpose [1]. This is done by finding the eigenvalues of the matrix and square rooting them, then multiplying by a constant of proportionality to get the major and minor axes.
- Angle of the error ellipse is determined by finding the eigenvectors and taking a ratio and the inverse tangent
- The values of the state for x and y were also outputted to MATLAB for use in the script.
- The error ellipse 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 and the state was also plotted.

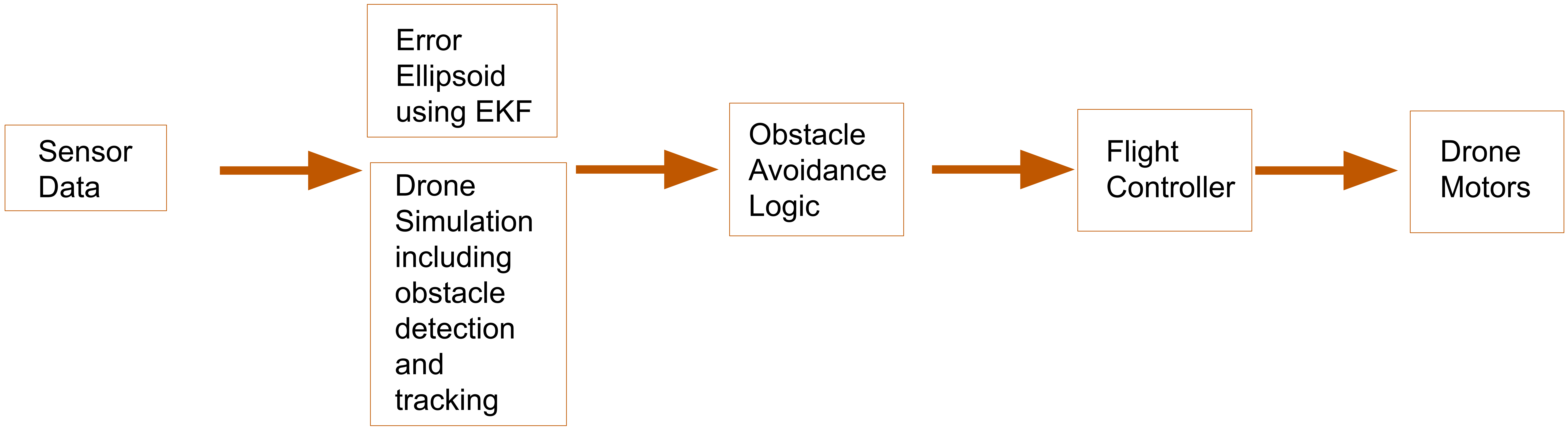
VISUALIZATION

NEXT STEPS

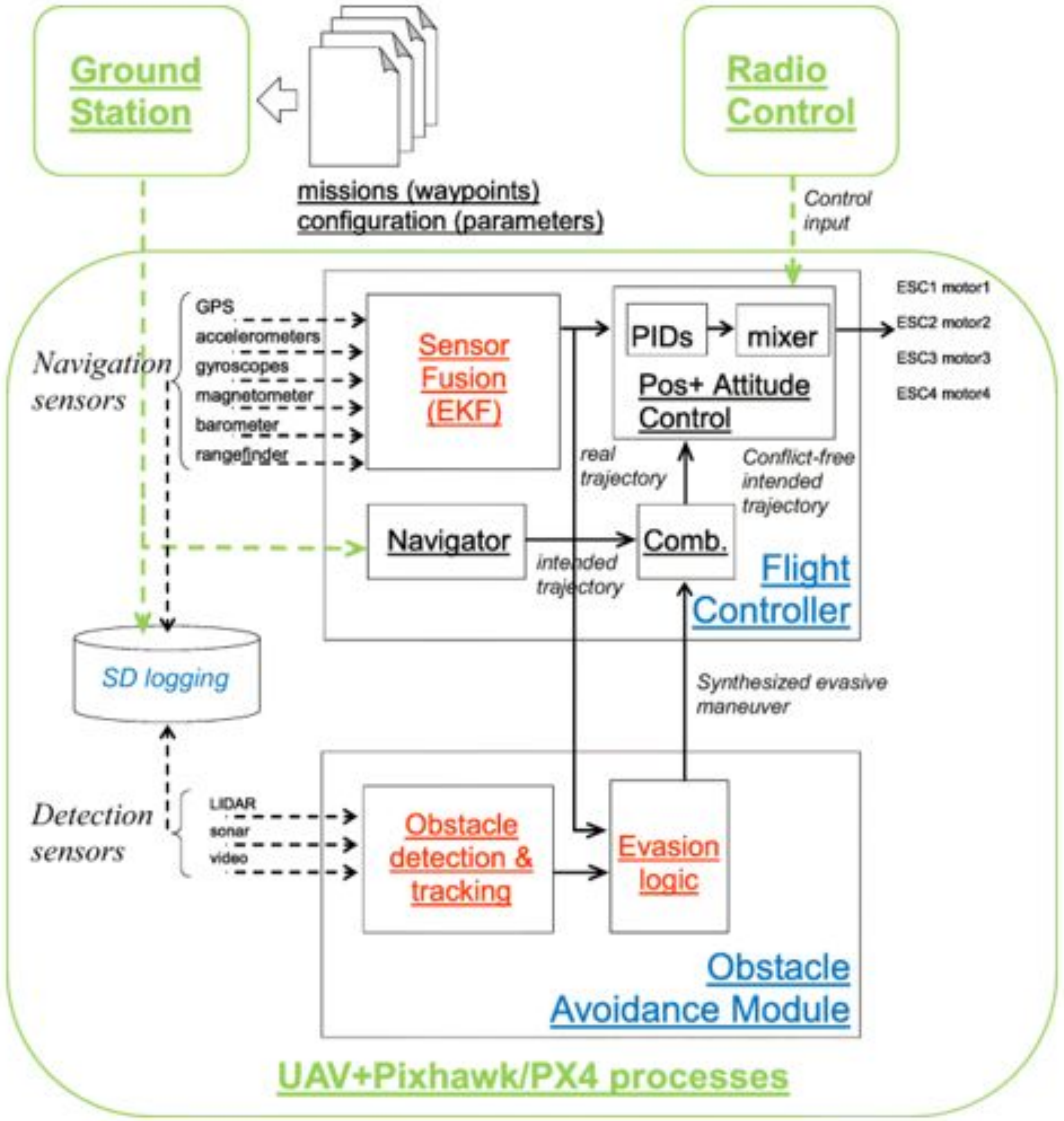
Future Work

- Finalize and polish the code for error ellipse creation in the 2D model
- Research how to apply the extended kalman filter to a three dimensional system
- Deciding how to further implement an EKF for our main purpose

Drone System Pipeline



Fully Integrated Solution



THANK YOU.

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