

Vehicle Dynamic Model Assisted Inertial Navigation: Zero Velocity and Zero Turning Update

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Outline and Motivation

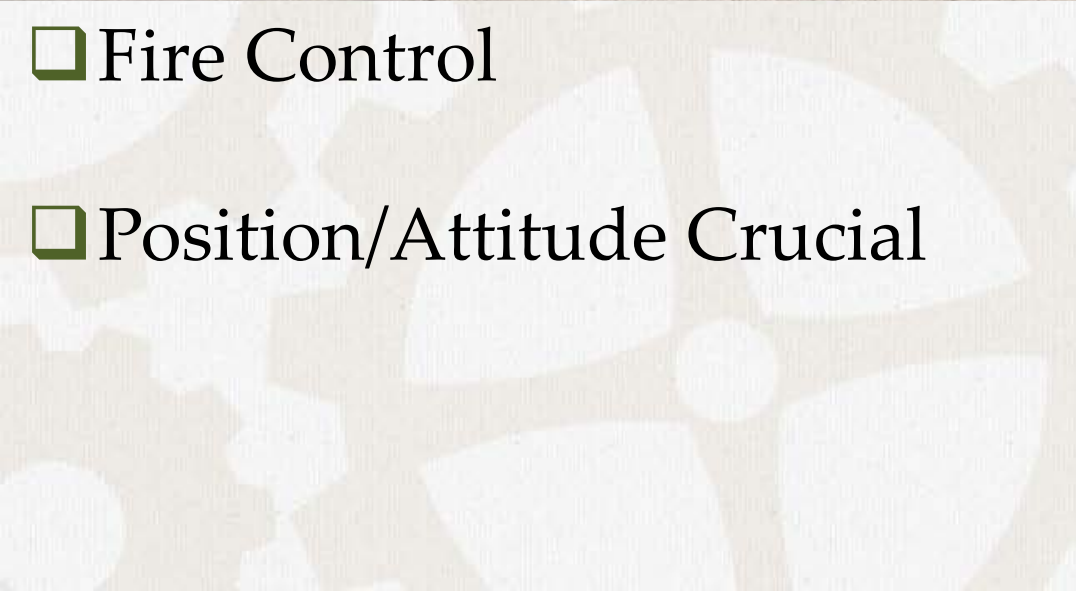
- ❑ Objective: Bound INS errors when GNSS not available
- ❑ Use vehicle model for auxiliary information
 - ❑ zero velocity
 - ❑ zero turn
 - ❑ only inertial sensors
- ❑ Problem Description
- ❑ Solution
- ❑ Preliminary Results

Outline and Motivation



Zero Velocity Update

Zero Turn Update



Fire Control

Position/Attitude Crucial



Navigation Equations

Sensors

$$\mathbf{f}^b = \begin{bmatrix} f_x \\ f_y \\ f_z \end{bmatrix} \quad \omega_{ib}^b = \begin{bmatrix} \omega_x \\ \omega_y \\ \omega_z \end{bmatrix}$$

Earth Rate

$$\omega_{ie}^n = \begin{bmatrix} \Omega \cos L \\ 0 \\ -\Omega \sin L \end{bmatrix}$$

Transport Rate

$$\omega_{en}^n = \begin{bmatrix} \frac{v_E}{R+h} \\ \frac{v_N}{R+h} \\ \frac{v_E \tan L}{R+h} \end{bmatrix}$$

Position

$$\begin{bmatrix} \dot{L} \\ \dot{\lambda} \\ \dot{h} \end{bmatrix} = \begin{bmatrix} \frac{1}{R+h} & 0 & 0 \\ 0 & \frac{\sec L}{R+h} & 0 \\ 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} v_N \\ v_E \\ v_D \end{bmatrix}$$

Velocity

$$\begin{bmatrix} \dot{v}_N \\ \dot{v}_E \\ \dot{v}_D \end{bmatrix} = \mathbf{C}_b^n \mathbf{f}^b - (2\omega_{ie}^n + \omega_{en}^n) \times \begin{bmatrix} v_N \\ v_E \\ v_D \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ g(h) \end{bmatrix}$$

Attitude

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} 1 & \sin \phi \tan \theta & \cos \phi \tan \theta \\ 0 & \cos \phi & -\sin \phi \\ 0 & \sin \phi / \cos \theta & \cos \phi / \cos \theta \end{bmatrix} \omega_{nb}^b$$

$$\omega_{nb}^b = \omega_{ib}^b - \mathbf{C}_n^b (\omega_{ie}^n + \omega_{en}^n)$$

Discretize & Linearize

$$x_{k+1} = f(x_k, u_k), \quad x(0) = x_o$$

States and Inputs

$$x_k = \begin{bmatrix} L & \lambda & h & v_N & v_E & v_D & \phi & \theta & \psi \end{bmatrix}_k^T$$

$$u_k = \begin{bmatrix} f_x & f_y & f_z & \omega_x & \omega_y & \omega_z \end{bmatrix}_k^T$$

Linear System

$$x_{k+1} = \mathbf{A}_k x_k + \mathbf{B}_k u_k$$

$$y_k = \mathbf{C}_k x_k + \mathbf{D}_k u_k$$

Augment with Bias States

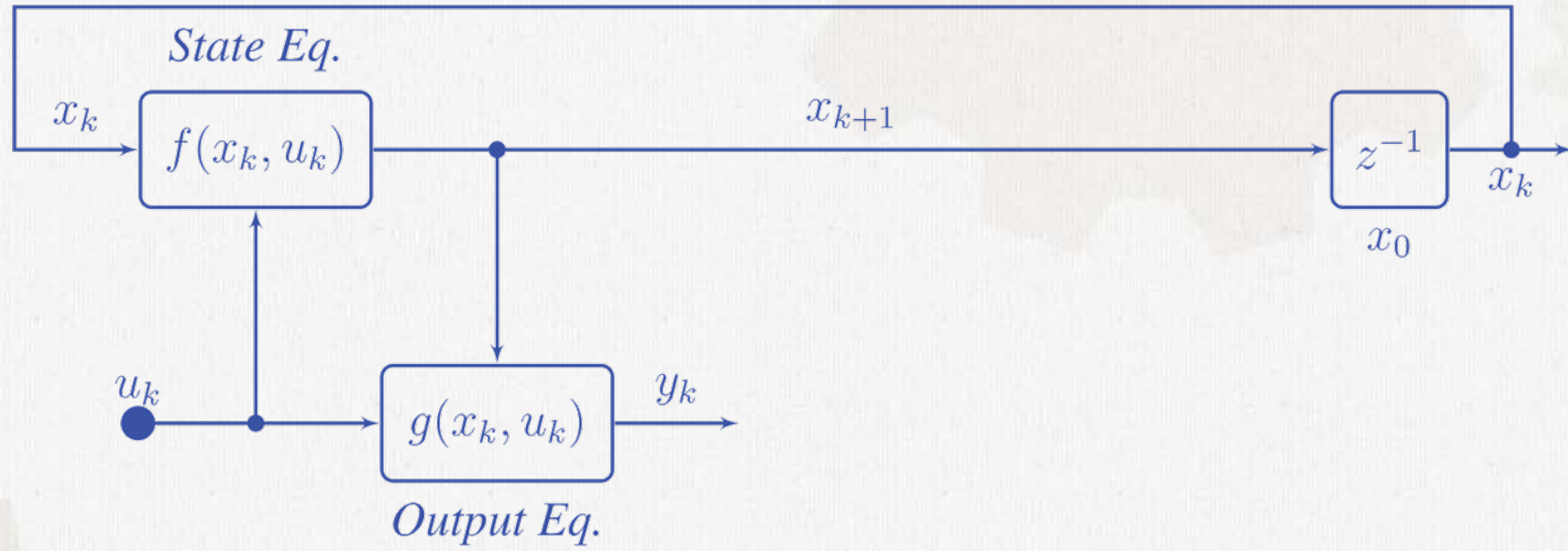
$$b_k = \begin{bmatrix} d_x & d_y & d_z & b_x & b_y & b_z \end{bmatrix}_k^T$$

Linear Augmented System

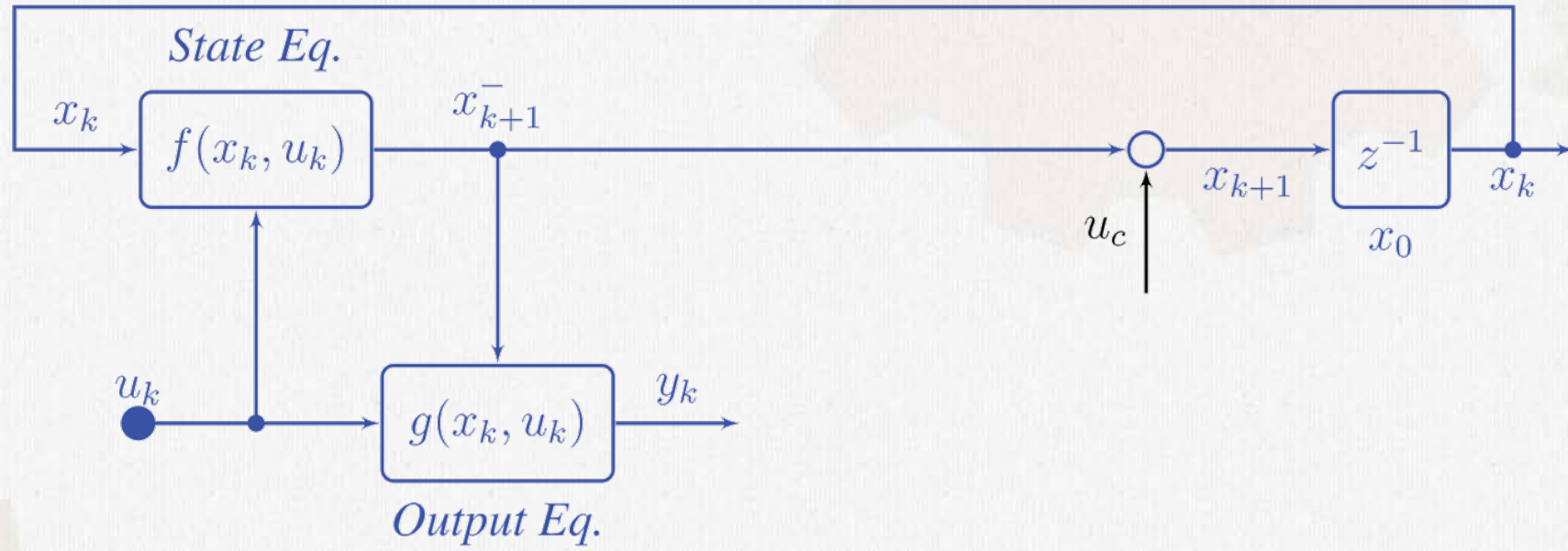
$$\begin{bmatrix} x_{k+1} \\ b_{k+1} \end{bmatrix} = \begin{bmatrix} \mathbf{A}_k & \mathbf{B}_k \\ \mathbf{0} & \mathbf{I} \end{bmatrix} \begin{bmatrix} x_k \\ b_k \end{bmatrix} + \begin{bmatrix} \mathbf{B}_k \\ \mathbf{0} \end{bmatrix} u_k$$

$$y_k = \begin{bmatrix} \mathbf{C}_k & \mathbf{0} \end{bmatrix} \begin{bmatrix} x_k \\ b_k \end{bmatrix} + \mathbf{D}_k u_k$$

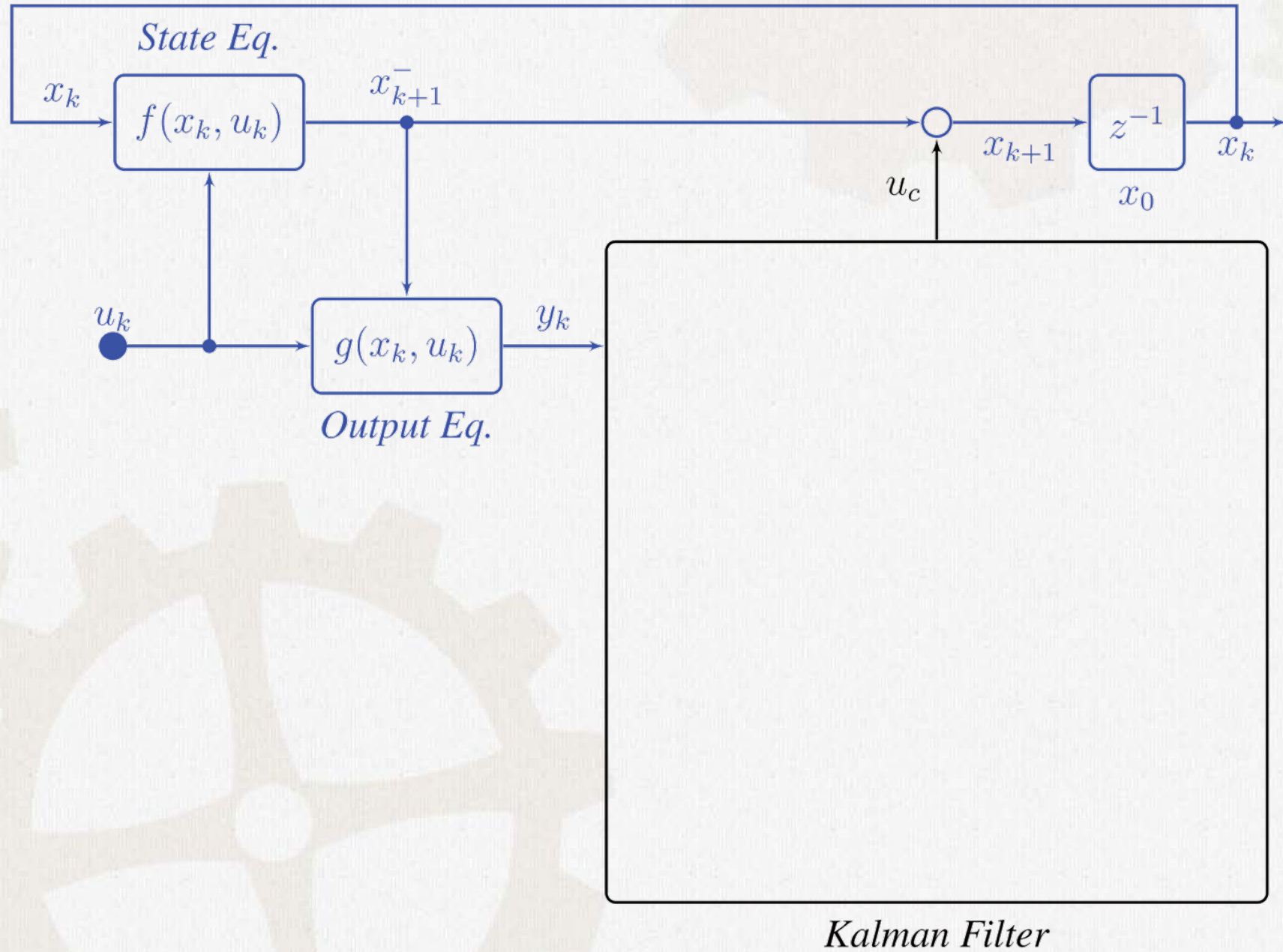
Method



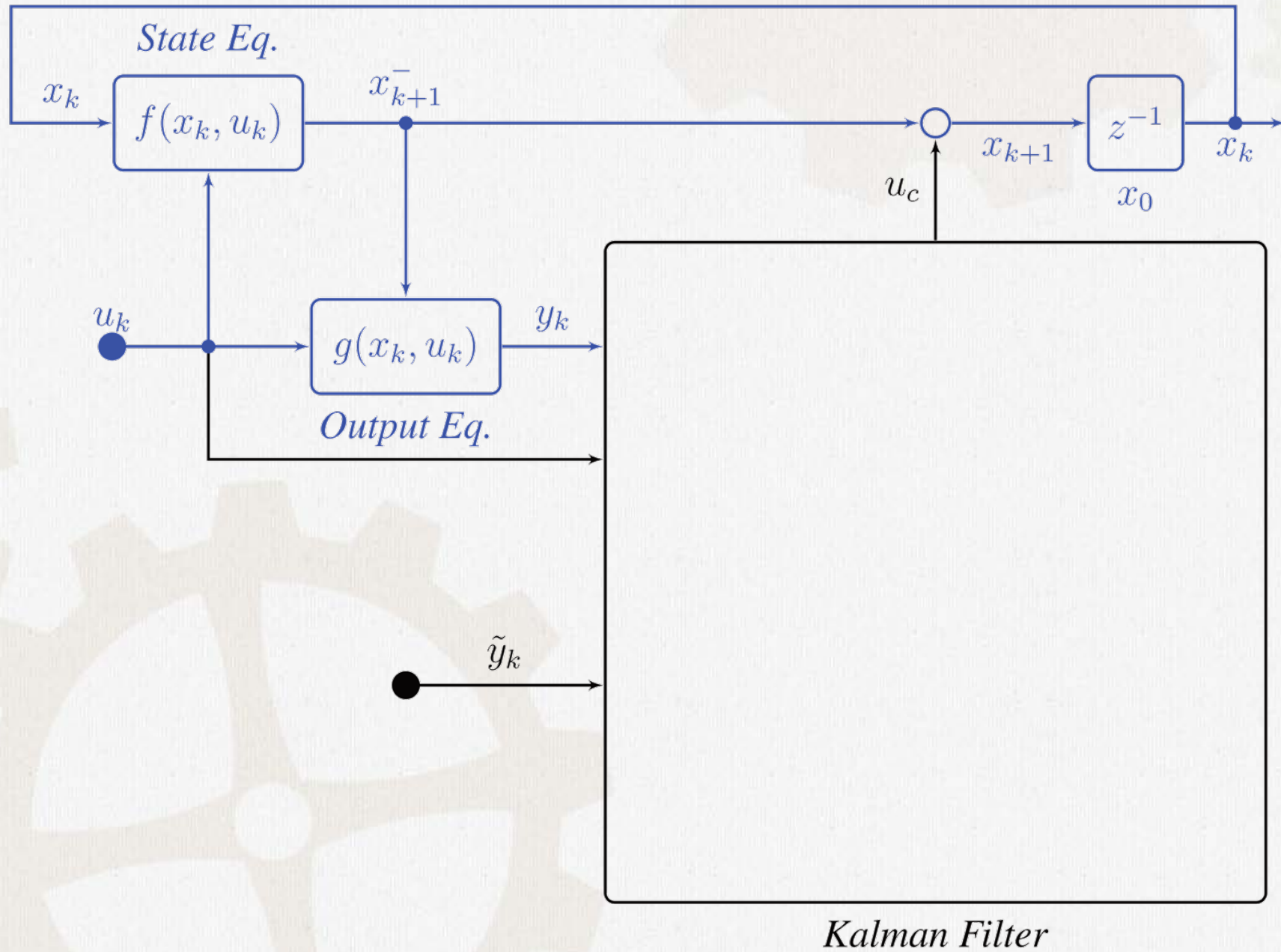
Method



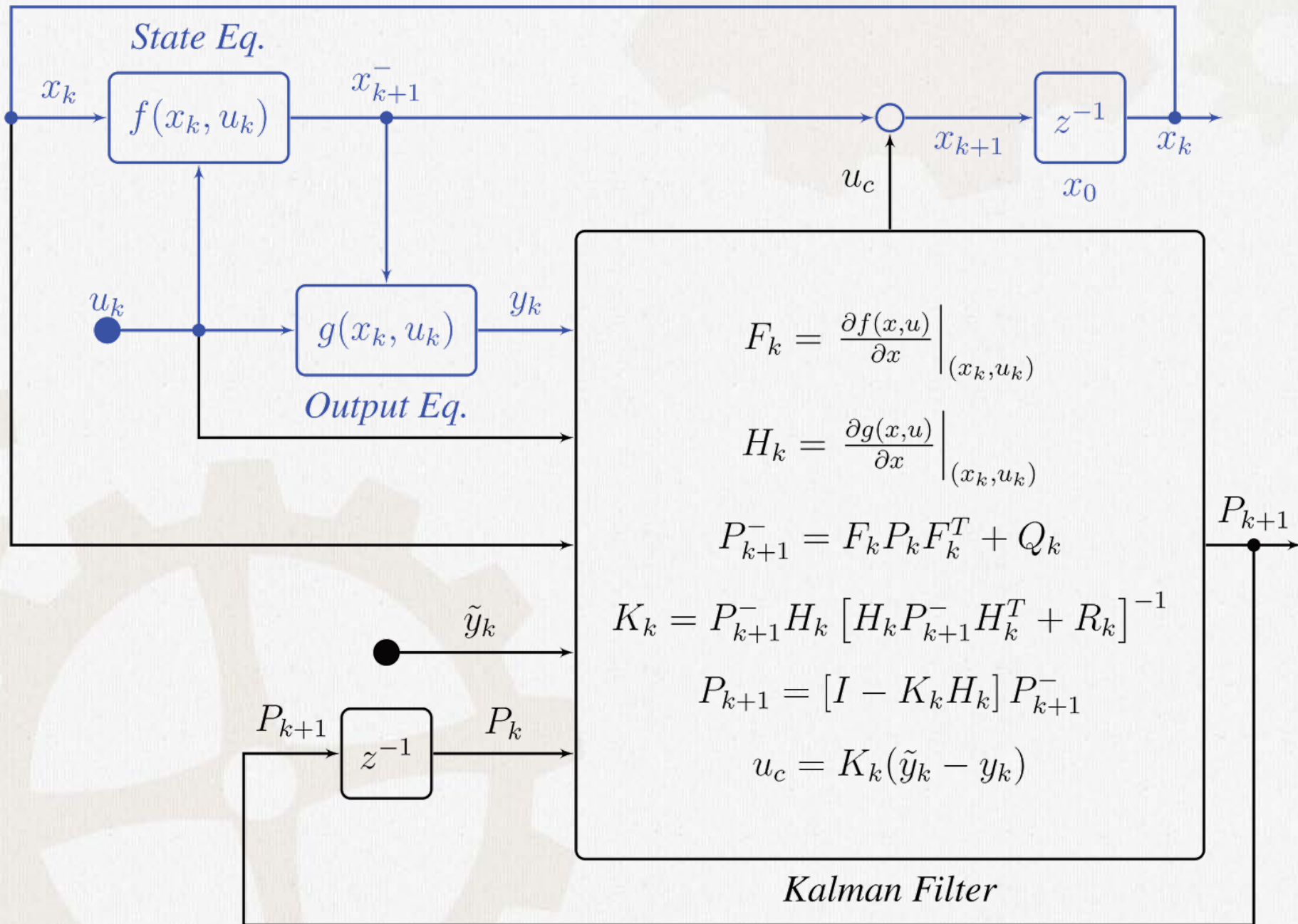
Method



Method



Method



Zero Velocity Update

External Outputs

$$\tilde{y} = [L \ \lambda \ h \ v_N \ v_E \ v_D]^T$$

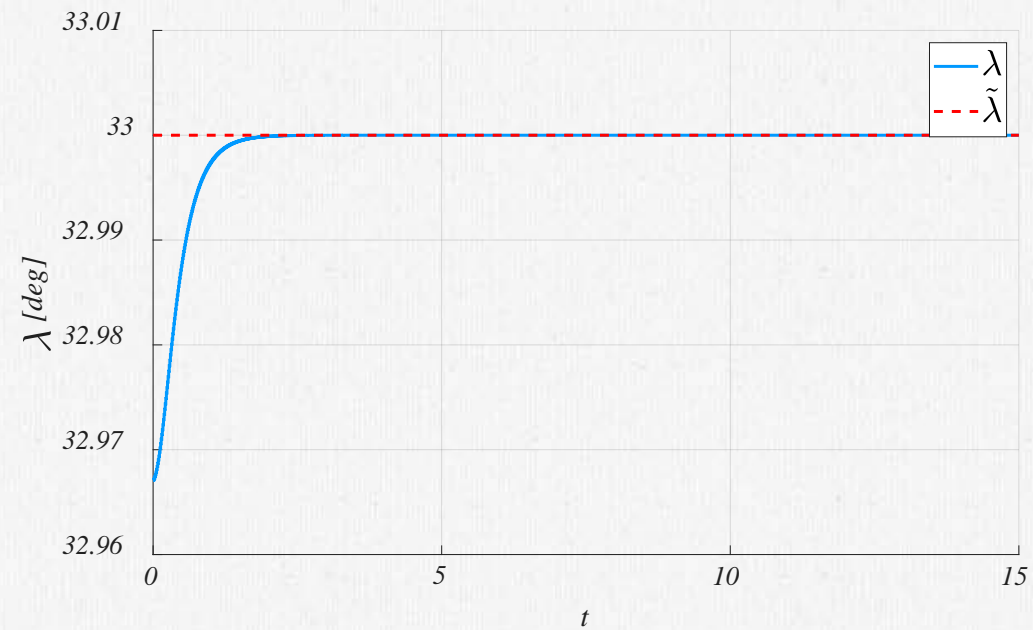
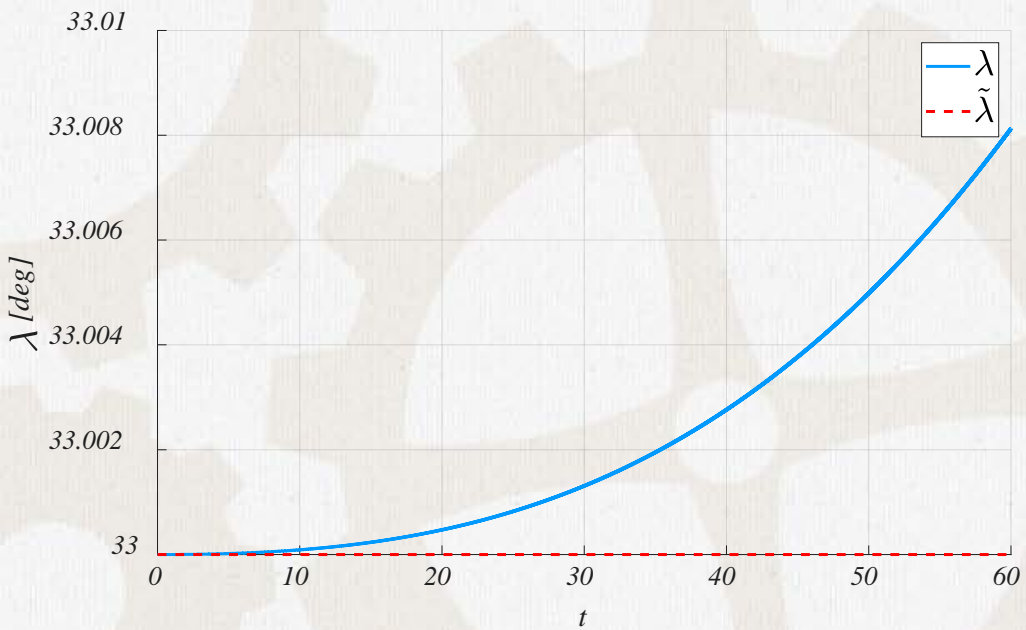
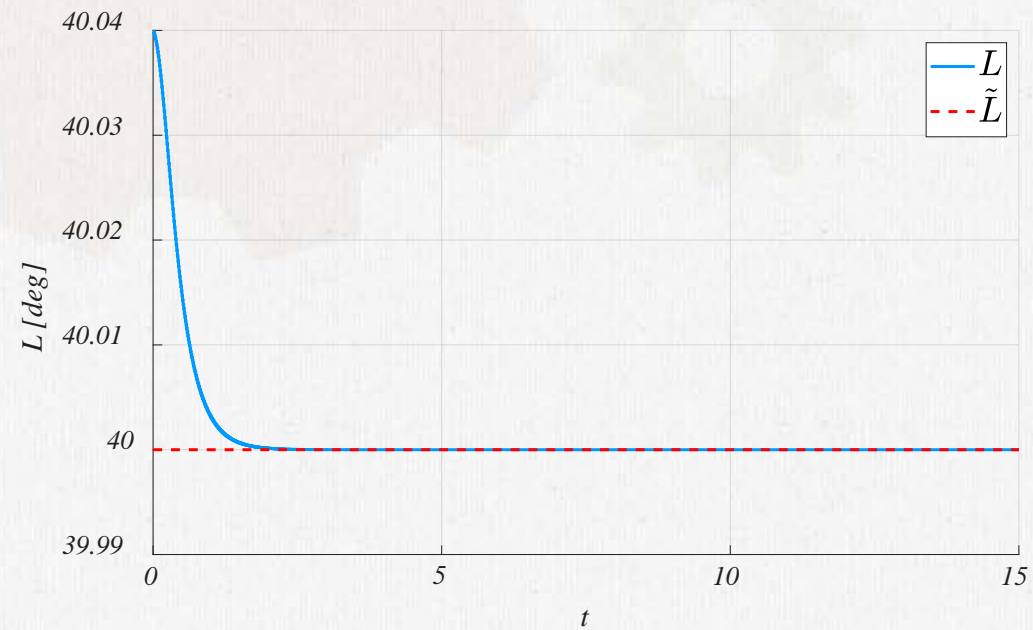
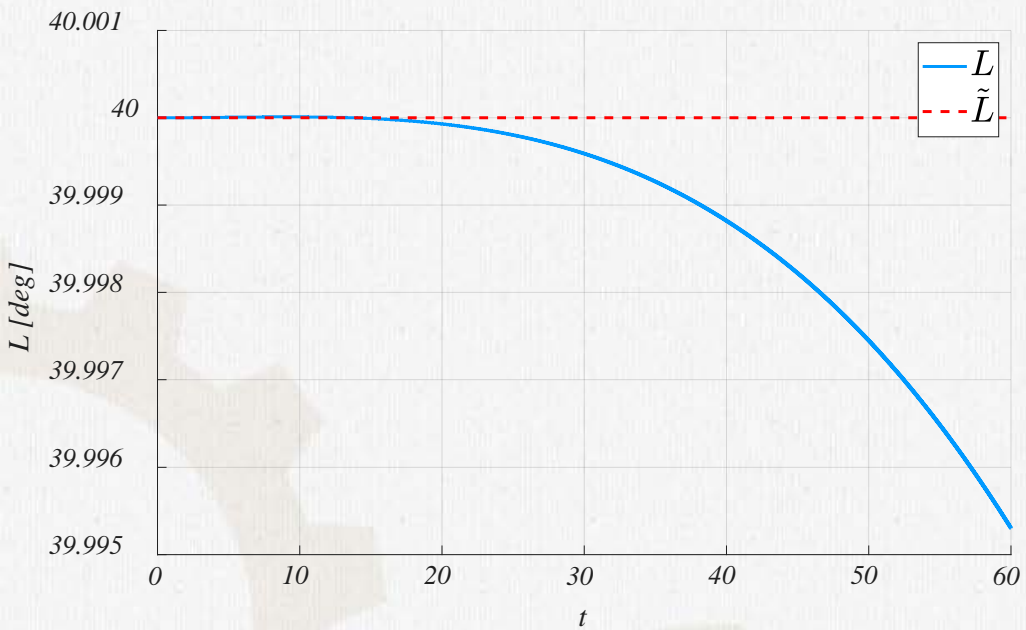
States

$$\begin{bmatrix} L \\ \lambda \\ h \end{bmatrix} = \begin{bmatrix} L_o \\ \lambda_o \\ h_o \end{bmatrix}, \quad \begin{bmatrix} v_N \\ v_E \\ v_D \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} \phi \\ \theta \\ \psi \end{bmatrix} = \begin{bmatrix} \phi_o \\ \theta_o \\ \psi_o \end{bmatrix}$$

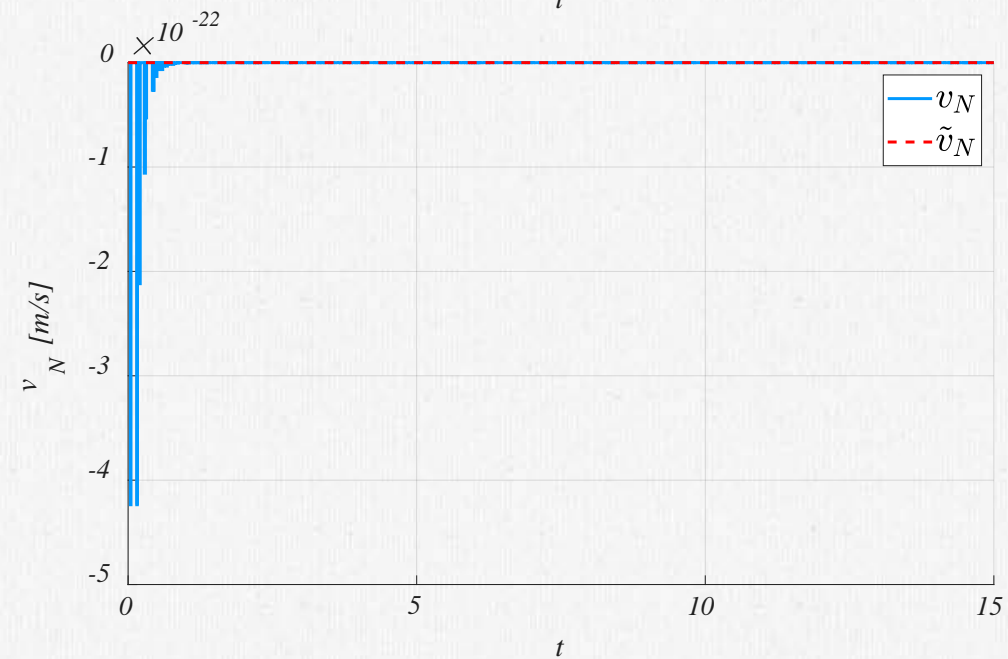
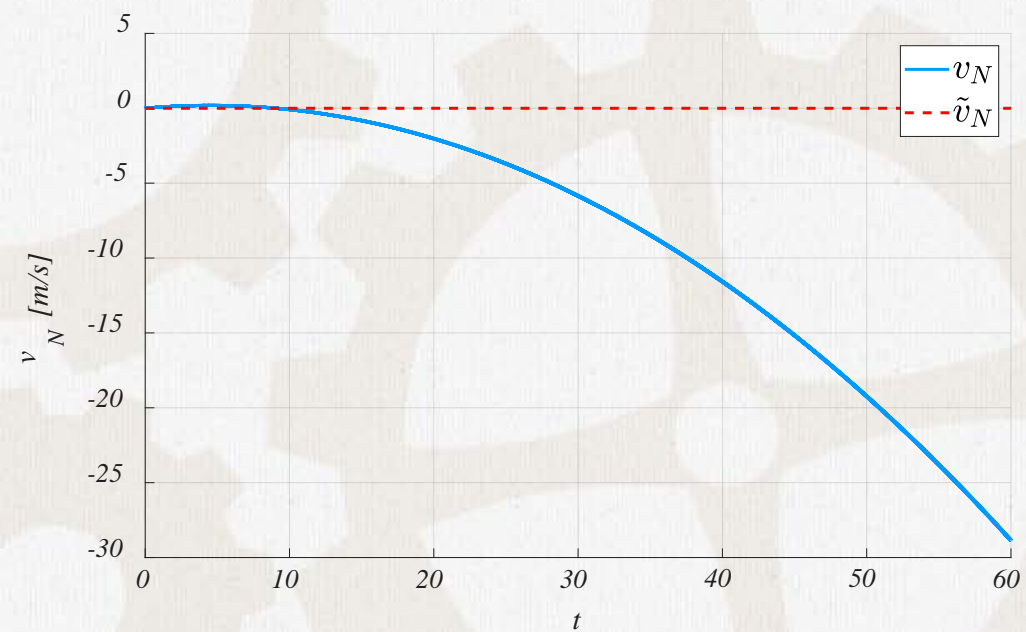
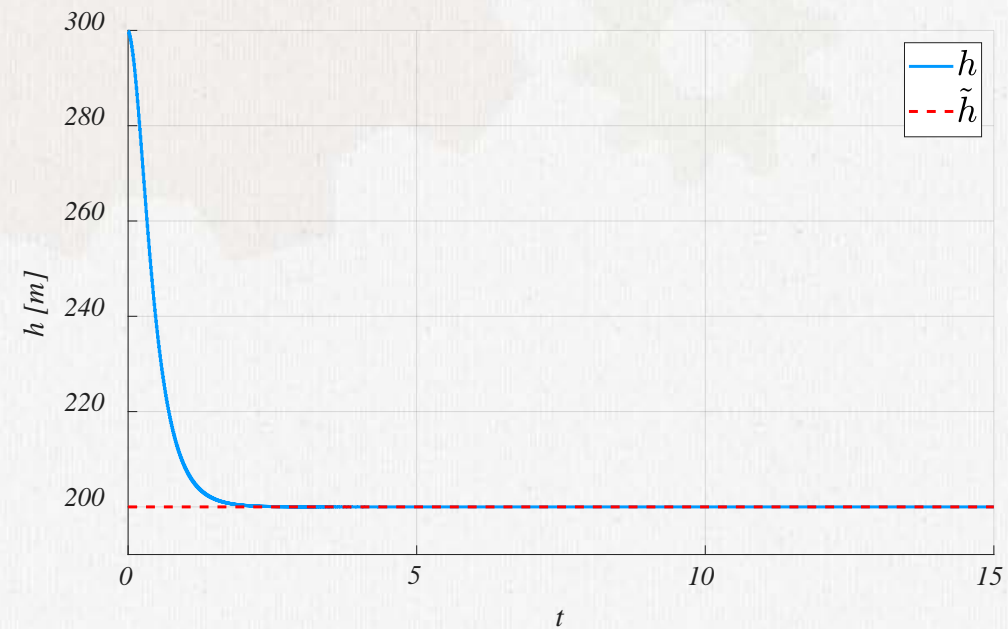
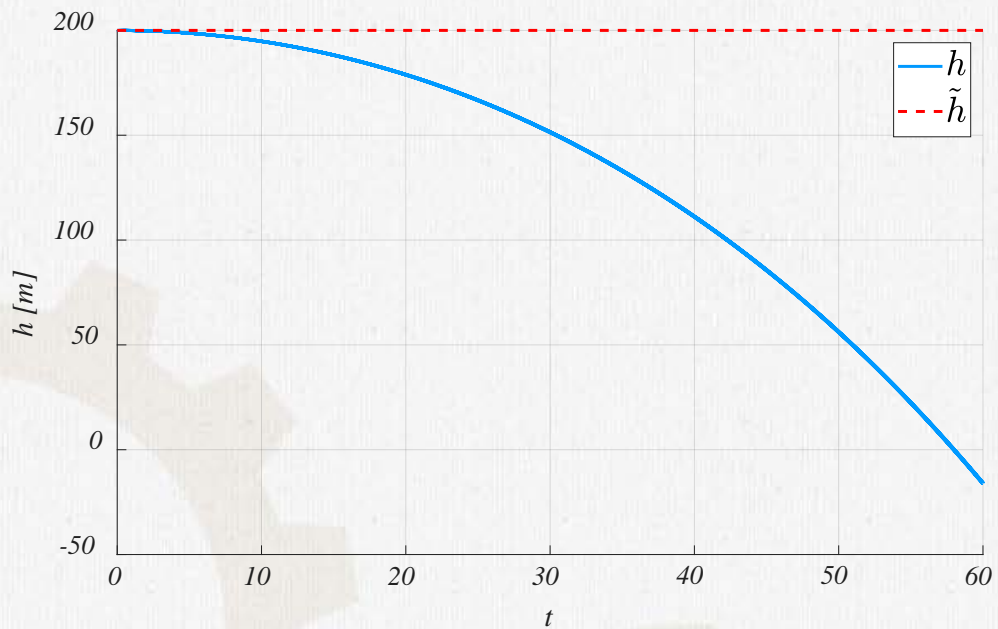
Ideal Sensor Measurements

$$\begin{bmatrix} f_x \\ f_y \\ f_z \end{bmatrix} = \begin{bmatrix} -g \sin \theta \\ g \cos \theta \sin \phi \\ g \cos \theta \cos \phi \end{bmatrix} \quad \begin{bmatrix} \omega_x \\ \omega_y \\ \omega_z \end{bmatrix} = C_n^b \begin{bmatrix} \Omega \cos L \\ 0 \\ -\Omega \sin L \end{bmatrix}$$

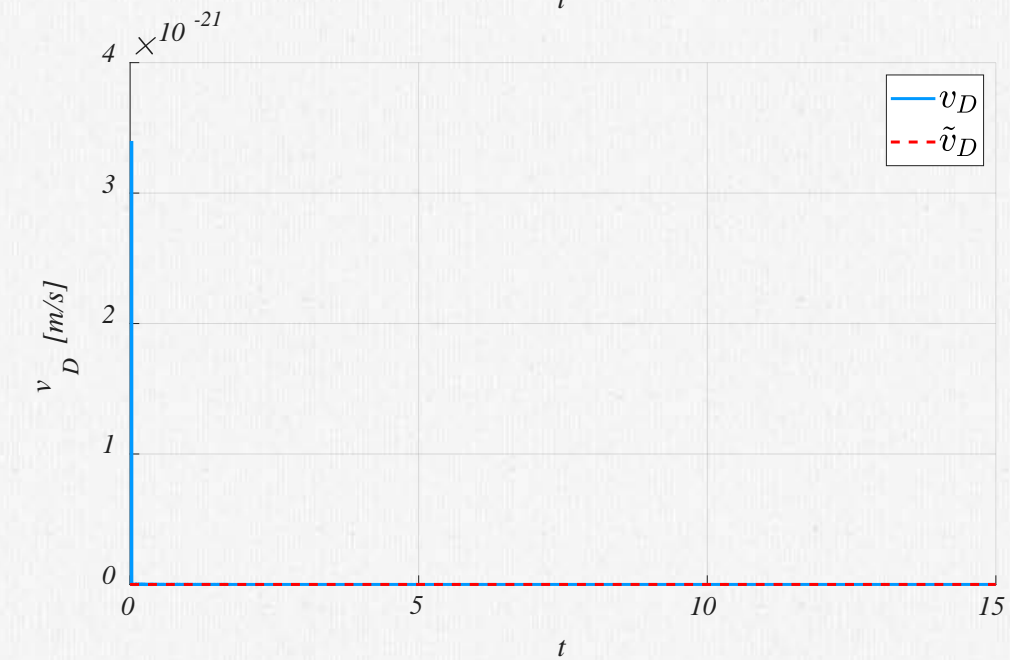
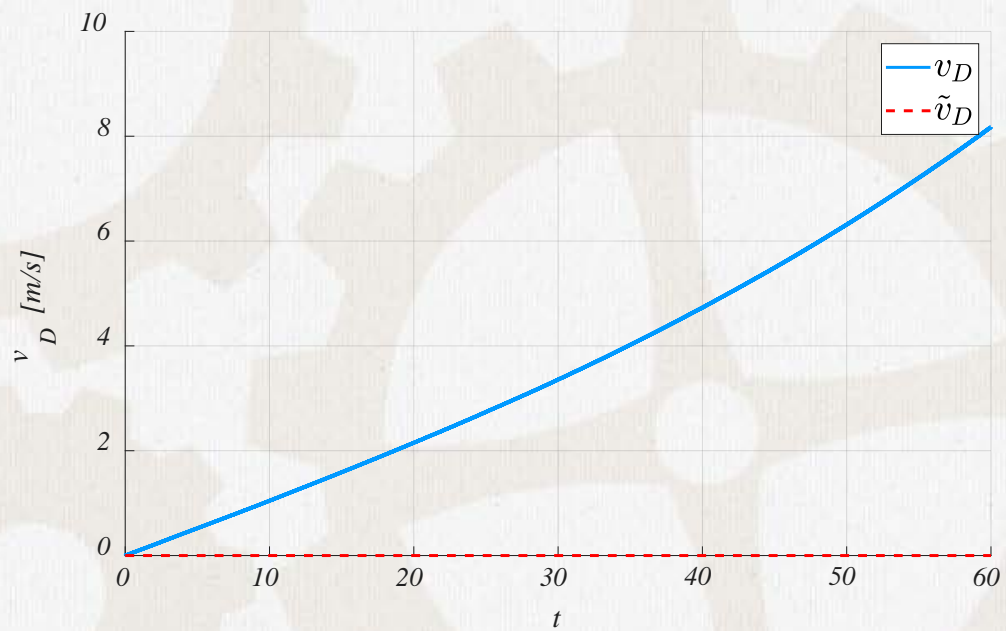
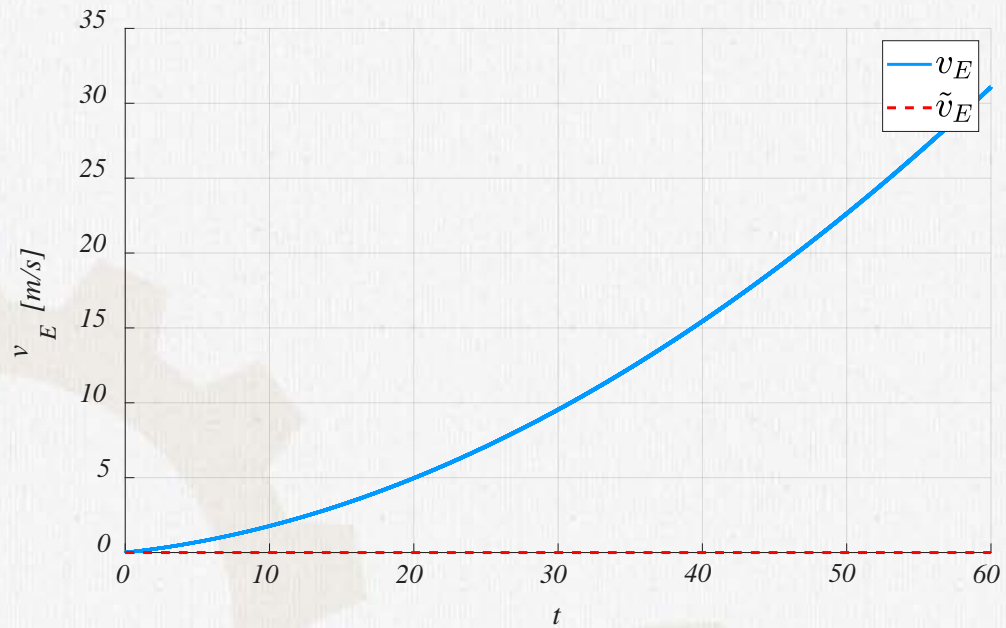
Zero Velocity Update



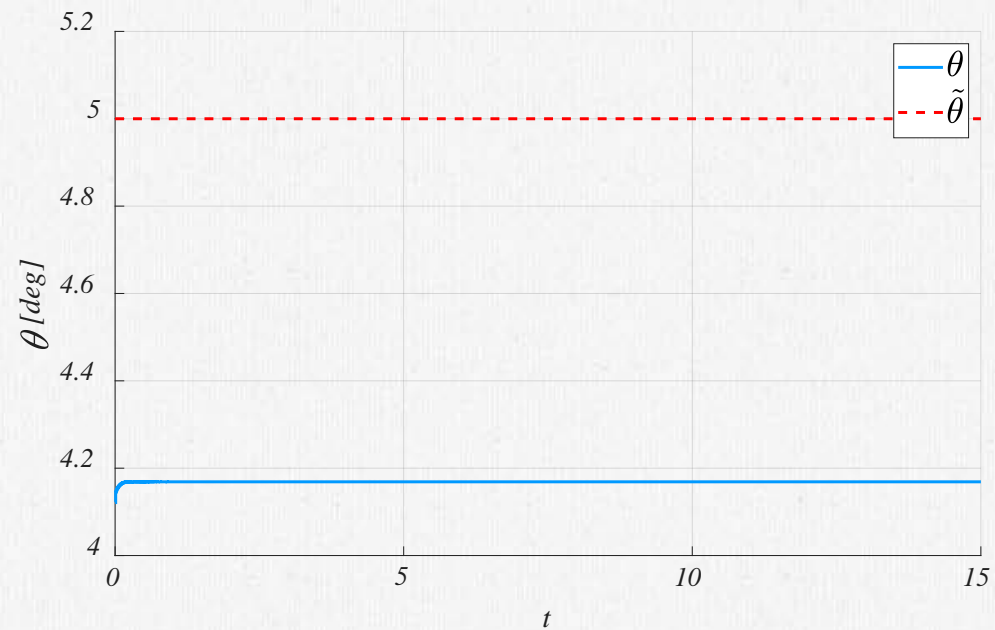
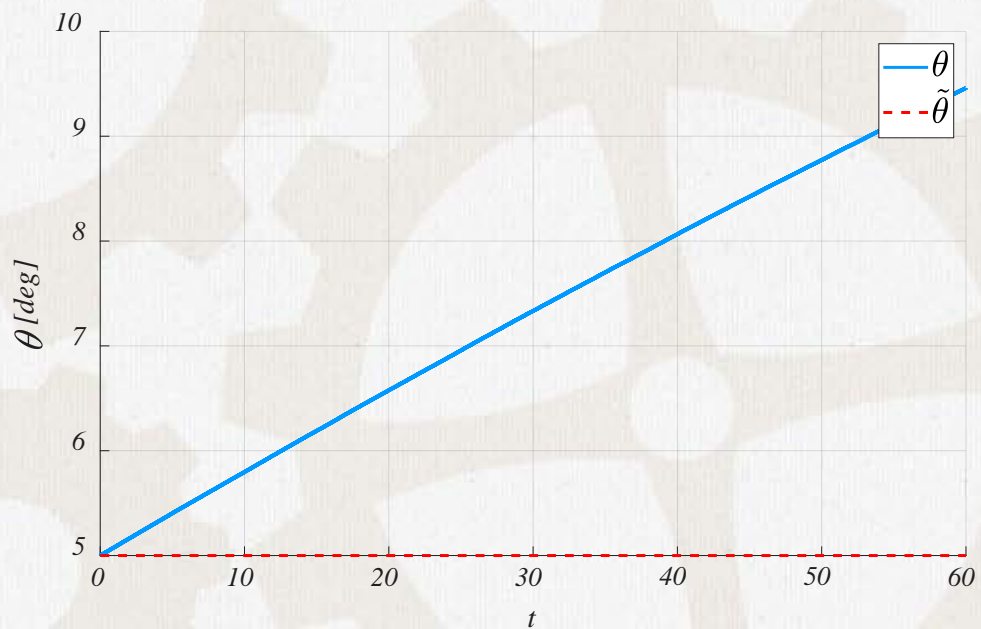
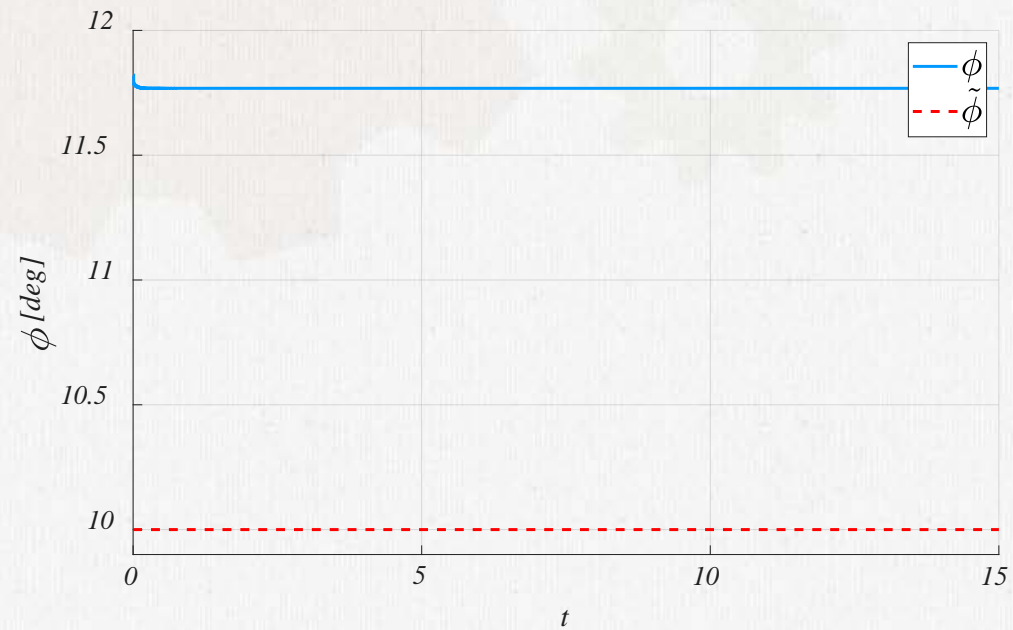
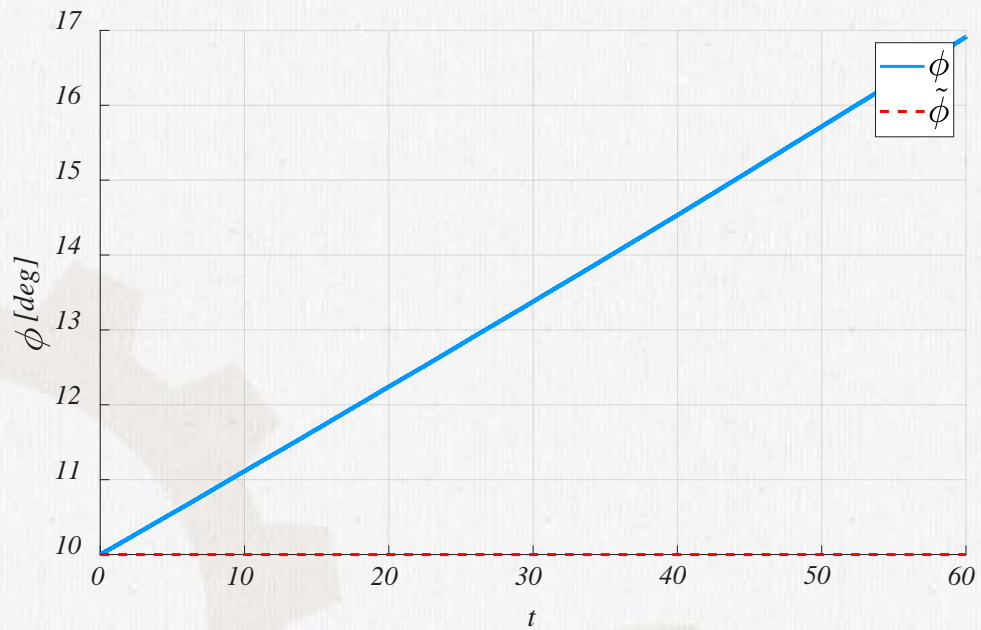
Zero Velocity Update



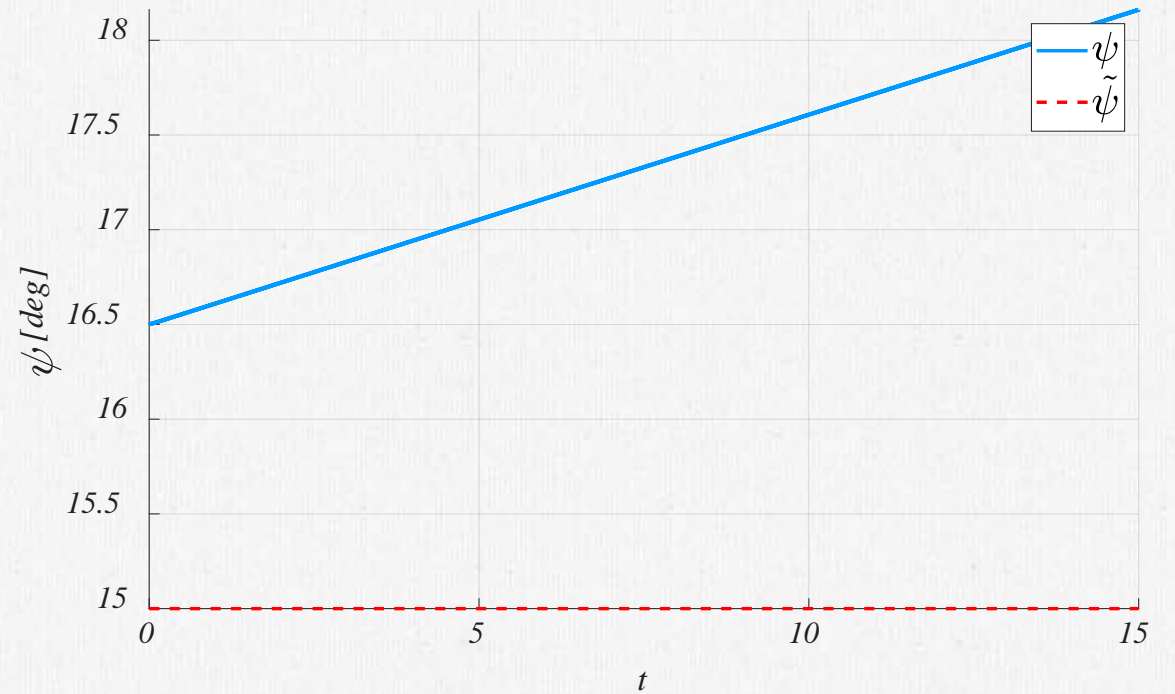
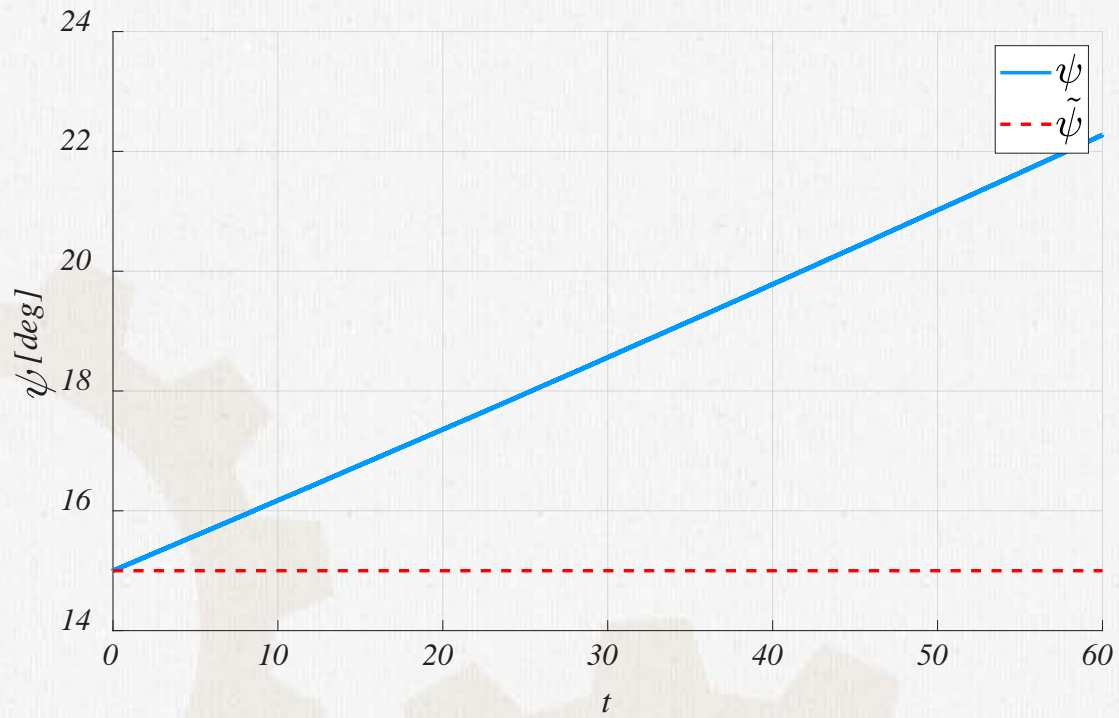
Zero Velocity Update



Zero Velocity Update



Zero Velocity Update



Zero Turn Update

Zero Turn Equations

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} 1 & \sin \phi \tan \theta & \cos \phi \tan \theta \\ 0 & \cos \phi & -\sin \phi \\ 0 & \sin \phi / \cos \theta & \cos \phi / \cos \theta \end{bmatrix} (\omega_{ib}^b - C_n^b (\omega_{ie}^n + \omega_{en}^n)) = 0 \implies \omega_{ib}^b - C_n^b \omega_{ie}^n = 0$$

External Outputs

$$\tilde{y} = [L \ \lambda \ h \ v_N \ v_E \ v_D \ \dot{\phi} \ \dot{\theta} \ \dot{\psi}]^T$$

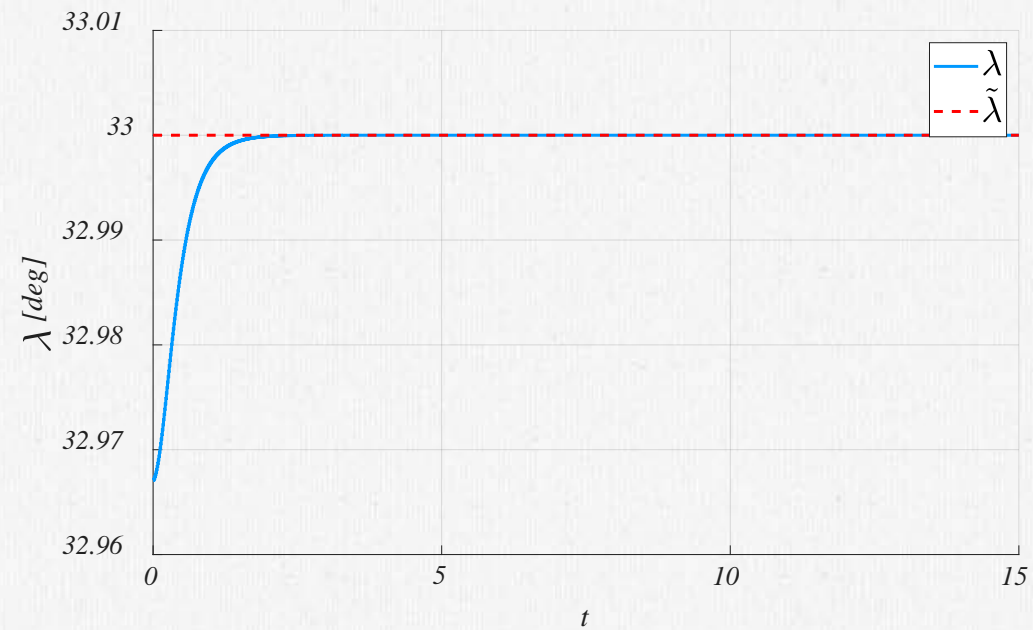
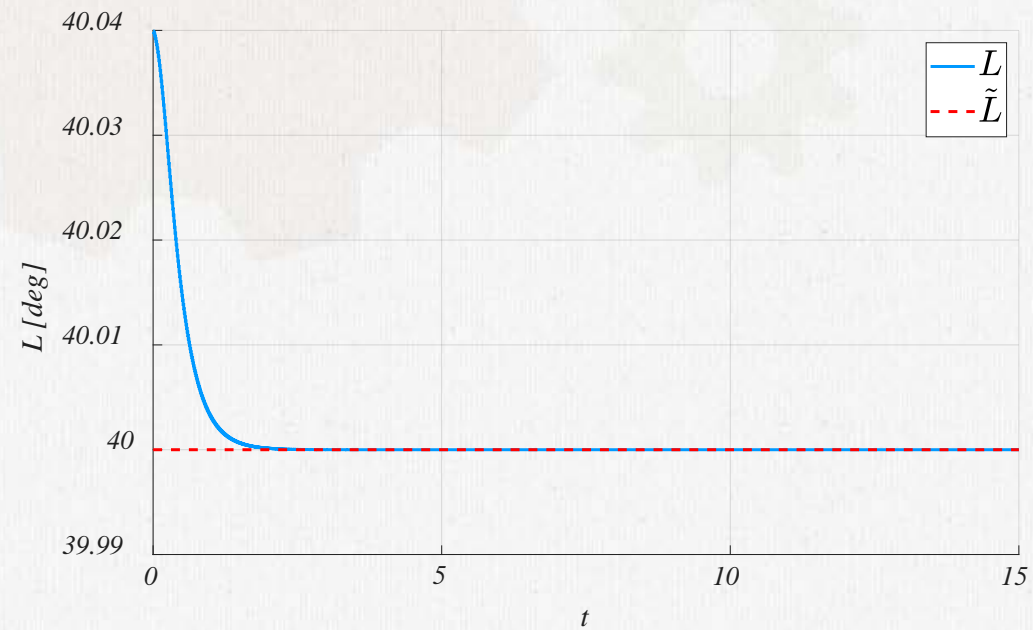
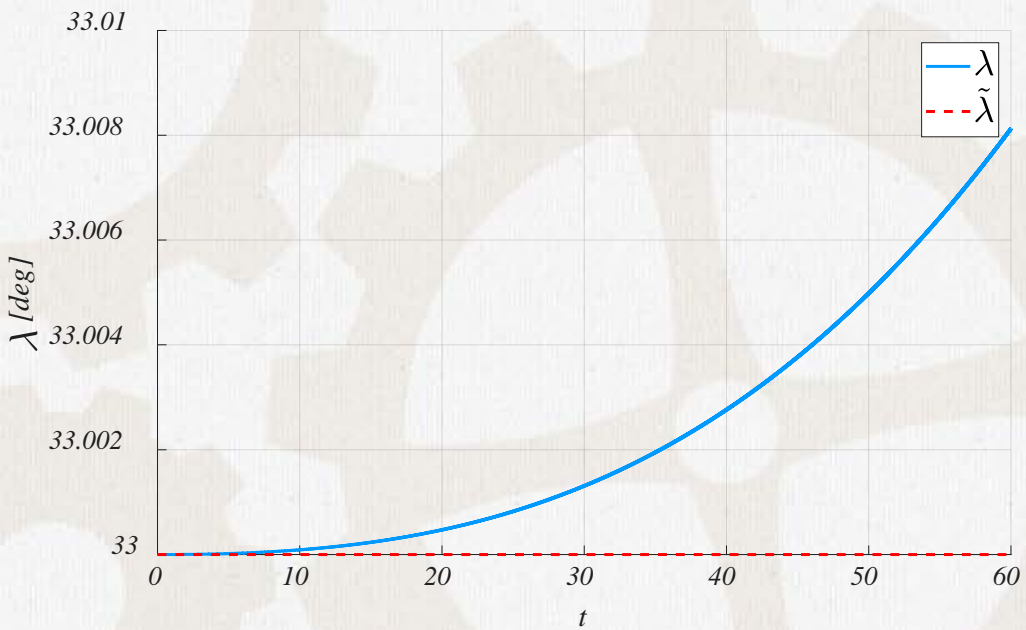
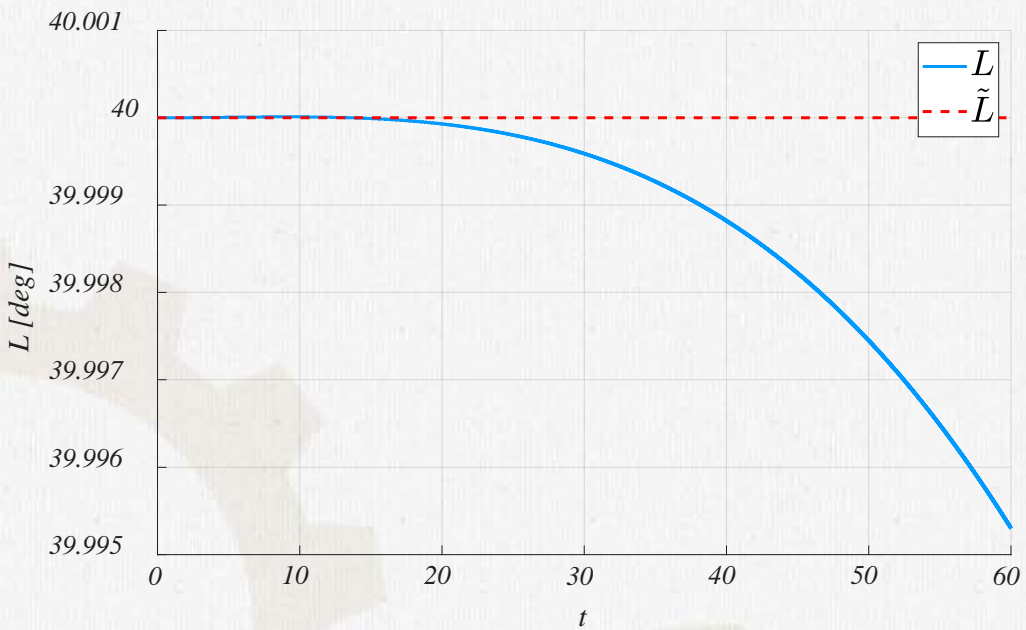
States

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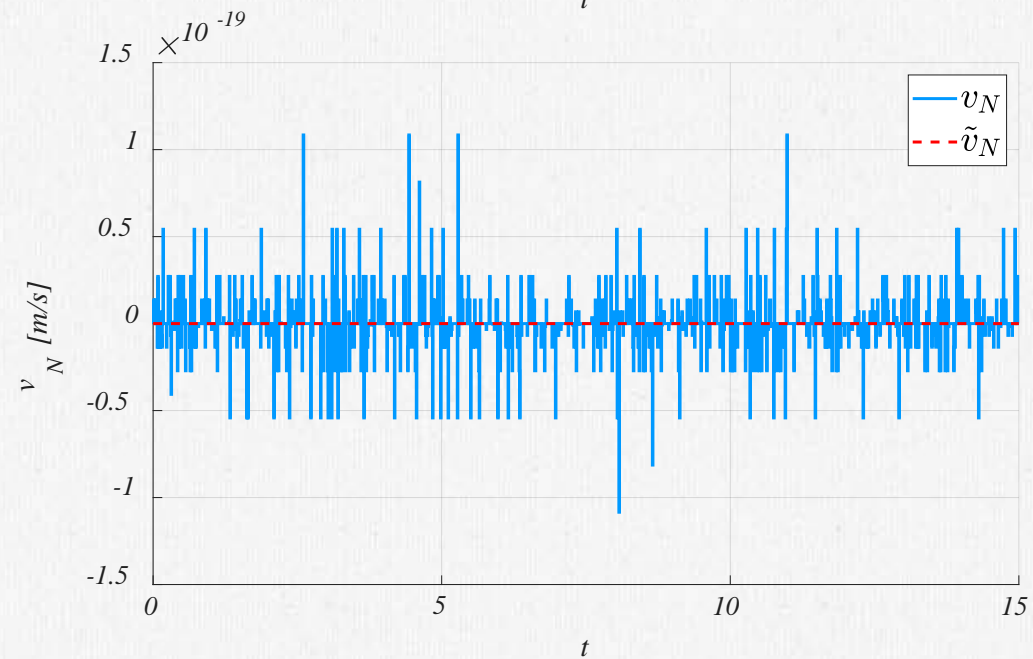
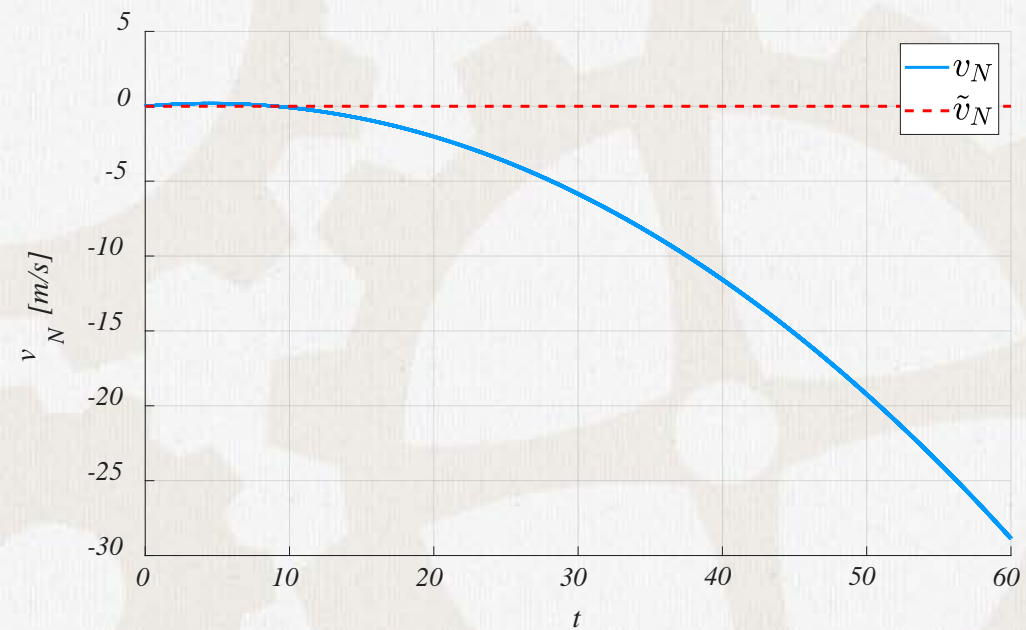
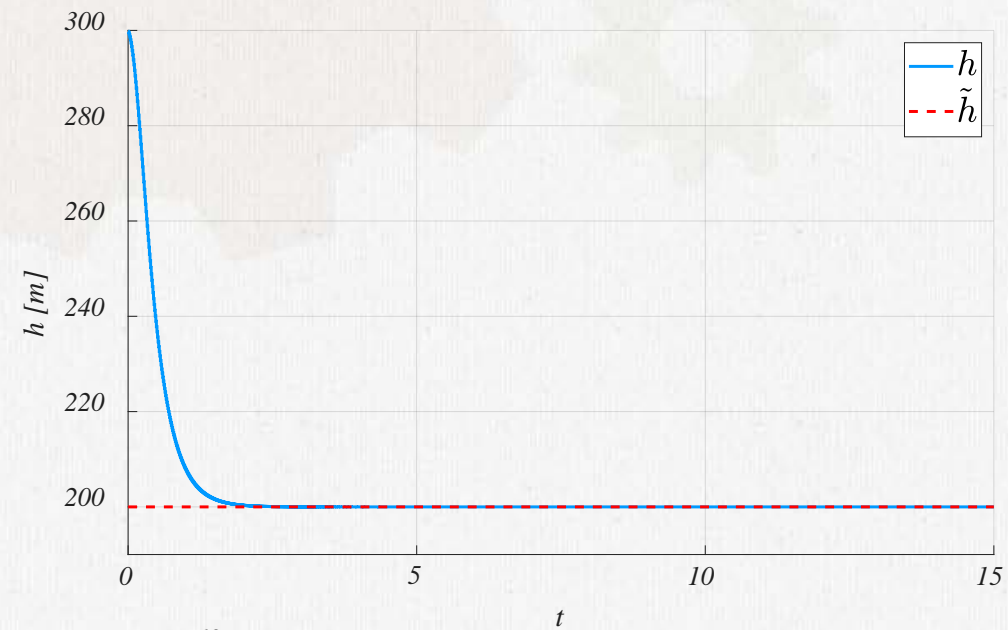
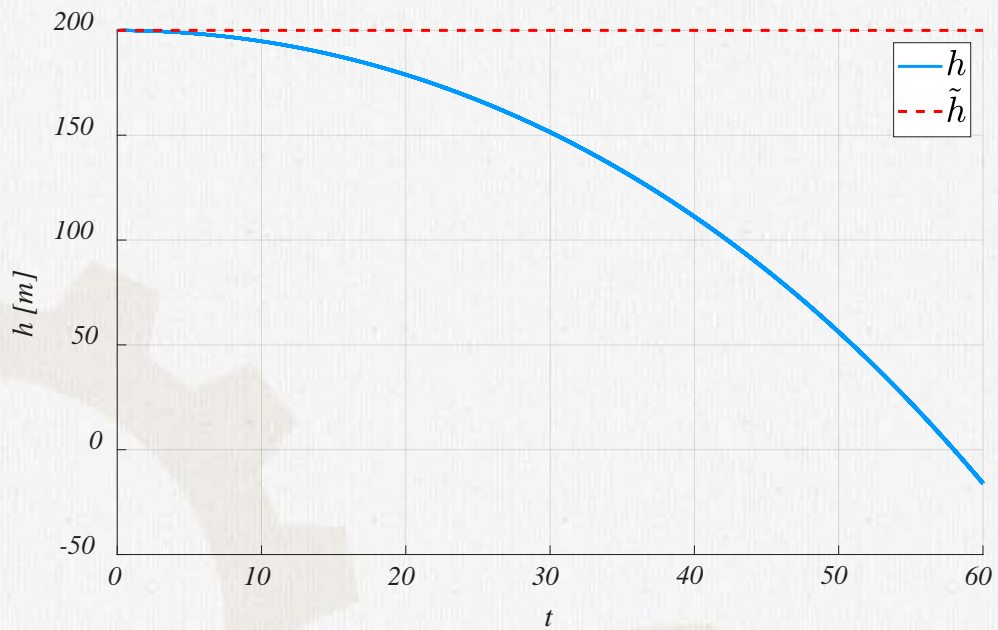
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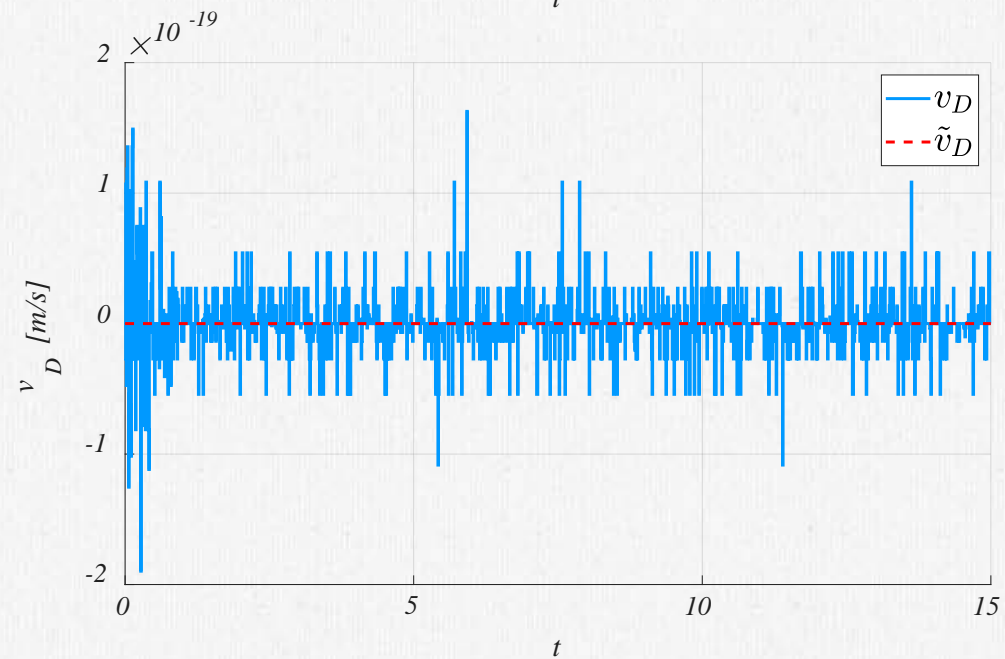
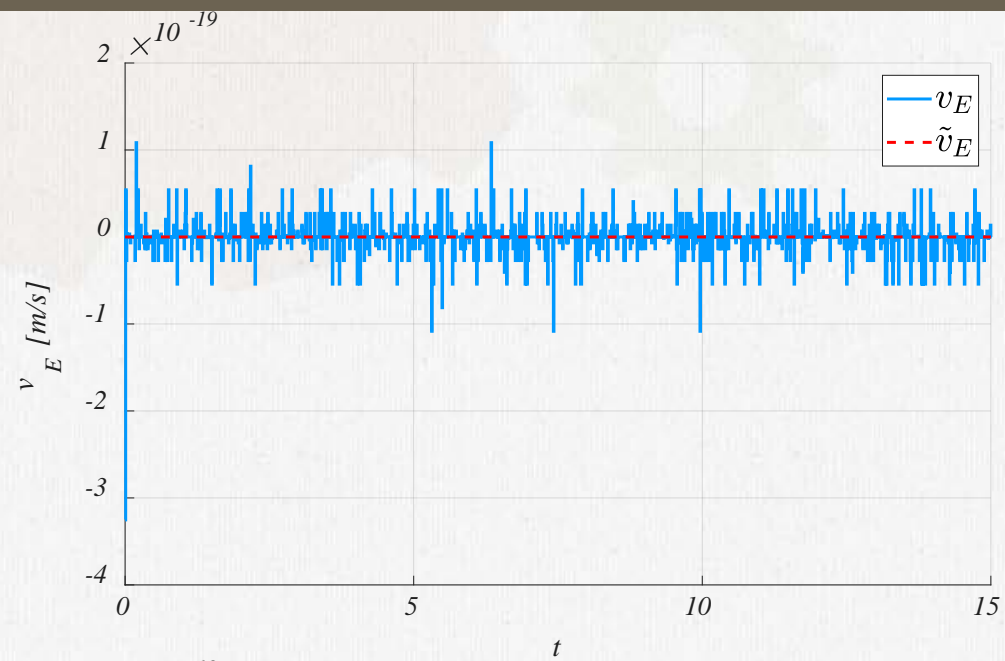
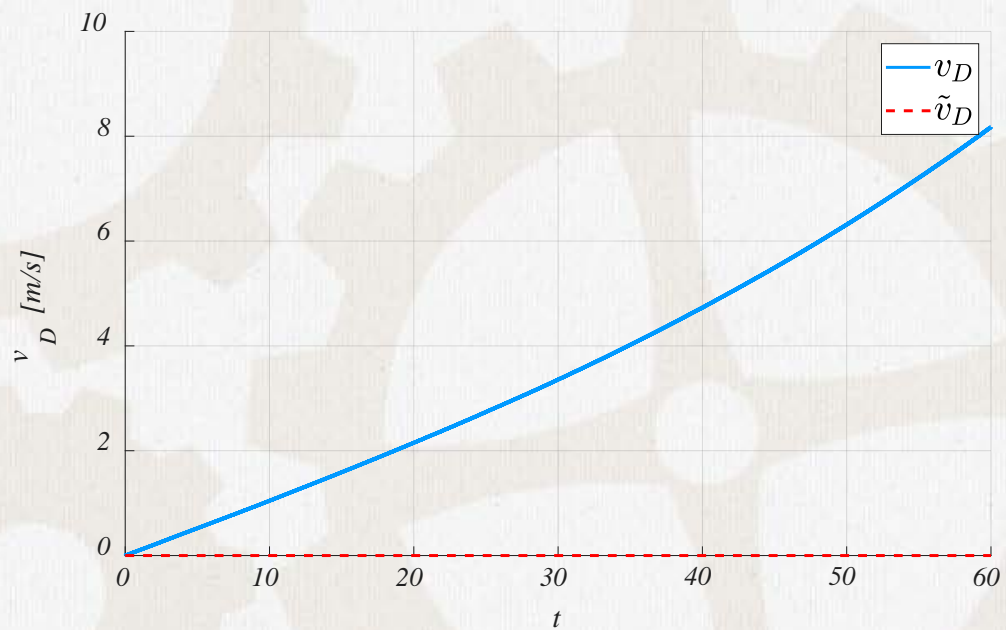
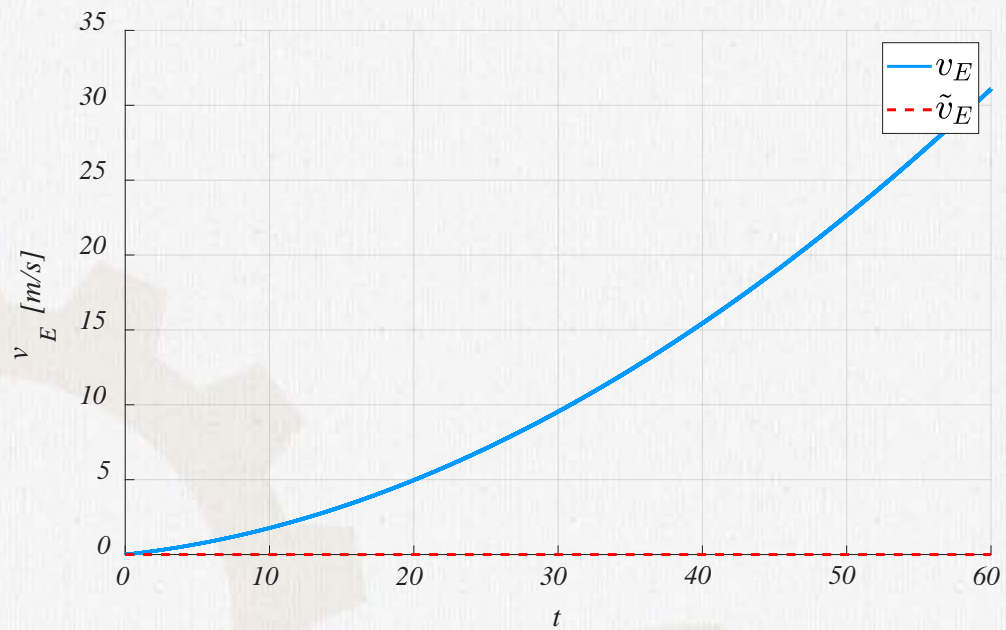
Zero Turn Update



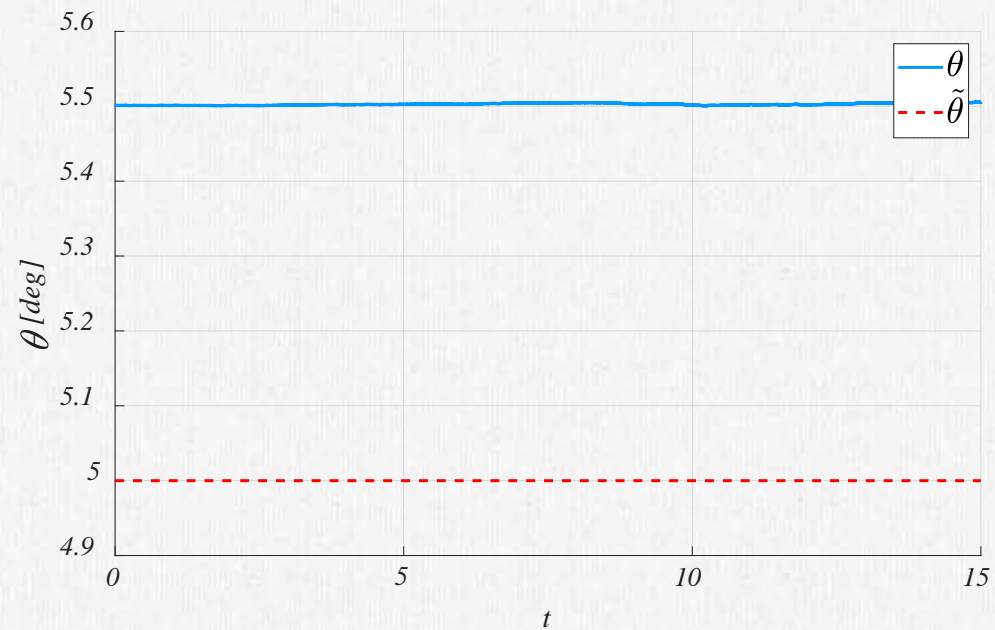
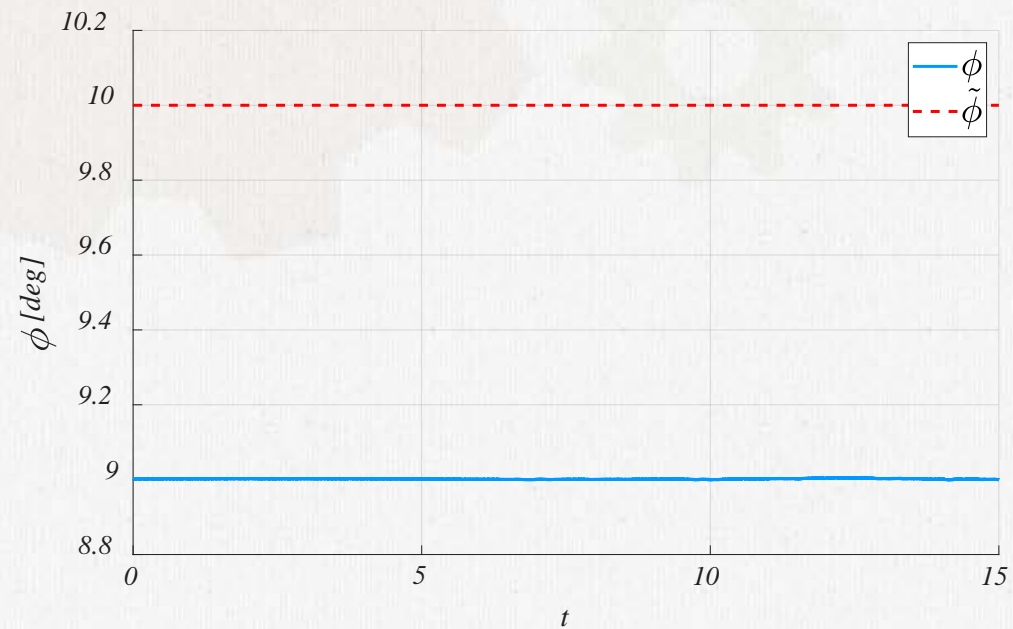
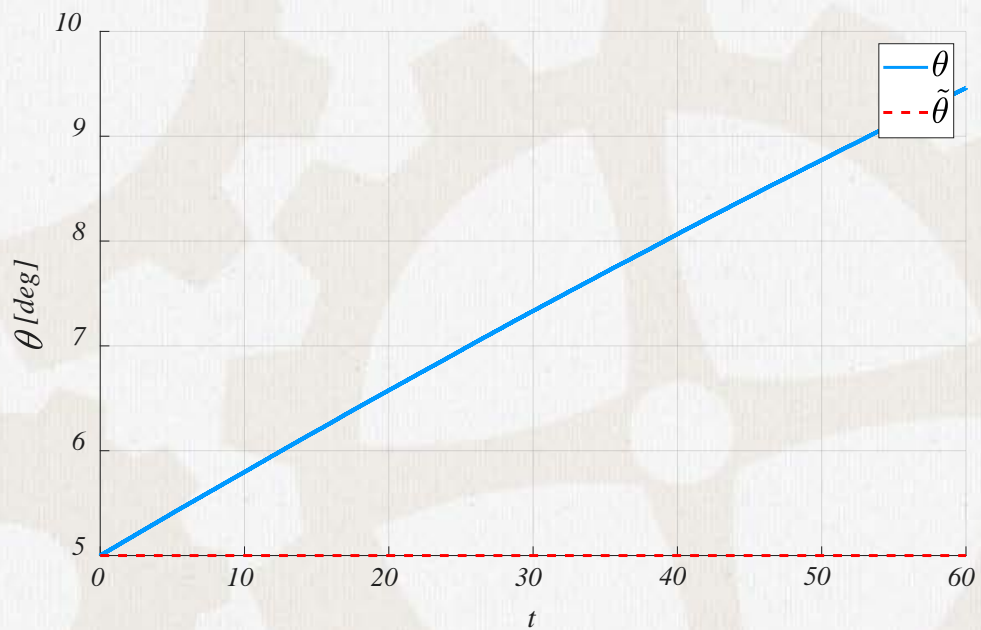
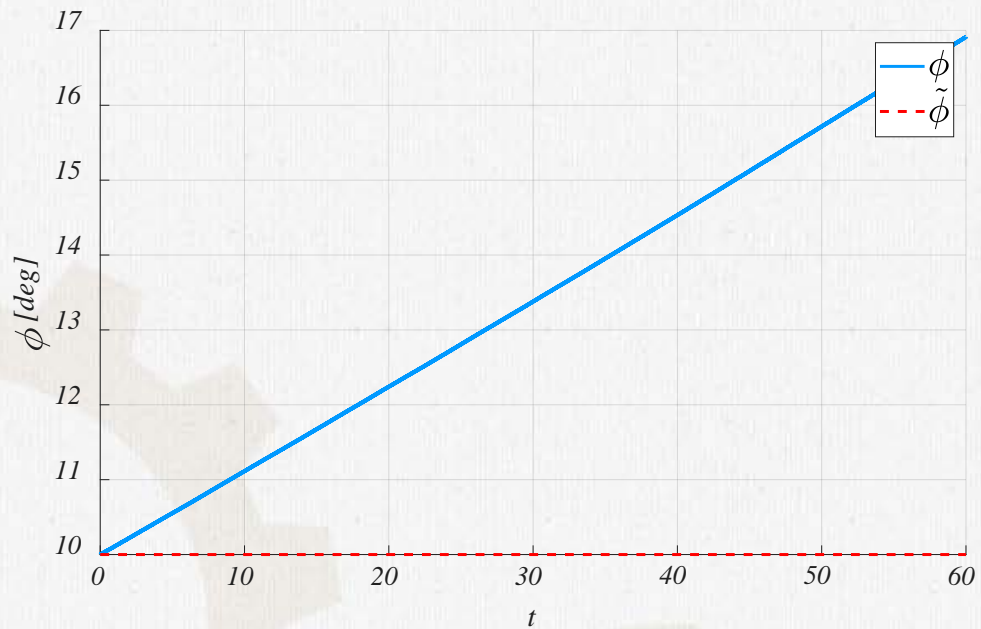
Zero Turn Update



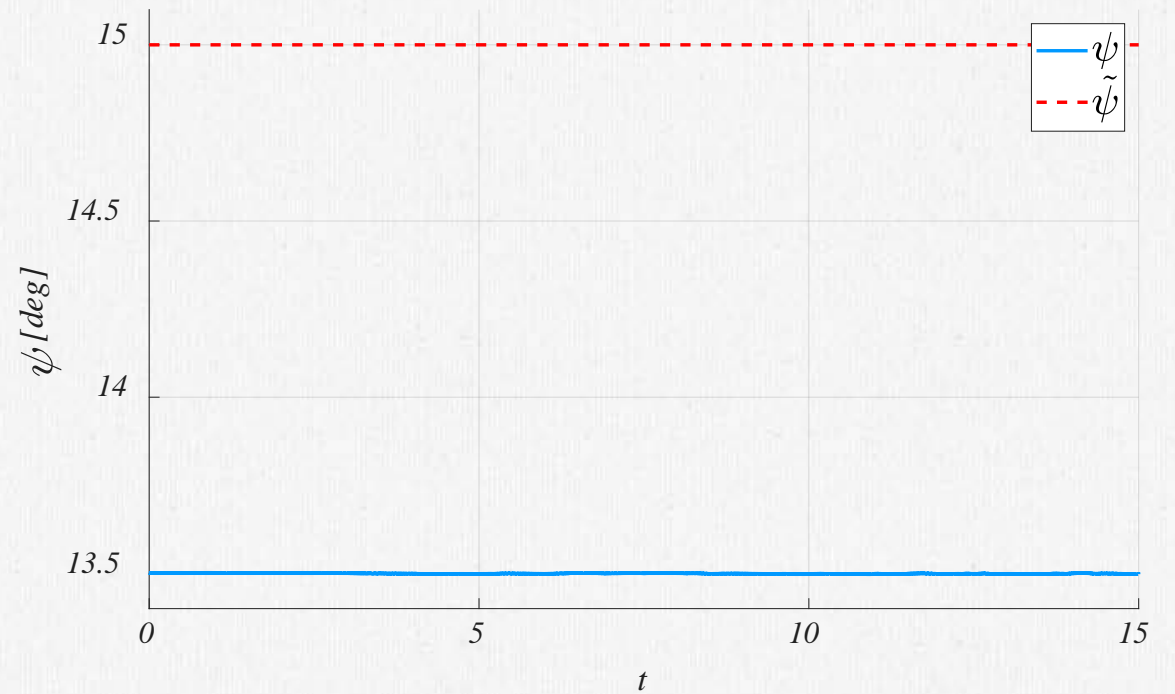
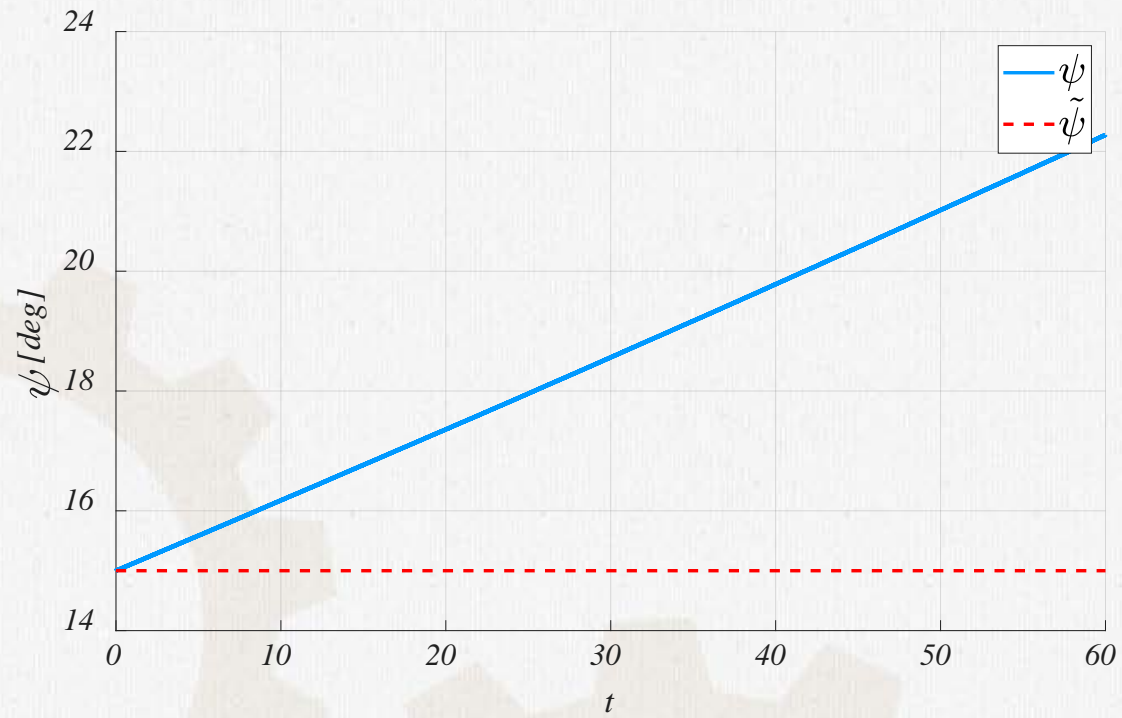
Zero Turn Update



Zero Turn Update



Zero Turn Update



Summary and Future Directions

- ❑ Stationary Vehicle Attitude Determination
- ❑ Moving Vehicle Attitude Determination
 - ❑ Dynamic Model Inclusion, Non-holonomic constraints
- ❑ Auxiliary Data
 - ❑ Other Sensors (AoA, sideslip)
 - ❑ Other Systems (VOR, etc)

Thank You...

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