Full Autonomy of HAUV

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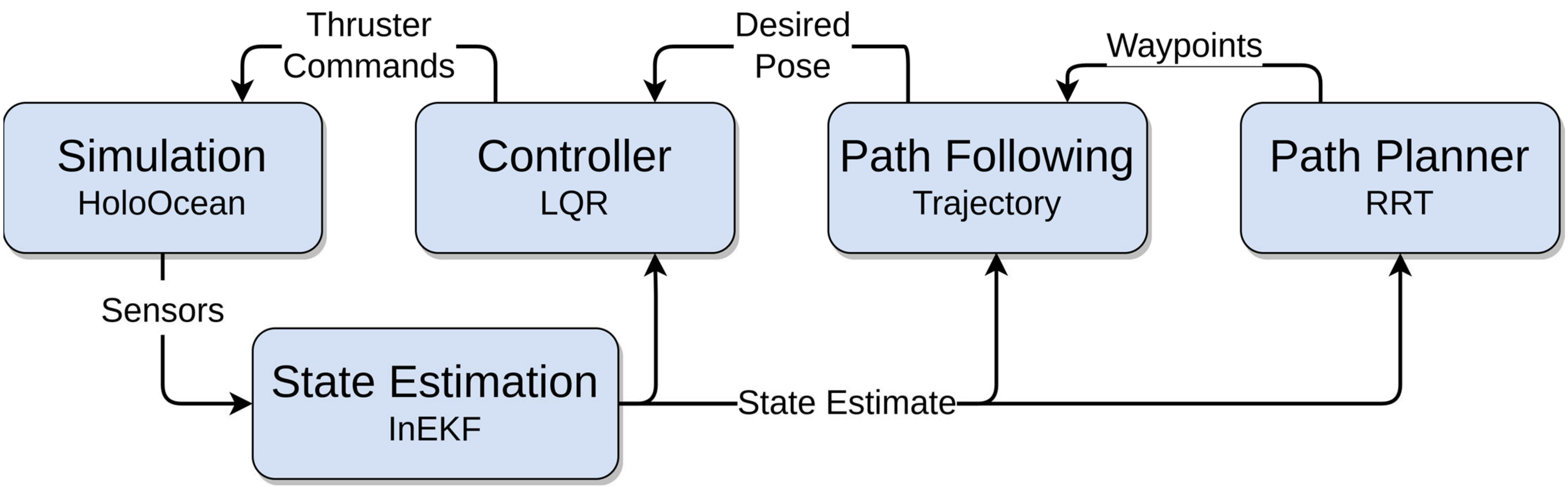
Thruster Commands
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Trajectory
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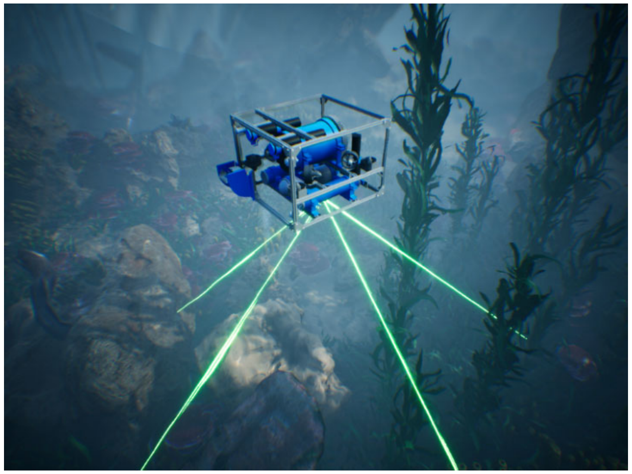
State Estimation
InEKF
State Estimate

Simulation - HoloOcean



State Estimation – Invariant Kalman Filter

- Represent state as a matrix

$$X = \begin{bmatrix} R & p \\ 0 & 1 \end{bmatrix}$$

- Using error $\hat{X}X^{-1}$, process model is log-linear with constant A.
- This means no Jacobians and no approximation error.
- Measurement models have also have constant H.

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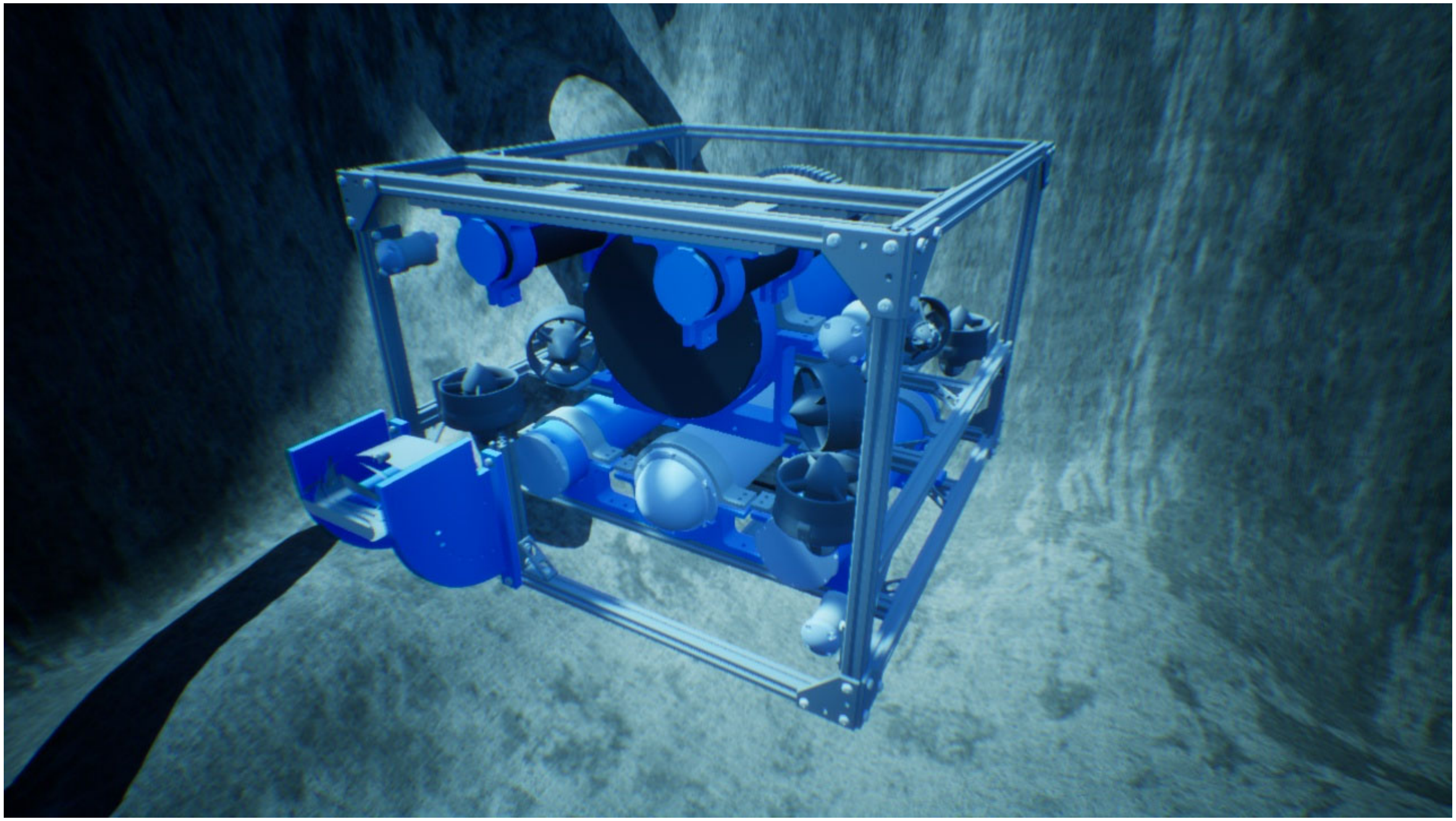
State Estimation – Invariant Kalman Filter

- Track R, v, p along with biases of IMU.
- Use IMU for prediction step
- Use the following for update step
  - Doppler Velocity Log
  - Magnetometer
  - Pressure Sensor
  - GPS (when close to surface)

Controller - Dynamics



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Controller - Dynamics

$$\dot{p} = v$$

$$\dot{v} = e_3 g - \frac{\rho g V}{m} e_3 + \frac{1}{m} R_b^g \sum d_i f_i - Dv$$

$$\dot{\Theta} = S(\Theta)\omega$$

$$\dot{\omega} = J^{-1}\left(-\omega \times (J\omega) + \tau_{COB}^b + \sum(p_i \times d_i f_i)\right) - E\omega$$

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Controller - Dynamics

$$W^b = \begin{bmatrix} F^b \\ \tau^b \end{bmatrix} = Mf = \begin{bmatrix} d_1 & \cdots & d_8 \\ p_1 \times d_1 & \cdots & p_8 \times d_8 \end{bmatrix} f$$

$$f = M^{\dagger} W^b = M^T \left(M M^T\right)^{-1} W^b$$

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Controller - Dynamics

- Assume gravity & buoyancy have same magnitude
- Assume pitch & roll are close to 0
- Feedback linearize

$$\tilde{F} = R^{g}{}_{b}\, F^{b}$$
$$\tilde{\tau} = \tau^{b} - \tau^{b}{}_{BY}$$

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Controller - Dynamics

- Results in a linear system!
- I implemented LQR to control it.

$$\begin{bmatrix} \dot{p} \\ \dot{v} \\ \dot{\Theta} \\ \dot{\omega} \end{bmatrix} = \begin{bmatrix} 0 & I & 0 & 0 \\ 0 & -D & 0 & 0 \\ 0 & 0 & 0 & I \\ 0 & 0 & 0 & -E \end{bmatrix} \begin{bmatrix} p \\ v \\ \Theta \\ \omega \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ \frac{1}{m} I & 0 \\ 0 & 0 \\ 0 & J^{-1} \end{bmatrix} \begin{bmatrix} \tilde{F} \\ \tilde{\tau} \end{bmatrix}$$

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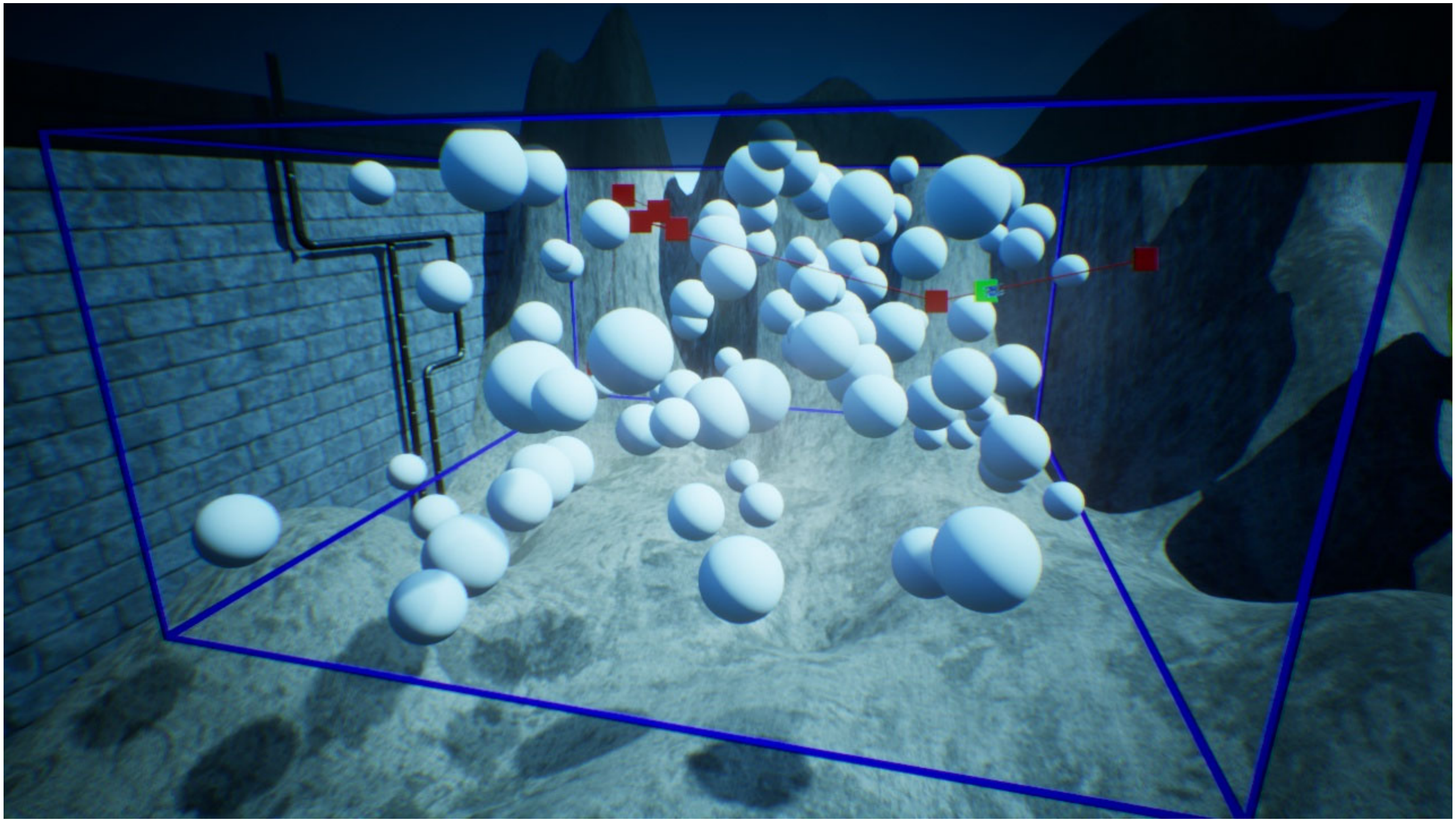
Path Planning – RRT



Path Following – Trajectory

- Since HAUV is fully controllable, we can send it a desired pose at every timestep
- Define functions for desired position and orientation
- Get desired linear and angular velocity using numerical derivatives