INDIRECT FIRE TARGET STATE ESTIMATION AND PREDICTION USING AERIAL SCOUT VEHICLES

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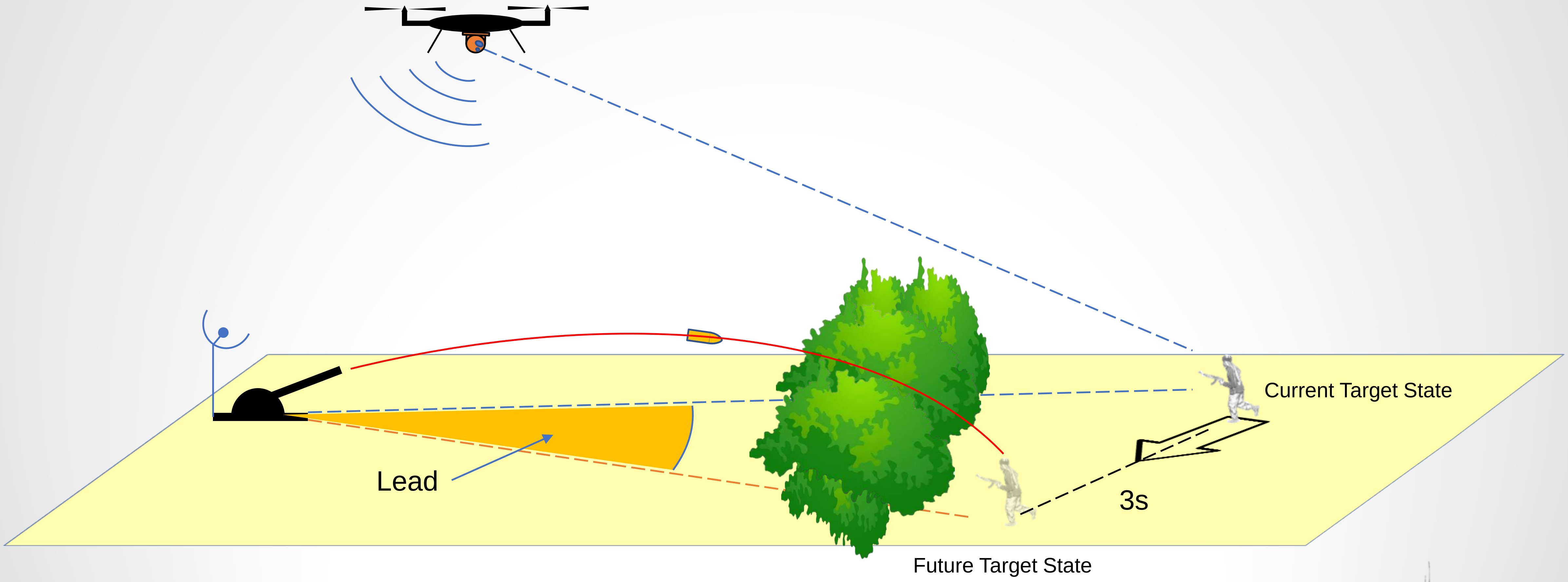
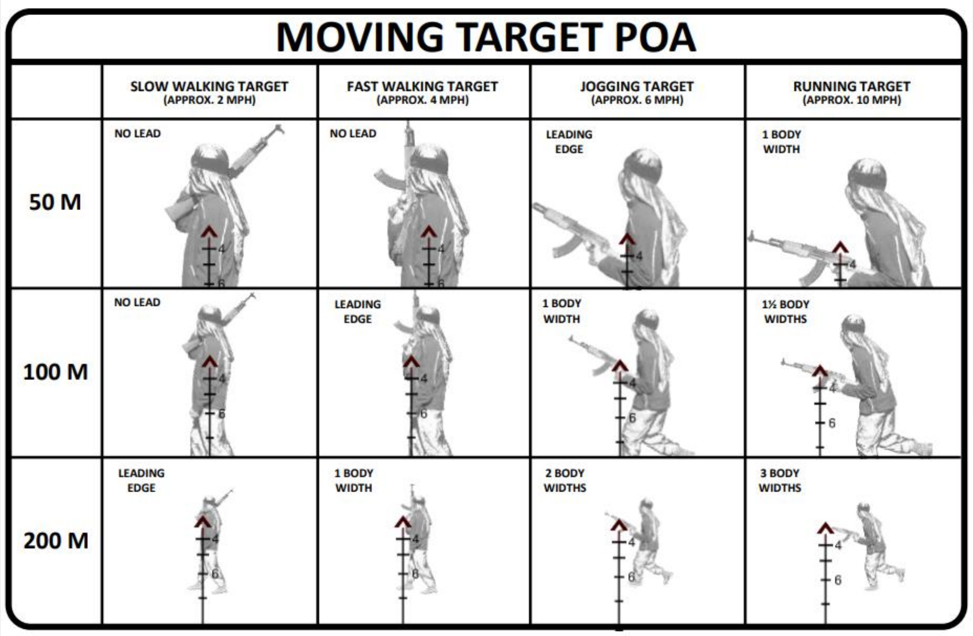
AGENDA

- Problem Statement
- Review of Previous Solutions
- Problem Characteristics
- Solutions
- Test Results

PROBLEM STATEMENT

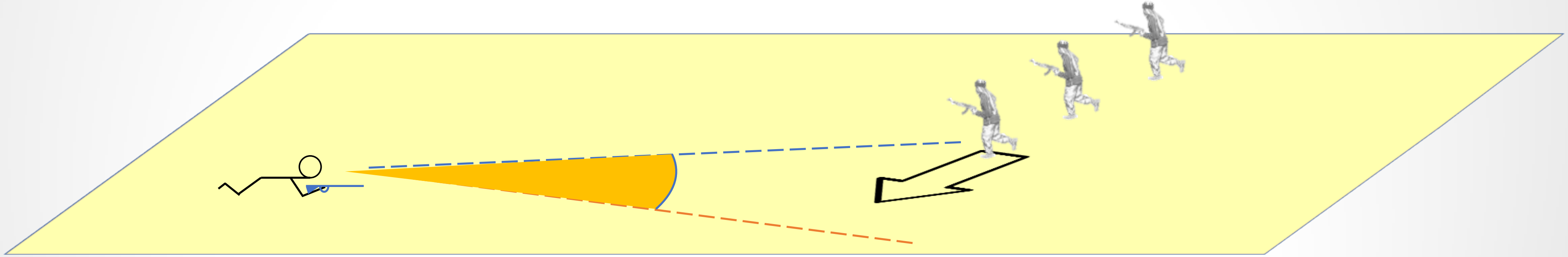


TYPICAL APPROACH 1



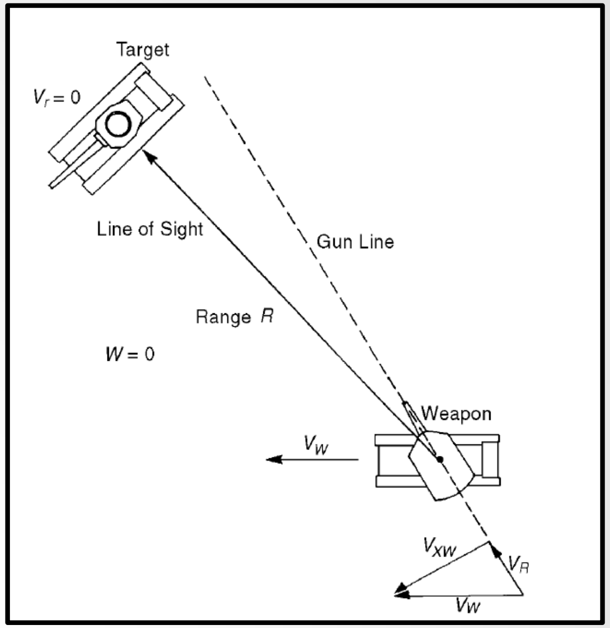
MOVING TARGET POA

	SLOW WALKING TARGET (APPROX. 2 MPH)	FAST WALKING TARGET (APPROX. 4 MPH)	JOGGING TARGET (APPROX. 6 MPH)	RUNNING TARGET (APPROX. 10 MPH)
50 M	NO LEAD	NO LEAD	LEADING EDGE	1 BODY WIDTH
100 M	NO LEAD	LEADING EDGE	1 BODY WIDTH	1½ BODY WIDTHS
200 M	LEADING EDGE	1 BODY WIDTH	2 BODY WIDTHS	3 BODY WIDTHS



TYPICAL APPROACH 2

$$L_{AZ} = -KV_{XW}\frac{T_F}{R} - A_{ZW}(-V_{XW}),\ \text{mil}$$



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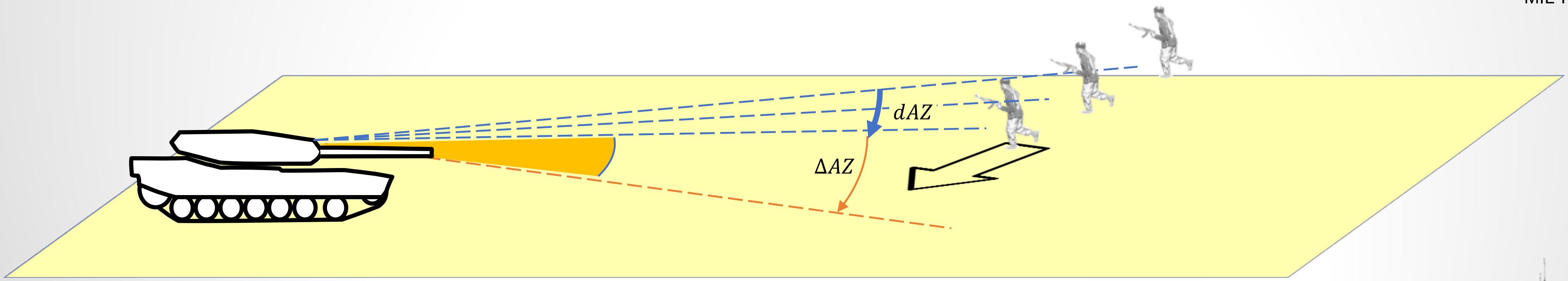
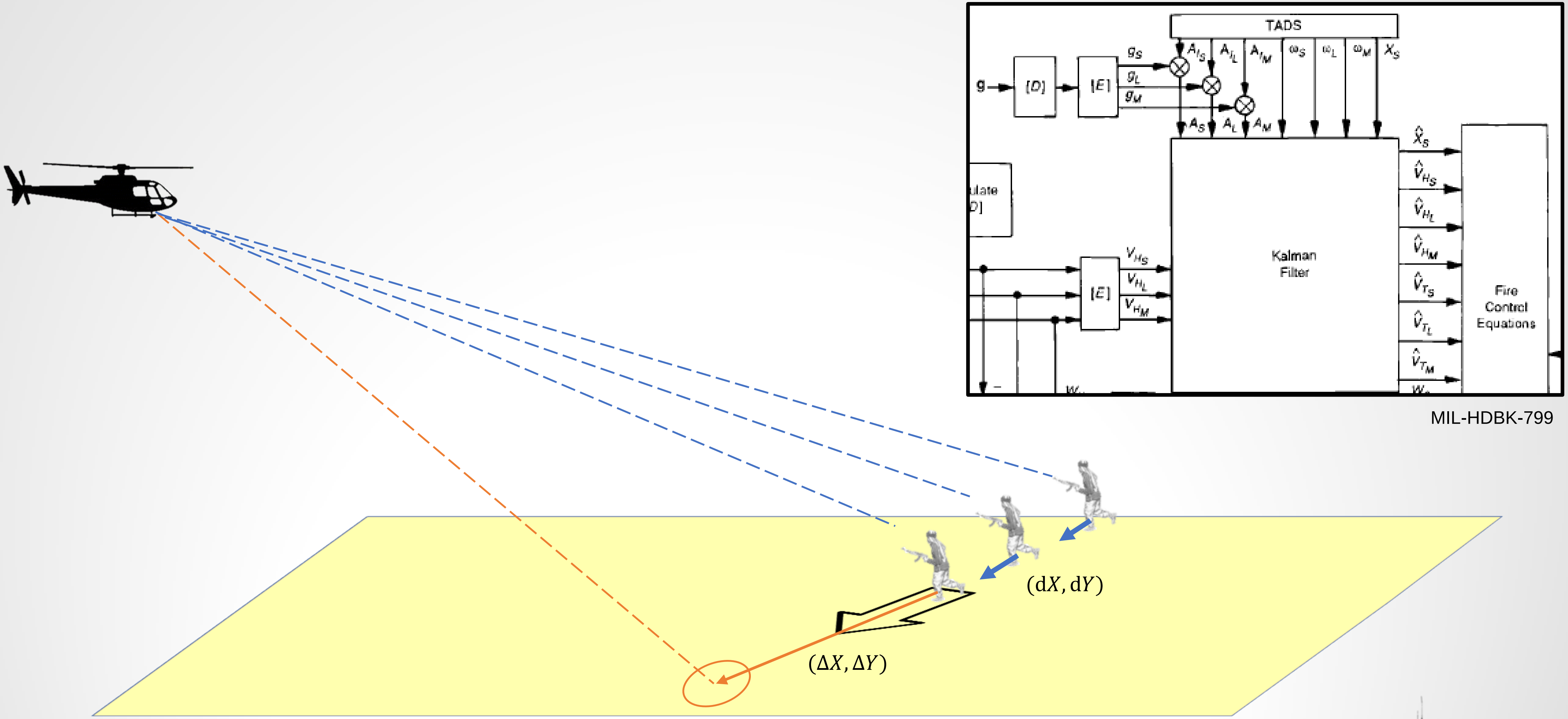


TYPICAL APPROACH 3



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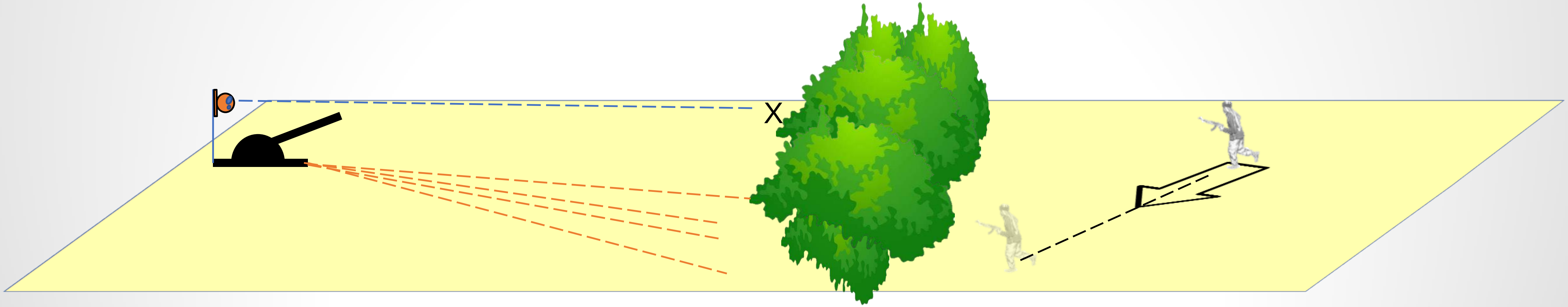
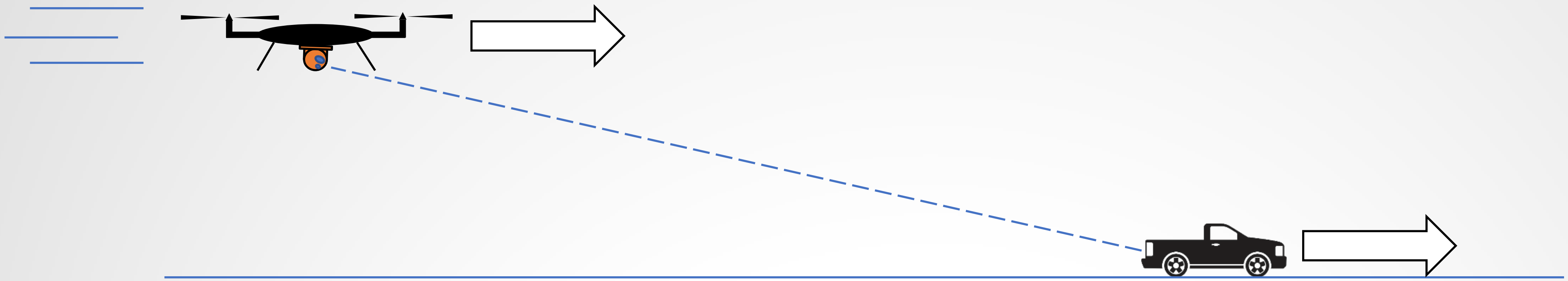
APPLICABILITY OF LEGACY SOLUTIONS

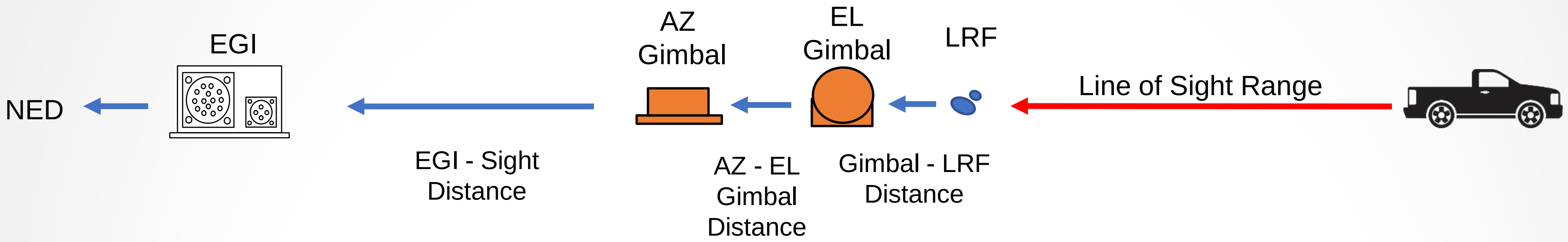


PATH FORWARD

1. Convert scout sensor data to local North, East, Down (NED) frame.
2. Convert the NED grid to Earth Center Earth Fixed (ECEF) coordinates and transmit to weapon platform.
3. Receive ECEF data stream and convert to weapon-centered NED.
4. Apply a filter utilizing a horizontal constant turn model to received data.
5. Calculate ballistic solution.
6. Leverage motion model to predict the change in target position over the time of flight of the munition.

CONVERT SCOUT SENSOR DATA TO LOCAL NORTH, EAST, DOWN (NED) FRAME.

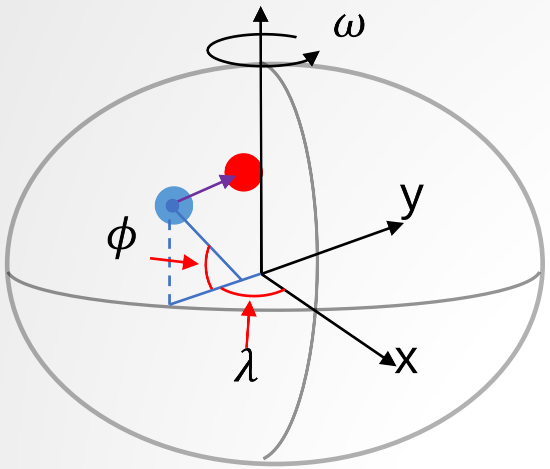




$$
\begin{aligned}
T_{EL} &= [r,0,0]^T + O_{EL-LRF} \\
T_{AZ} &= [R_{EL}]^T T_{EL} + O_{AZ-EL} \\
T_{EGI} &= [R_{AZ}]^T T_{AZ} + O_{EGI-AZ} \\
T_{NED} &= [R_{EGI}]^T T_{EGI}
\end{aligned}
$$

$$
V_{NED} \approx \frac{\Delta T}{\Delta t} = \frac{T(n) - T(n-1)}{t(n) - t(n-1)} + [R_{EGI}]^T v_{egi}
$$

CONVERT THE NED GRID TO EARTH CENTER EARTH FIXED (ECEF)



$$n = \frac{a}{\sqrt{1 - e^2 \sin^2(\phi)}}$$

$$S_X = (h + n)\cos(\phi)\cos(\lambda)$$

$$S_Y = (h + n)\cos(\phi)\sin(\lambda)$$

$$S_Z = (h + n - e^2 n)\sin(\phi)$$

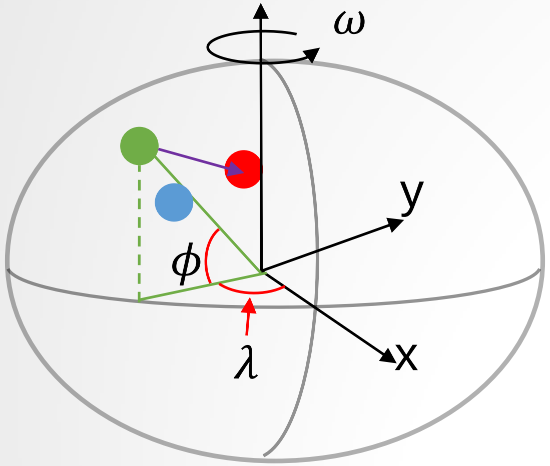
$$\begin{bmatrix} \Delta T_X \\ \Delta T_Y \\ \Delta T_Z \end{bmatrix} = \begin{bmatrix} -\mathrm{c}(\lambda_s)\,\mathrm{s}(\phi_s) & -\mathrm{s}(\lambda_s) & -\mathrm{c}(\lambda_s)\,\mathrm{c}(\phi_s) \\ -\mathrm{s}(\lambda_s)\,\mathrm{s}(\phi_s) & \mathrm{c}(\lambda_s) & -\mathrm{s}(\lambda_s)\,\mathrm{c}(\phi_s) \\ \mathrm{c}(\phi_s) & 0 & -\mathrm{s}(\phi_s) \end{bmatrix} \begin{bmatrix} T_N \\ T_E \\ T_D \end{bmatrix}$$

$$T_{XYZ} = S_{XYZ} + \Delta T_{XYZ}$$

$$\begin{bmatrix} V_X \\ V_Y \\ V_Z \end{bmatrix} = \begin{bmatrix} -\mathrm{c}(\lambda_s)\,\mathrm{s}(\phi_s) & -\mathrm{s}(\lambda_s) & -\mathrm{c}(\lambda_s)\,\mathrm{c}(\phi_s) \\ -\mathrm{s}(\lambda_s)\,\mathrm{s}(\phi_s) & \mathrm{c}(\lambda_s) & -\mathrm{s}(\lambda_s)\,\mathrm{c}(\phi_s) \\ \mathrm{c}(\phi_s) & 0 & -\mathrm{s}(\phi_s) \end{bmatrix} \begin{bmatrix} V_N \\ V_E \\ V_D \end{bmatrix}$$

RECEIVE ECEF DATA STREAM AND CONVERT TO WEAPON-CENTERED NED

$$T_{XYZ_w} = W_{XYZ} - T_{XYZ}$$



$$\begin{bmatrix} T_N \\ T_E \\ T_D \end{bmatrix} = \begin{bmatrix} -(\lambda_w)\,\mathrm{s}(\phi_w) & -\mathrm{s}(\lambda_w)\,\mathrm{s}(\phi_w) & \mathrm{c}(\phi_w) \\ -\mathrm{s}(\lambda_w) & \mathrm{c}(\lambda_w) & 0 \\ -\mathrm{c}(\lambda_w)\,\mathrm{c}(\phi_w) & -\mathrm{s}(\lambda_w)\,\mathrm{c}(\phi_w) & -\mathrm{s}(\phi_w) \end{bmatrix} \begin{bmatrix} T_{X_w} \\ T_{Y_w} \\ T_{Z_w} \end{bmatrix}$$

$$\begin{bmatrix} V_N \\ V_E \\ V_D \end{bmatrix} = \begin{bmatrix} -(\lambda_w)\,\mathrm{s}(\phi_w) & -\mathrm{s}(\lambda_w)\,\mathrm{s}(\phi_w) & \mathrm{c}(\phi_w) \\ -\mathrm{s}(\lambda_w) & \mathrm{c}(\lambda_w) & 0 \\ -\mathrm{c}(\lambda_w)\,\mathrm{c}(\phi_w) & -\mathrm{s}(\lambda_w)\,\mathrm{c}(\phi_w) & -\mathrm{s}(\phi_w) \end{bmatrix} \begin{bmatrix} V_X \\ V_Y \\ V_Z \end{bmatrix}$$

APPLY A HORIZONTAL CONSTANT TURN FILTER

$$X_k = [p_n \;\; v_n \;\; a_n \;\; p_e \;\; v_e \;\; a_e \;\; p_d \;\; v_d \;\; a_d]^T$$

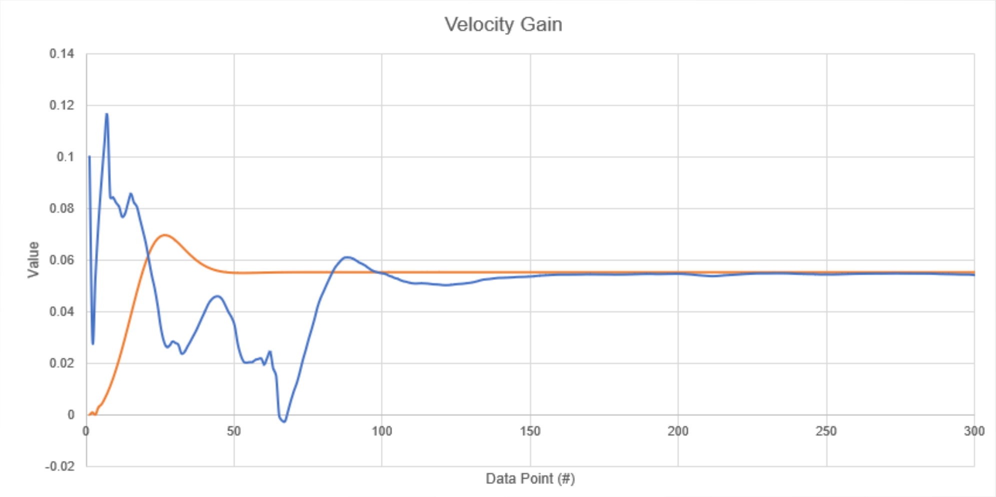
$$X_k^P = \begin{bmatrix} A_{ct} & O & O \\ O & A_{ct} & O \\ O & O & A_{ca} \end{bmatrix} [X_{k-1}]$$

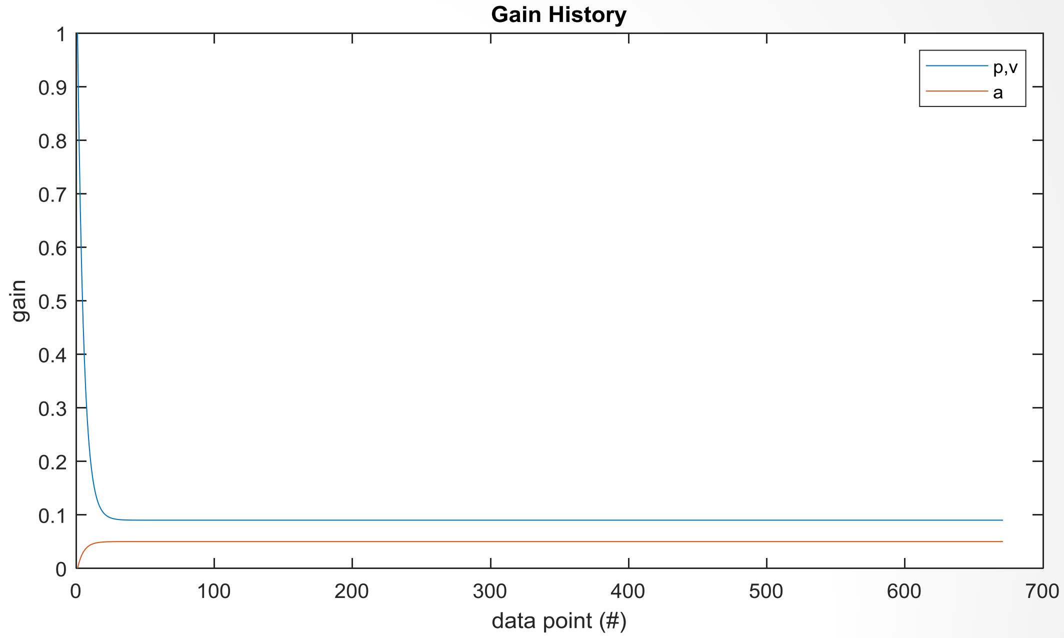
$$A_{ct} = \begin{bmatrix} 1 & \frac{\sin(\omega\Delta t)}{\omega} & (1-\cos(\omega\Delta t))/\omega^2 \\ 0 & \cos(\omega\Delta t) & \frac{\sin(\omega\Delta t)}{\omega} \\ 0 & -\omega\sin(\omega\Delta t) & \cos(\omega\Delta t) \end{bmatrix}$$

$$A_{ca} = \begin{bmatrix} 1 & \Delta t & \frac{\Delta t^2}{2} \\ 0 & 1 & \Delta t \\ 0 & 0 & 1 \end{bmatrix}$$

$$X_k = X_k^p + K_k \circ I_k$$

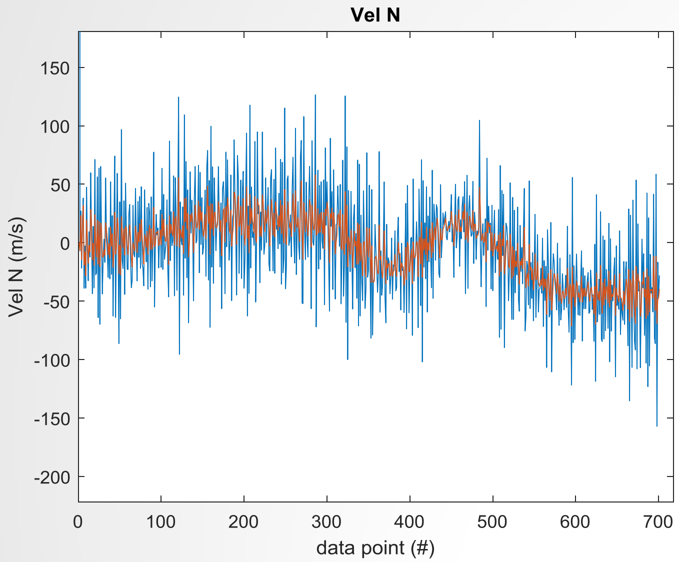
$$I_k = [A_{9f} \quad B_{9f} \quad C_{9f}]$$



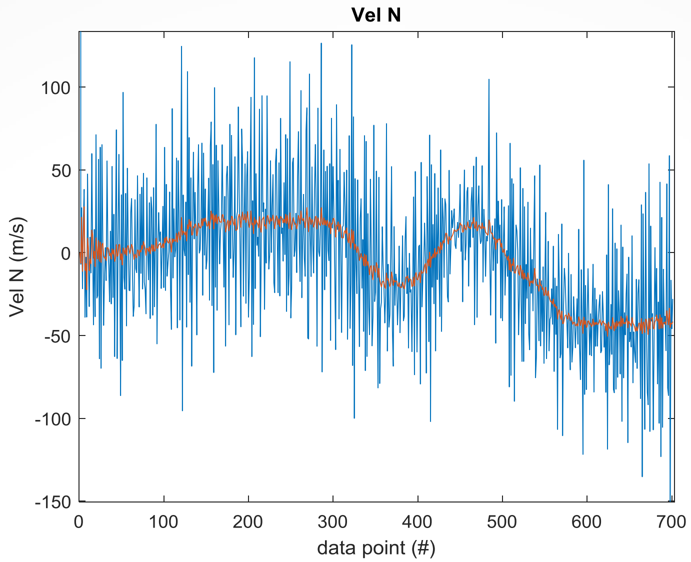


FILTERED VELOCITY

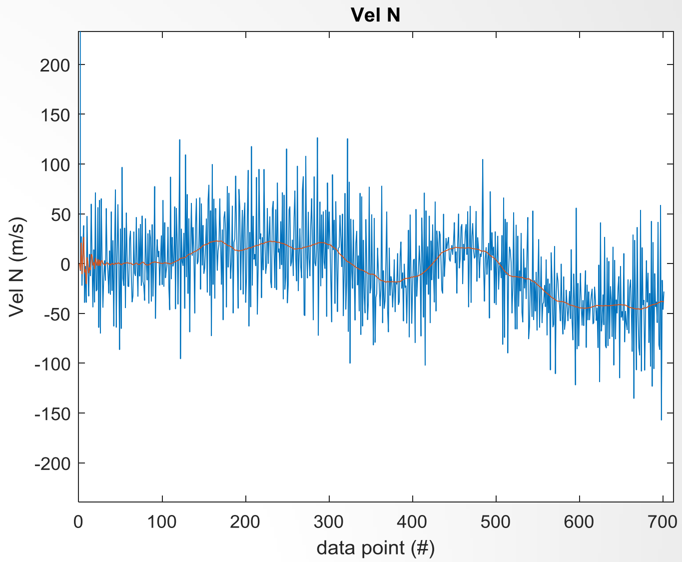
k = 0.4



k = 0.1



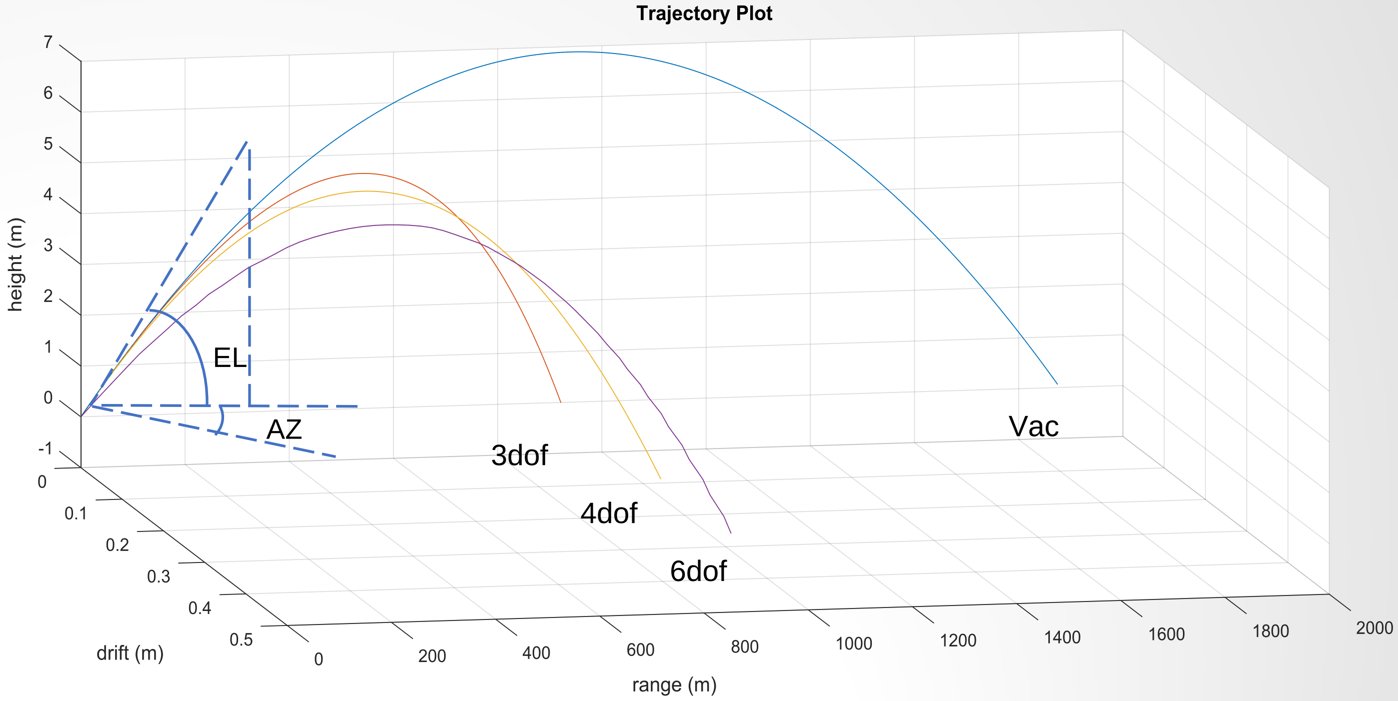
k = 0.01



CALCULATE BALLISTIC SOLUTION.

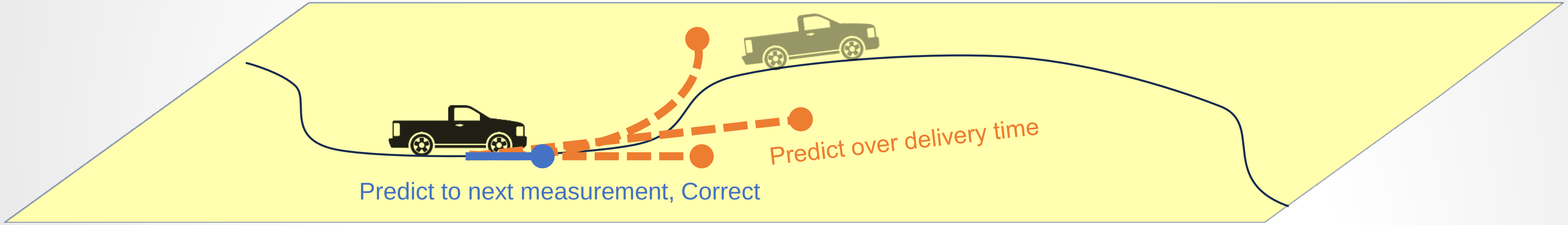
$$[AZ_k, EL_k, TOF_k] = B(A_{10}, B_{10}, C_{10})$$

$$A_{10} = X_k(1) + \Delta p_n(tof_{k-1})$$
$$B_{10} = X_k(4) + \Delta p_e(tof_{k-1})$$
$$C_{10} = X_k(7) + \Delta p_d(tof_{k-1})$$

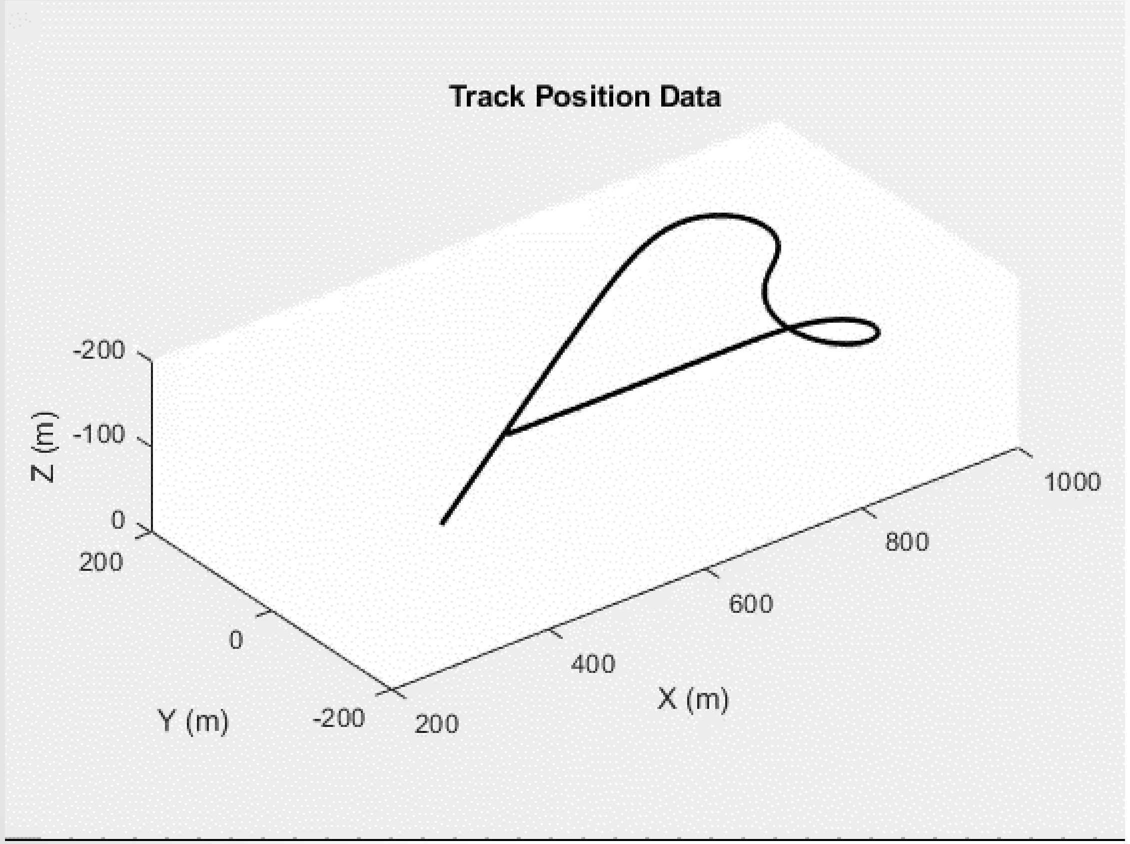


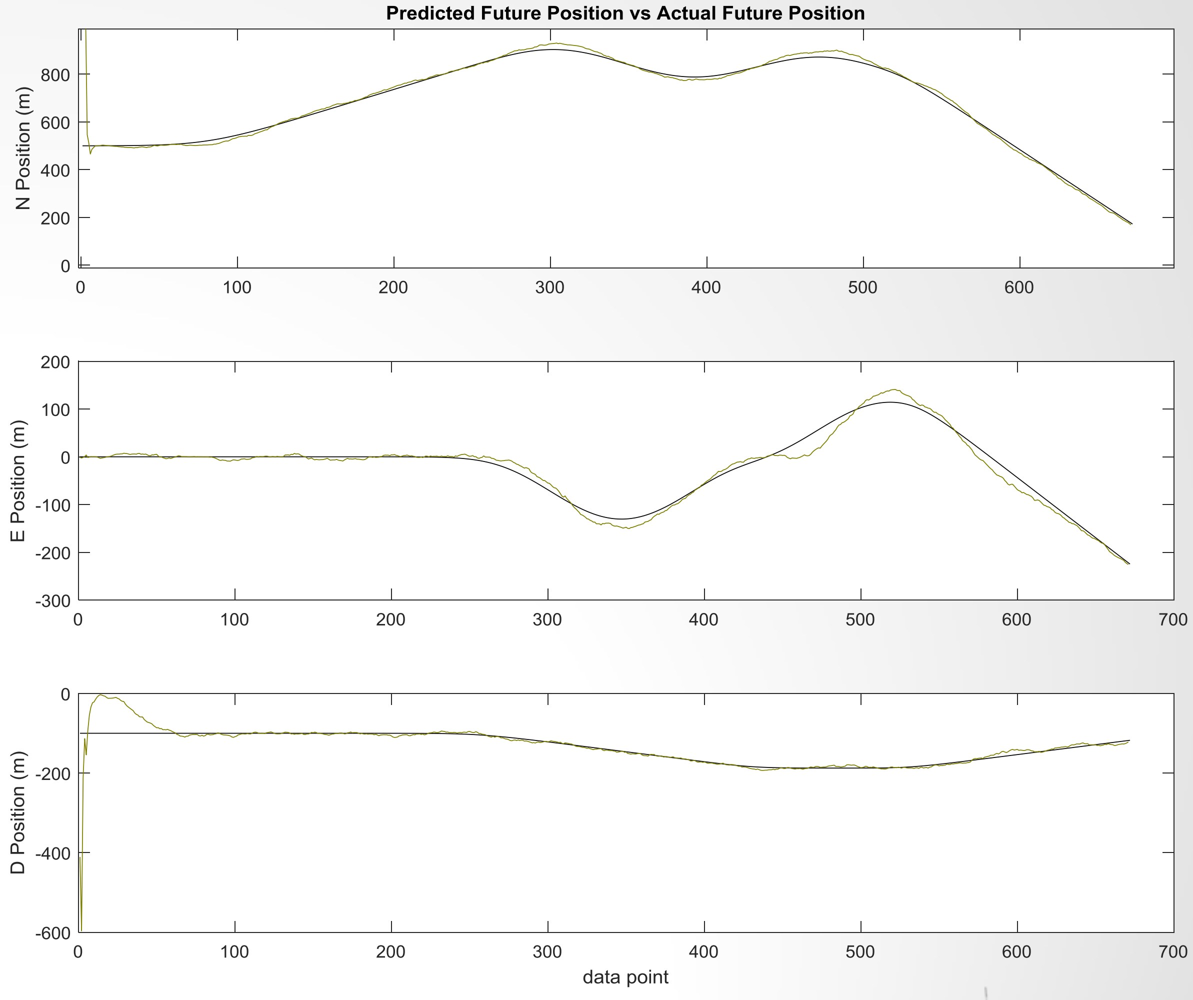
PREDICT THE CHANGE IN TARGET POSITION OVER THE TIME OF FLIGHT.

$$\Delta p_{n,e,d}(tof) = \mathrm{X}_i^{\mathrm{P}} - X_k$$
$$\mathrm{X}_i^{\mathrm{P}} = A\mathrm{X}_{i-1}^{\mathrm{p}} \; for \; i = 1 \; to \; \lfloor tof/\Delta t \rfloor$$

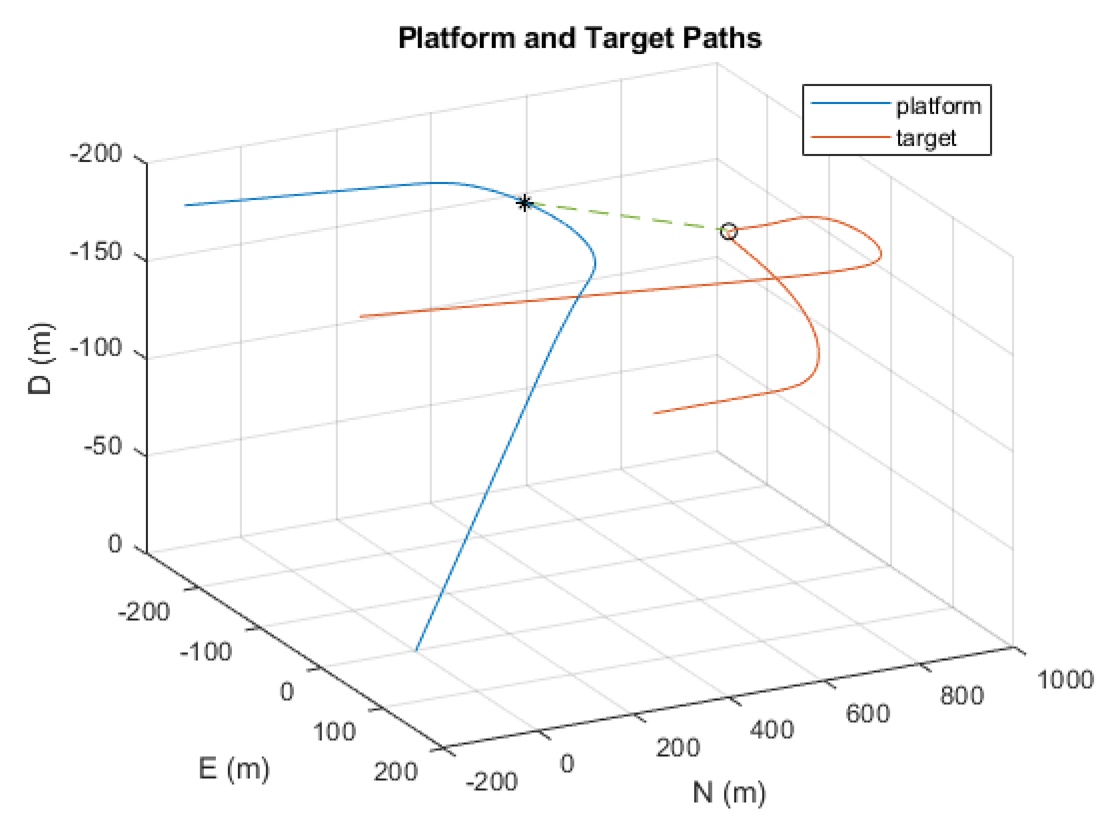


PUTTING IT TOGETHER





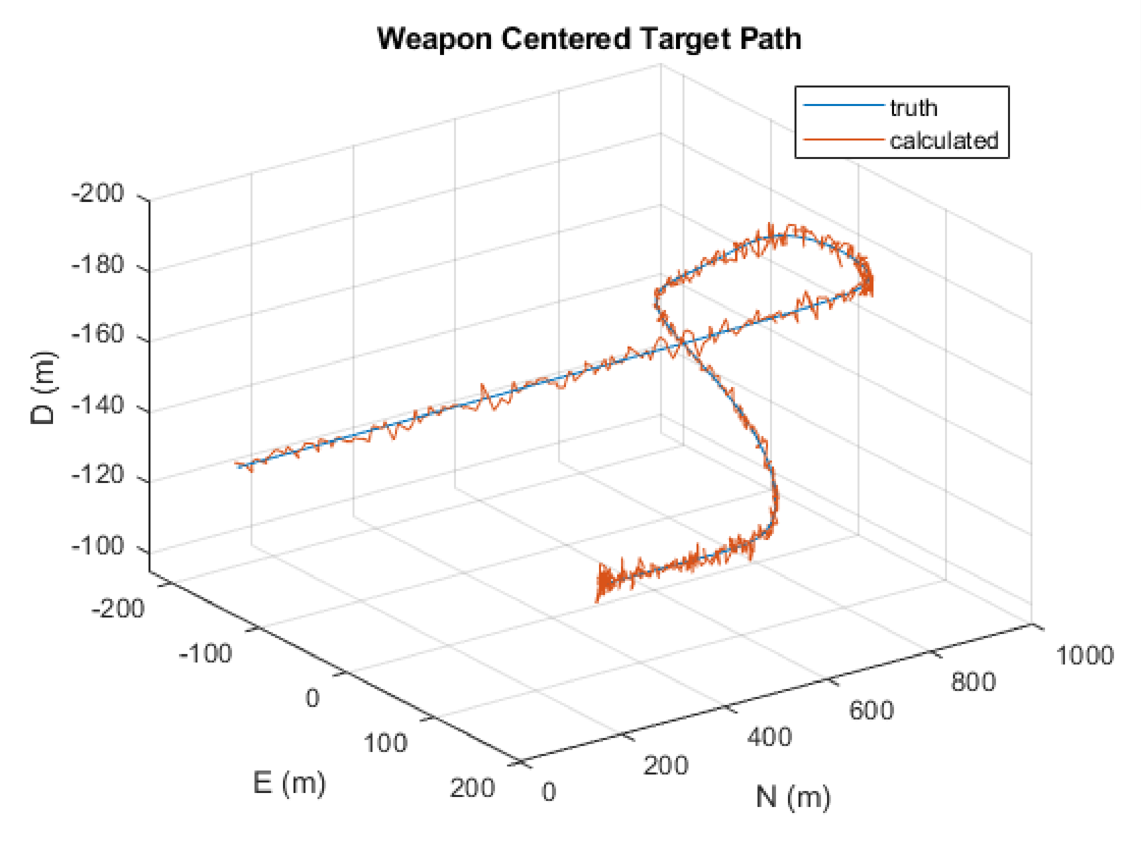
TEST CASE


Platform and Target Paths
platform
target
D (m)
-200
-150
-100
-50
0
E (m)
-200
-100
0
100
200
N (m)
-200
0
200
400
600
800
1000

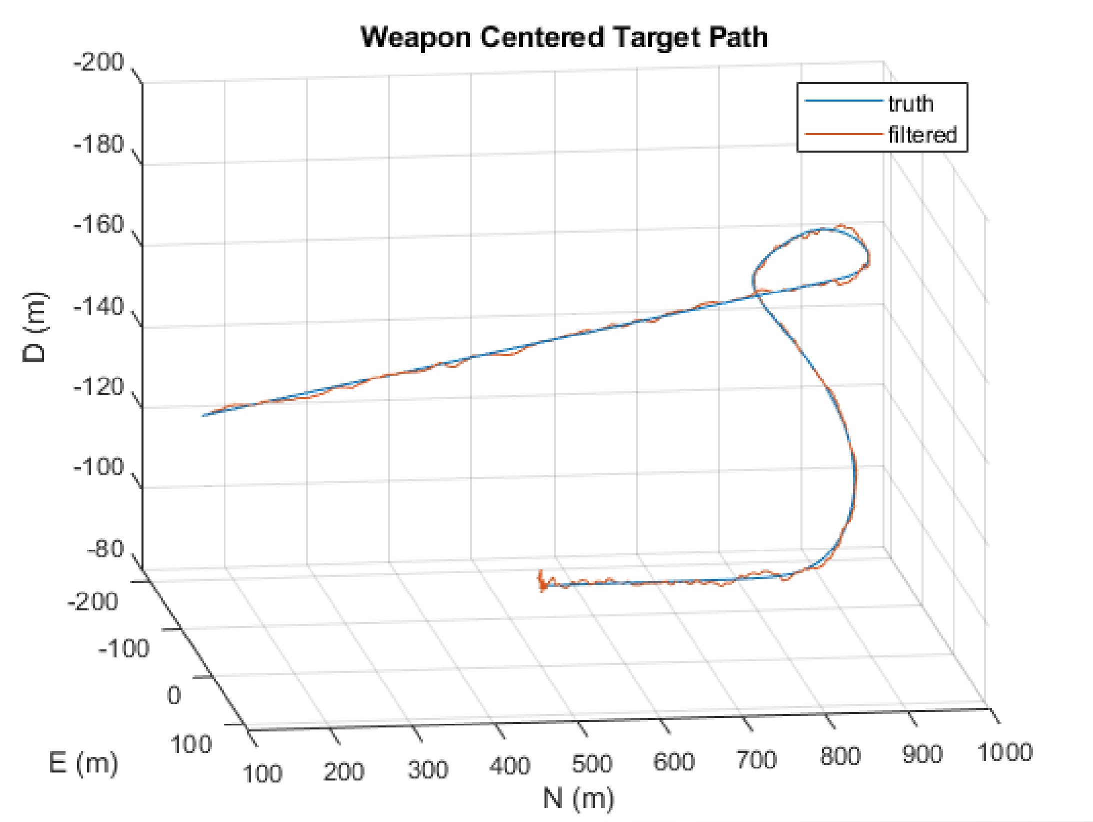

Scout
Target

TEST CASE DATA

k = 0.4

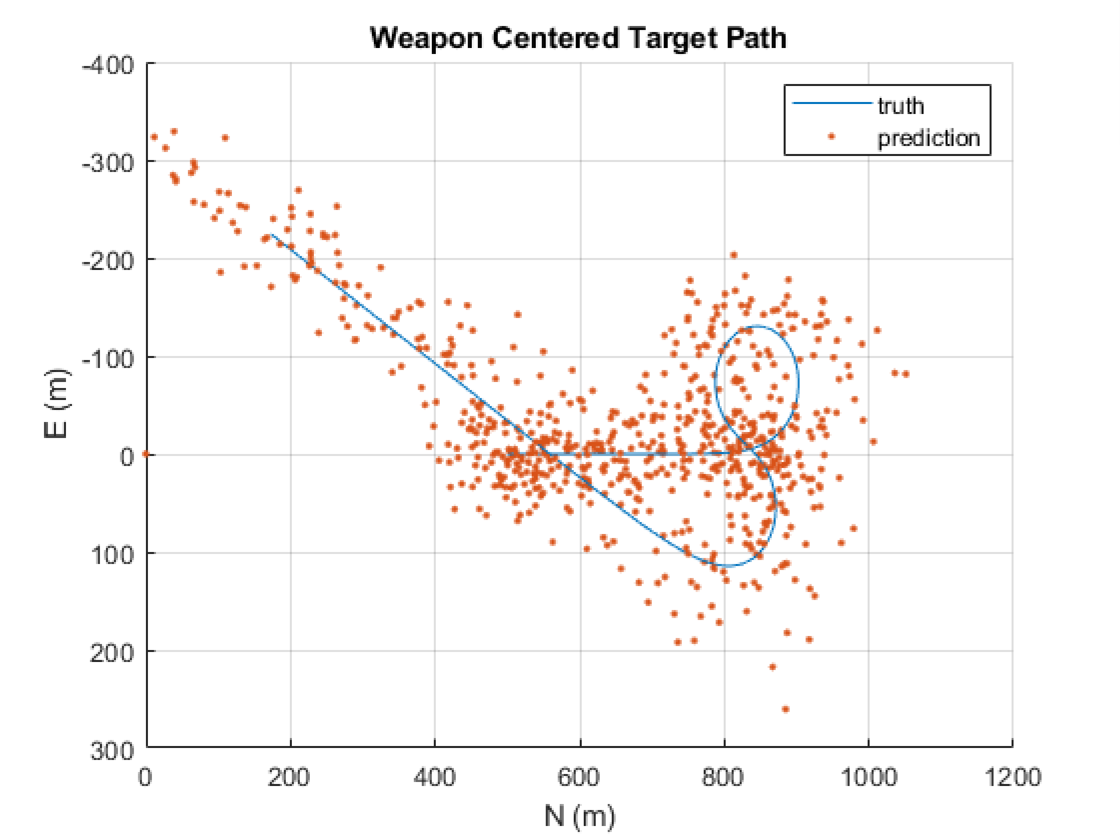


k = 0.01

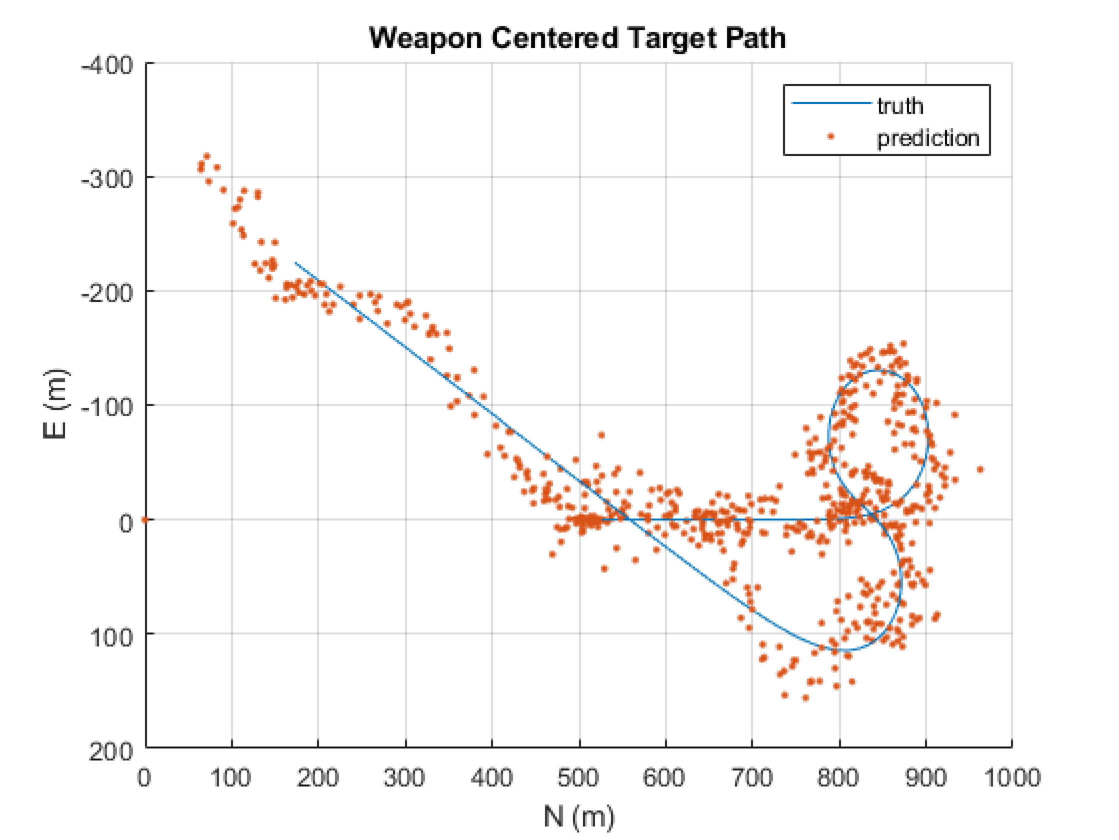


PREDICTION RESULTS

k = 0.4



k = 0.01

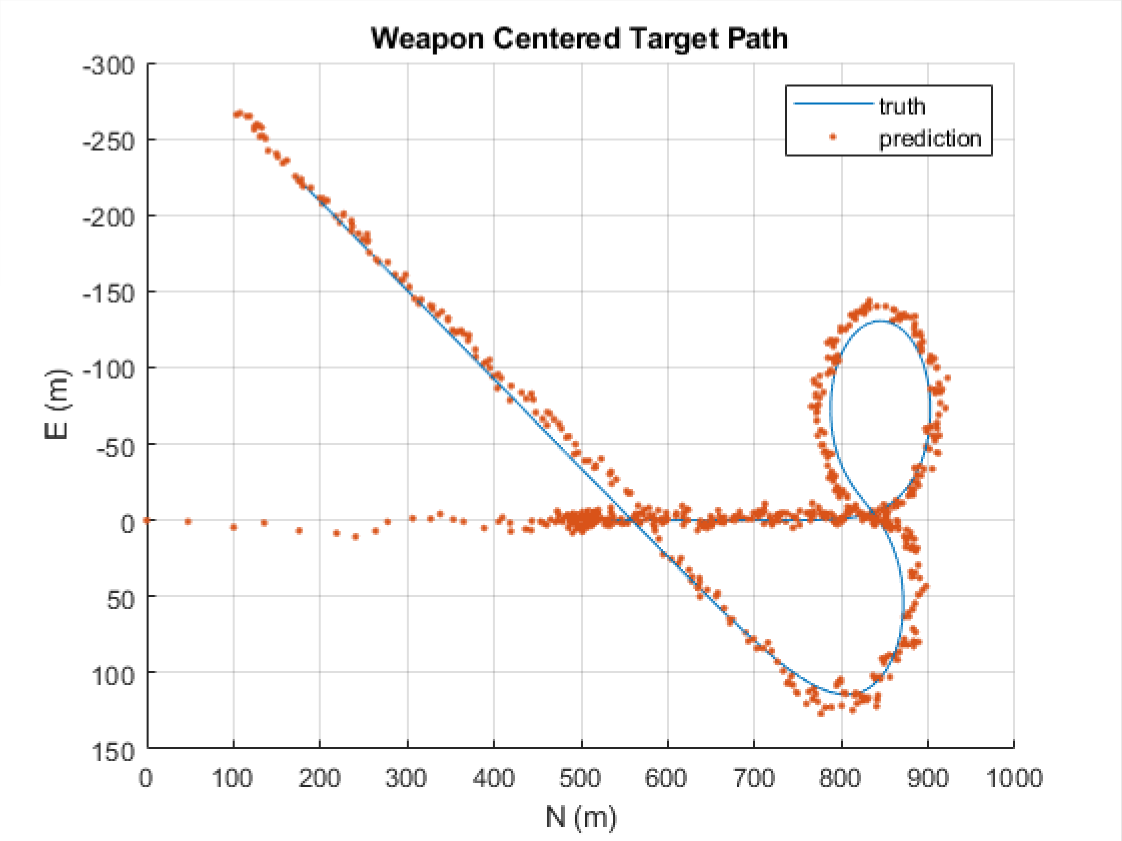


CONCLUSIONS

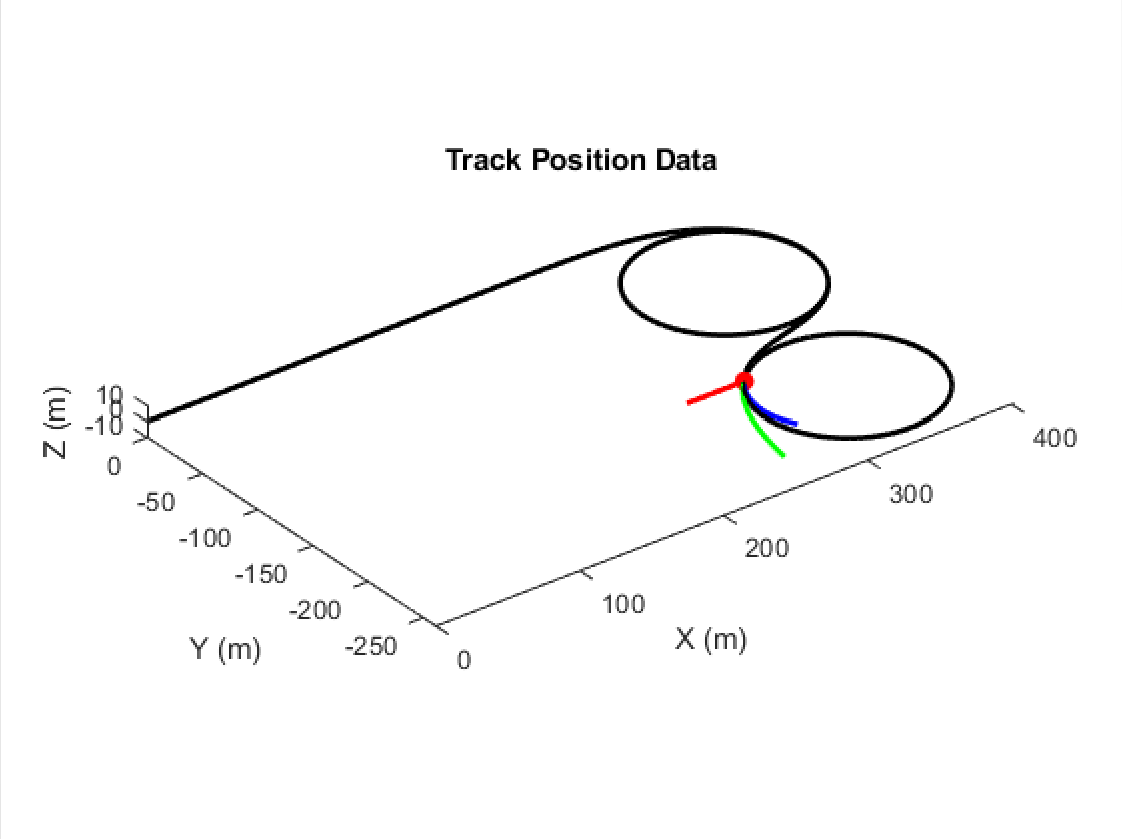
- A method for transferring targeting data between a remote reconnaissance asset and a weapon platform was described.
- The data was utilized to make target motion predictions in the weapon's local frame and calculate a weapon lead.
- In the given application, a Horizontal Constant Turn filter was utilized as the approach is expected to meet threshold performance requirements for ground to ground and air to ground engagements.
- The solution is not complete and could be improved upon via more advanced filtering and prediction methods.

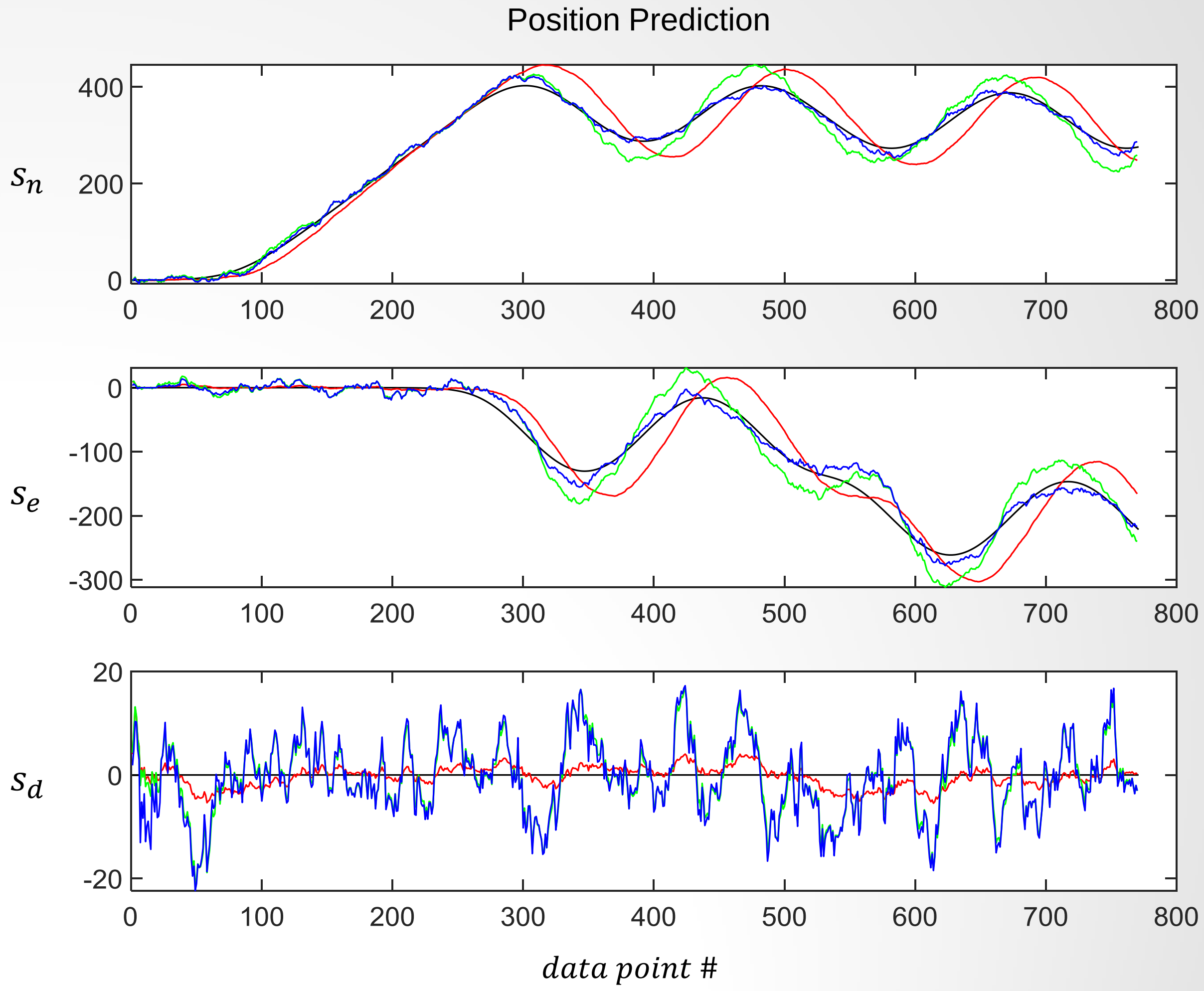
NEXT STEPS

- Exploration of other motion models
- Further refinement of the filtering routines
- Auto tuning feature
- Testing with colored noise
- More advanced routines
- Characterization of relationship between target motion and required prediction technique

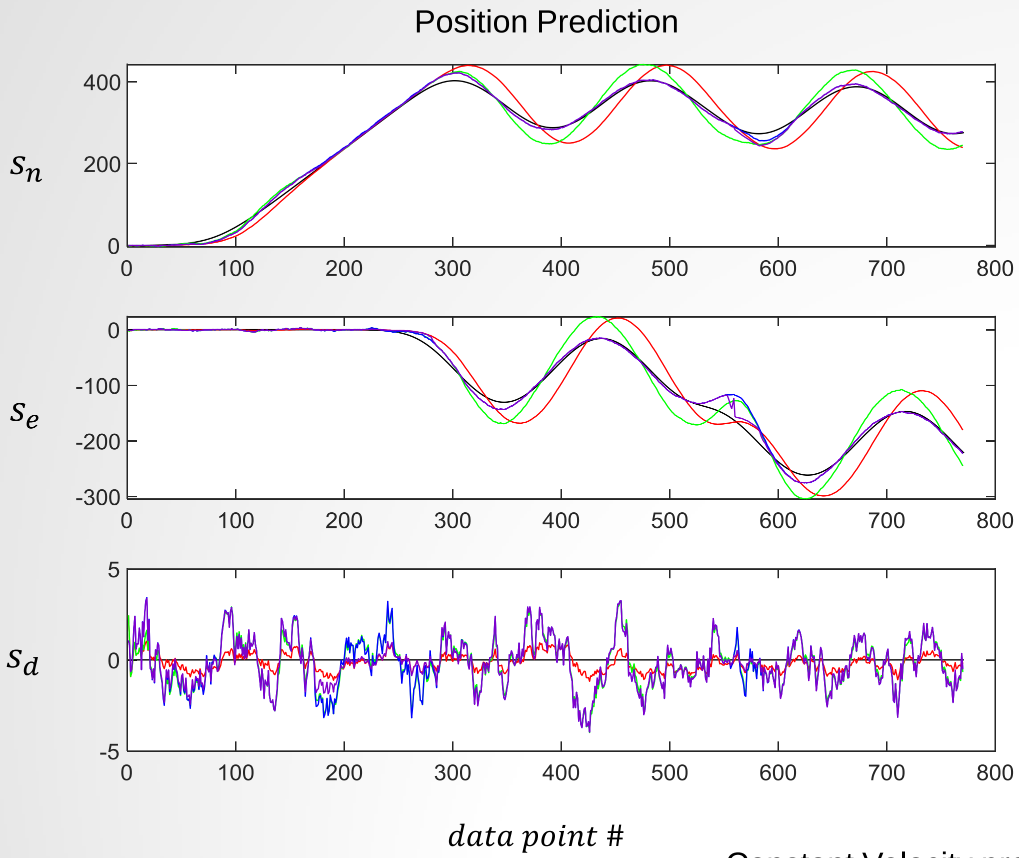


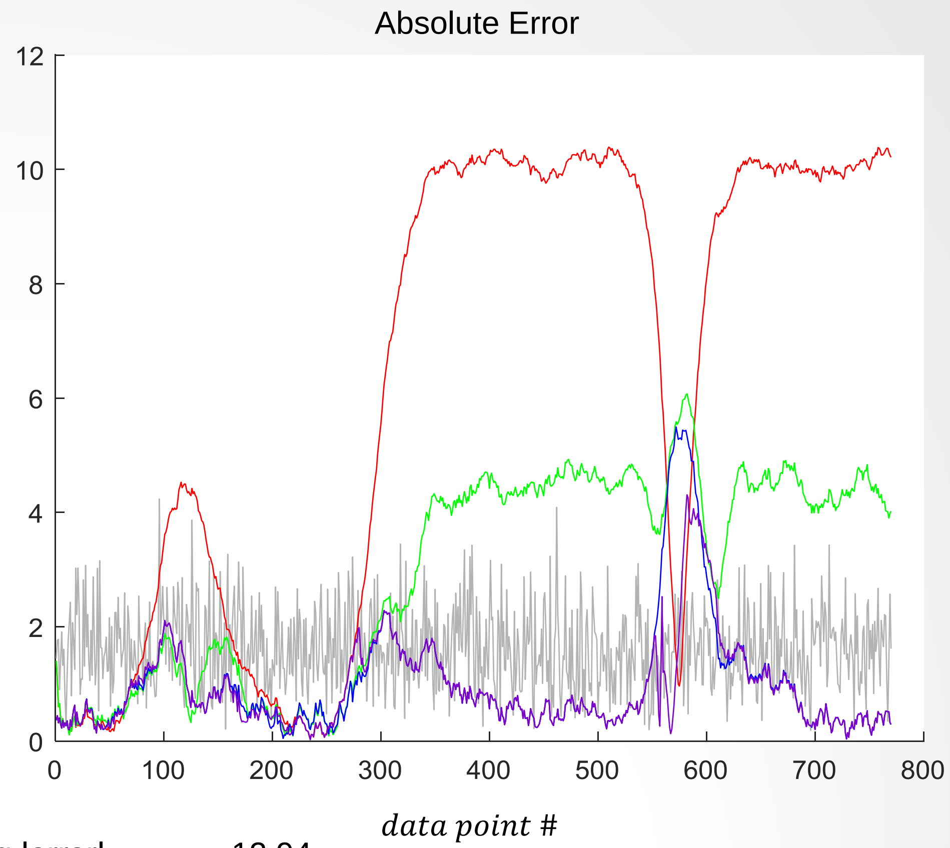
OTHER MOTION MODELS





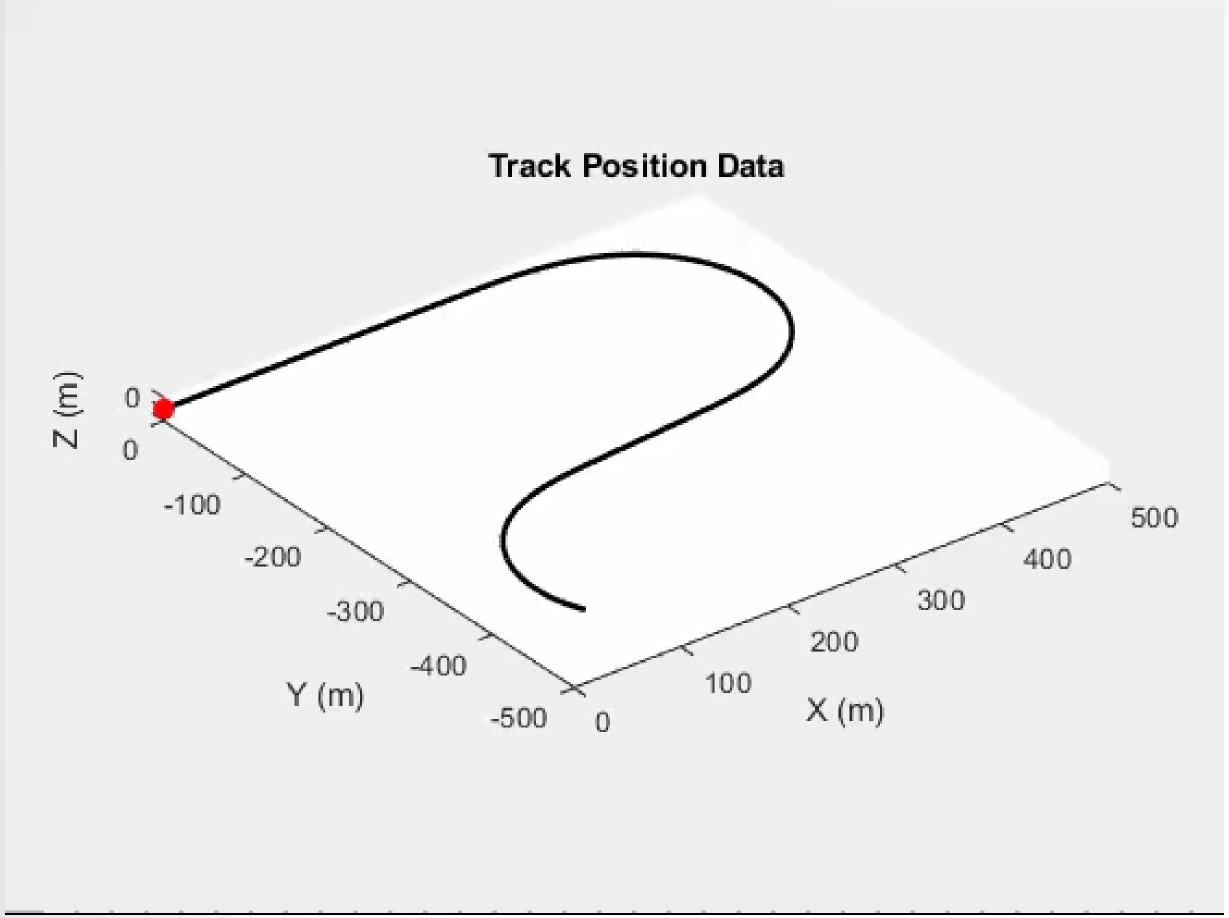
IMM RESULTS

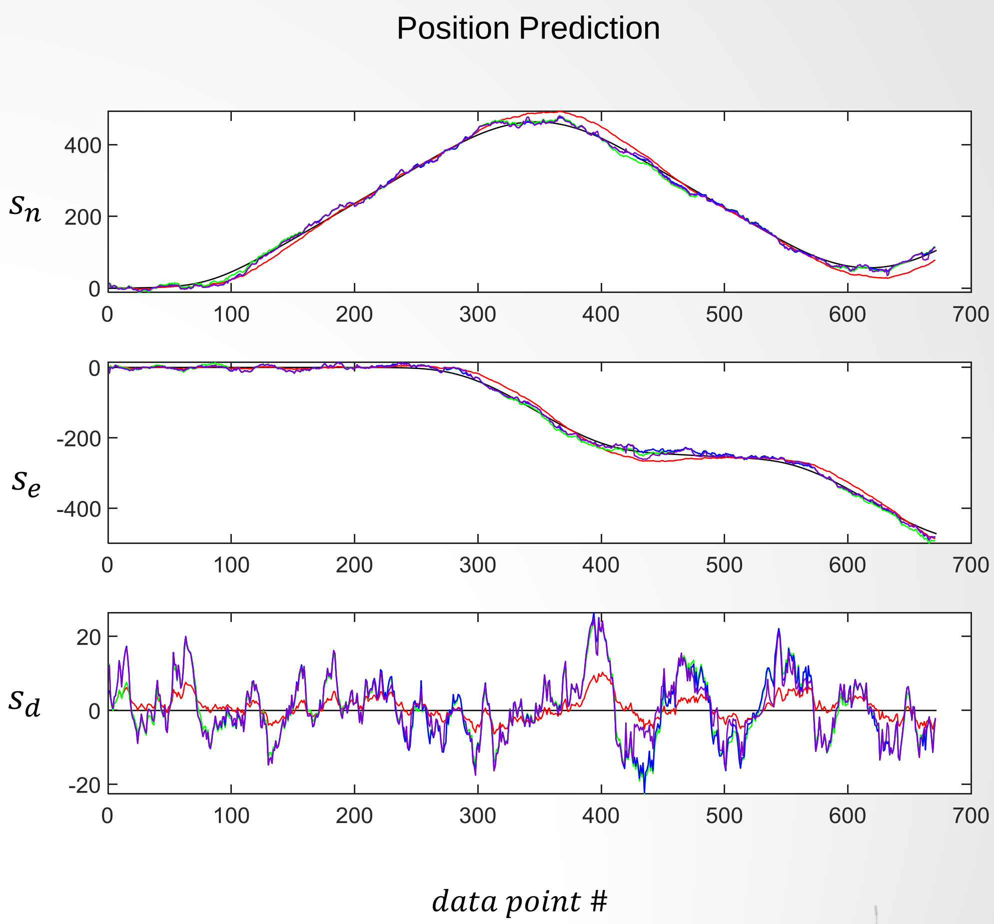




Constant Velocity prediction avg |error|	=	12.94
Constant Acceleration prediction avg |error|	=	8.24
Constant Turn prediction avg |error|	=	8.99
Interacting Multi Model prediction avg |error|	=	8.82

MOVIE SAMPLE





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