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Group & Subsidiary of ISRAEL AEROSPACE INDUSTRIES

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A Self-adjusting Model for Maneuvering Targets

by

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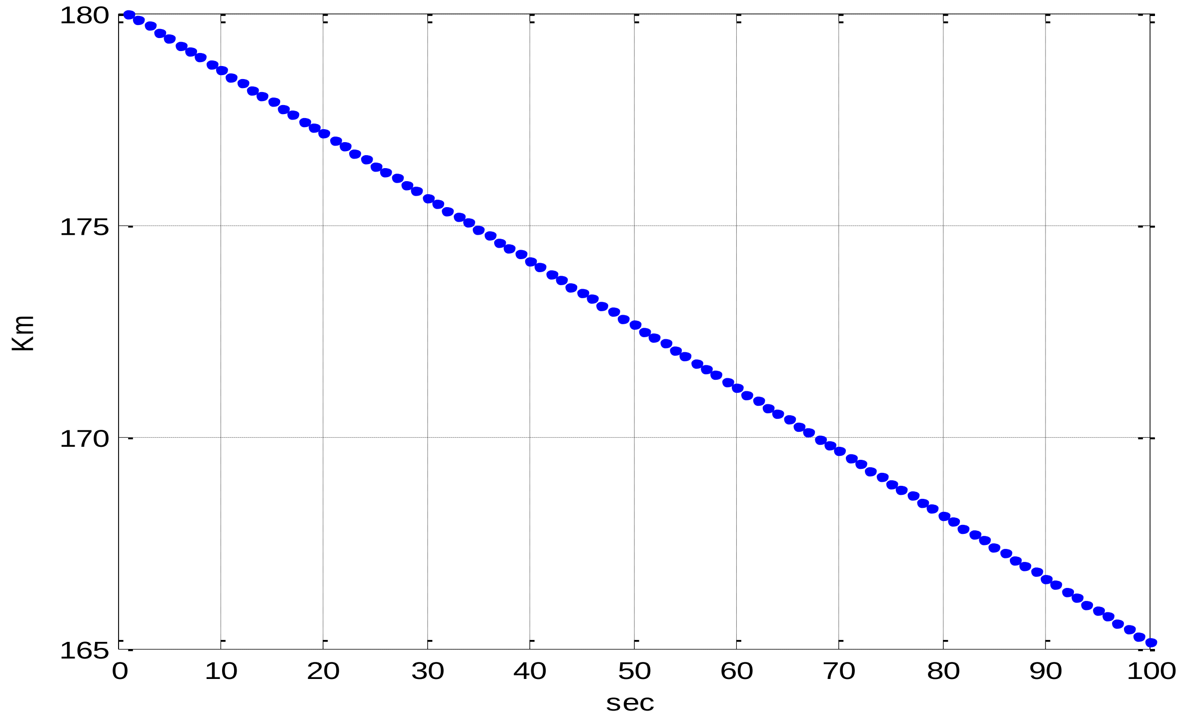
The Primary Task of Tracking

The **primary task** of tracking is prediction and filtering.

Target dynamics model and tracking algorithm work jointly.

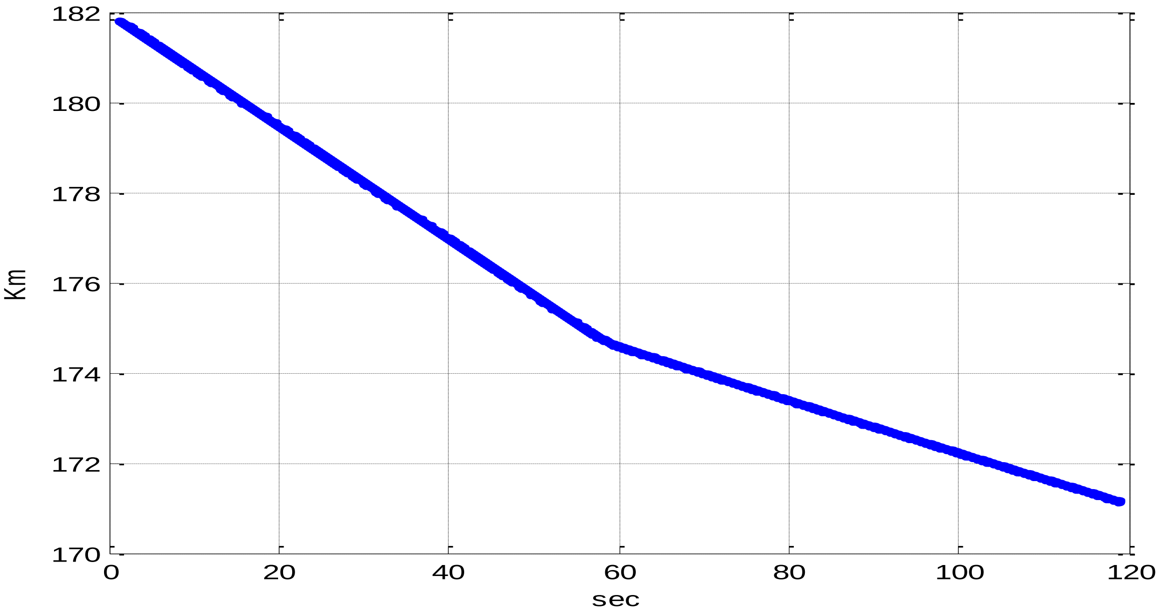
The closer the model matches the dynamics, the better the tracking performance.

Non maneuvering target (straight motion)



$$\mathbf{X}(k+1) = \mathbf{F}(k)\mathbf{X}(\mathrm{k}) + \mathbf{G}(k)\mathbf{W}(k)$$

Maneuvering target



$$\mathbf{X}(k+1)=\mathbf{F}(\mathrm{k})\mathbf{X}(\mathrm{k})+\mathbf{C}(k)\mathbf{U}(k)+\mathbf{G}(k)\mathbf{W}(k)$$

↑

Acceleration (completely unknown)

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Dilemma

The closer the model matches the dynamics, the better the tracking performance

Once a model is chosen, the prediction process is determined and does not reflect the reality in case of dynamics deviations

Major Problem

The **major problem** of tracking is prediction of position of maneuvering targets

Standard solution:

- Detect the target maneuver
- Estimate the strength of the maneuver
- Estimate the duration of the maneuver
- Correct the model

Novel approach to tracking maneuvering targets

Construct the **model** to be **compatible with a broad range of accelerations** which automatically handles both non maneuvering and maneuvering cases

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Approach

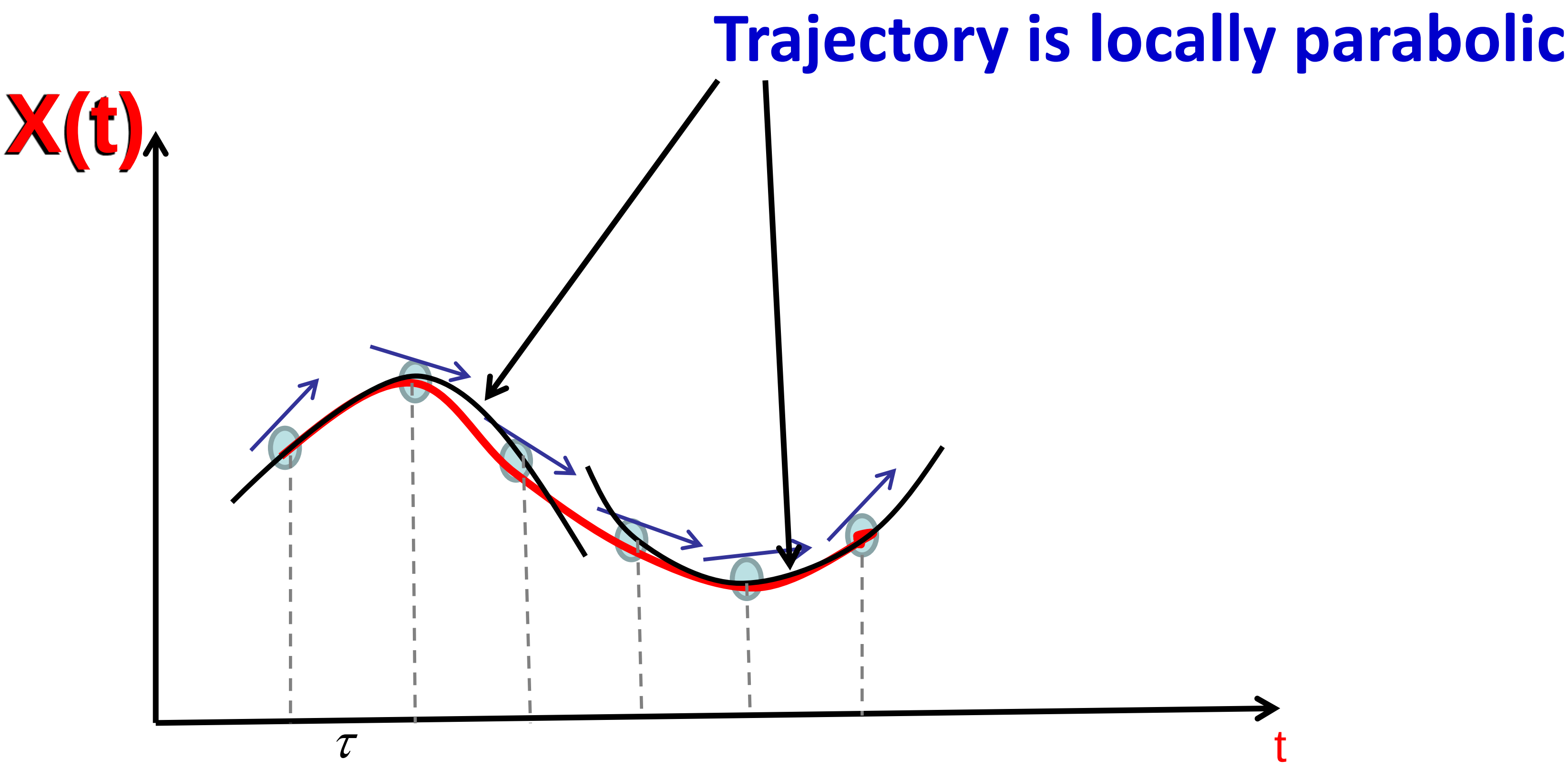
Physical basis:

- Real trajectories are smooth – the first derivatives are continuous

Assumption for our model

- Second derivative for physical systems can be viewed as constant for any three adjacent time samples

Approach (ctd)



Approach (ctd)

$\mathbf{X}(k)$ **is the four component vector -**

$$\mathbf{X}(k)=\begin{vmatrix} x(k) \\ \dot{x}(k) \\ x(k-1) \\ \dot{x}(k-1) \end{vmatrix} \qquad \mathbf{X}(k+1)=\begin{vmatrix} a_1(\tau) & a_2(\tau) & a_3(\tau) & a_4(\tau) \\ b_1(\tau) & b_2(\tau) & b_3(\tau) & b_4(\tau) \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{vmatrix}\begin{vmatrix} x(k) \\ \dot{x}(k) \\ x(k-1) \\ \dot{x}(k-1) \end{vmatrix}$$

Approach (ctd)

If the following equations are satisfied

$$\begin{cases} a_1 + a_3 = 1 \\ -a_1\tau + a_2 - 2a_3\tau + a_4 = 0 \\ a_1\dfrac{\tau}{2} - a_2 + 2a_3\tau - 2a_4 = 0 \end{cases}$$

Then $$x(k+1) = a_1(\tau)x(k) + a_2(\tau)\dot{x}(k) + a_3(\tau)x(k-1) + a_4(\tau)\dot{x}(k-1)$$

Is correct for any acceleration

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Approach (ctd)

Same for the $\dot{x}(k+1)$

If the following equations are satisfied

$$\begin{cases} b_1 + b_3 = 0 \\ -b_1\tau + b_2 - 2b_3\tau + b_4 = 1 \\ b_1\dfrac{\tau}{2} - b_2 + 2b_3\tau - 2b_4 = 0 \end{cases}$$

Then $\dot{x}(k+1) = b_1(\tau)x(k) + b_2(\tau)\dot{x}(k) + b_3(\tau)x(k-1) + b_4(\tau)\dot{x}(k-1)$

Is correct for any acceleration

Approach (ctd)

Deterministic relations

$$\begin{cases} X(1,k+1) = A^T X(1,\mathrm{k}) \\ X(2,k+1) = B^T X(1,\mathrm{k}) \end{cases}$$

$$A = \begin{vmatrix} -1 \\ \tau/2 \\ 1 \\ \tau/2 \end{vmatrix} a_3 + \begin{vmatrix} 0 \\ 3/2 \\ 0 \\ -1/2 \end{vmatrix} \tau + \begin{vmatrix} 1 \\ 0 \\ 0 \\ 0 \end{vmatrix}$$

$$B = \begin{vmatrix} -1 \\ \tau/2 \\ 1 \\ \tau/2 \end{vmatrix} b_3 + \begin{vmatrix} 0 \\ 2 \\ 0 \\ -1 \end{vmatrix}$$

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Approach (ctd)

Prediction accuracies

$$J_A = A^T \mathbf{P} A = \left\| \begin{vmatrix} -1 \\ \tau/2 \\ 1 \\ \tau/2 \end{vmatrix} a_3 + \begin{vmatrix} 0 \\ 3/2 \\ 0 \\ -1/2 \end{vmatrix} \tau + \begin{vmatrix} 1 \\ 0 \\ 0 \\ 0 \end{vmatrix} \right\|^T \mathbf{P} \left\| \begin{vmatrix} -1 \\ \tau/2 \\ 1 \\ \tau/2 \end{vmatrix} a_3 + \begin{vmatrix} 0 \\ 3/2 \\ 0 \\ -1/2 \end{vmatrix} \tau + \begin{vmatrix} 1 \\ 0 \\ 0 \\ 0 \end{vmatrix} \right\|$$

$$J_B = B^T \mathbf{P} B = \left\| \begin{vmatrix} -1 \\ \tau/2 \\ 1 \\ \tau/2 \end{vmatrix} b_3 + \begin{vmatrix} 0 \\ 2 \\ 0 \\ -1 \end{vmatrix} \right\|^T \mathbf{P} \left\| \begin{vmatrix} -1 \\ \tau/2 \\ 1 \\ \tau/2 \end{vmatrix} b_3 + \begin{vmatrix} 0 \\ 2 \\ 0 \\ -1 \end{vmatrix} \right\|$$

Approach (ctd)

Finding the minimum with respect to a_3 , b_3

$$\frac{\partial J}{\partial a_3} = \left\| \begin{vmatrix} -1 \\ \tau/2 \\ 1 \\ \tau/2 \end{vmatrix}^T \mathbf{P} \left\| \begin{vmatrix} -1 \\ \tau/2 \\ 1 \\ \tau/2 \end{vmatrix} a_3 + \begin{vmatrix} 0 \\ 3/2 \\ 0 \\ -1/2 \end{vmatrix} \tau + \begin{vmatrix} 1 \\ 0 \\ 0 \\ 0 \end{vmatrix} \right\| \right\| = 0$$

$$\frac{\partial J}{\partial b_3} = \left\| \begin{vmatrix} -1 \\ \tau/2 \\ 1 \\ \tau/2 \end{vmatrix}^T \mathbf{P} \left\| \begin{vmatrix} -1 \\ \tau/2 \\ 1 \\ \tau/2 \end{vmatrix} b_3 + \begin{vmatrix} 0 \\ 2 \\ 0 \\ -1 \end{vmatrix} \right\| \right\| = 0$$

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Approach (ctd)

Test for minimum

$$\frac{\partial^2 J}{\partial (a_3)^2} = \begin{vmatrix} -1 \\ \tau/2 \\ 1 \\ \tau/2 \end{vmatrix}^T \mathbf{P} \begin{vmatrix} -1 \\ \tau/2 \\ 1 \\ \tau/2 \end{vmatrix} \geq 0 \qquad \frac{\partial^2 J}{\partial (b_3)^2} = \begin{vmatrix} -1 \\ \tau/2 \\ 1 \\ \tau/2 \end{vmatrix}^T \mathbf{P} \begin{vmatrix} -1 \\ \tau/2 \\ 1 \\ \tau/2 \end{vmatrix} \geq 0$$

Simulation Results

Proposed Algorithm Response

Target with maneuver of 6 sec duration

Maximum range acceleration 2g

Constant sample rate 0.5 Hz

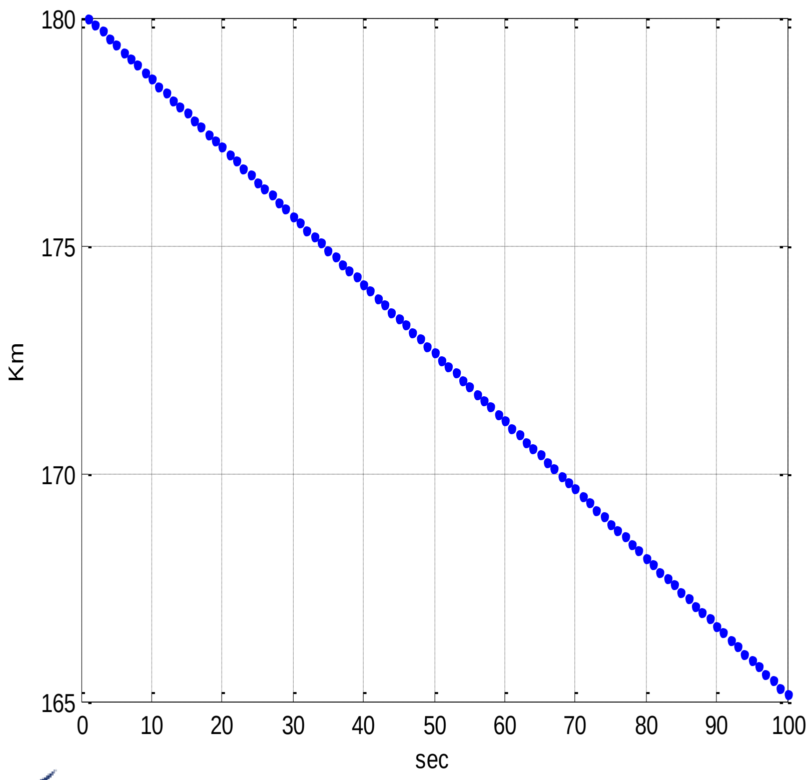
Measurement range accuracy 16 m

Track rms accuracy computed from 100 Monte-Carlo runs

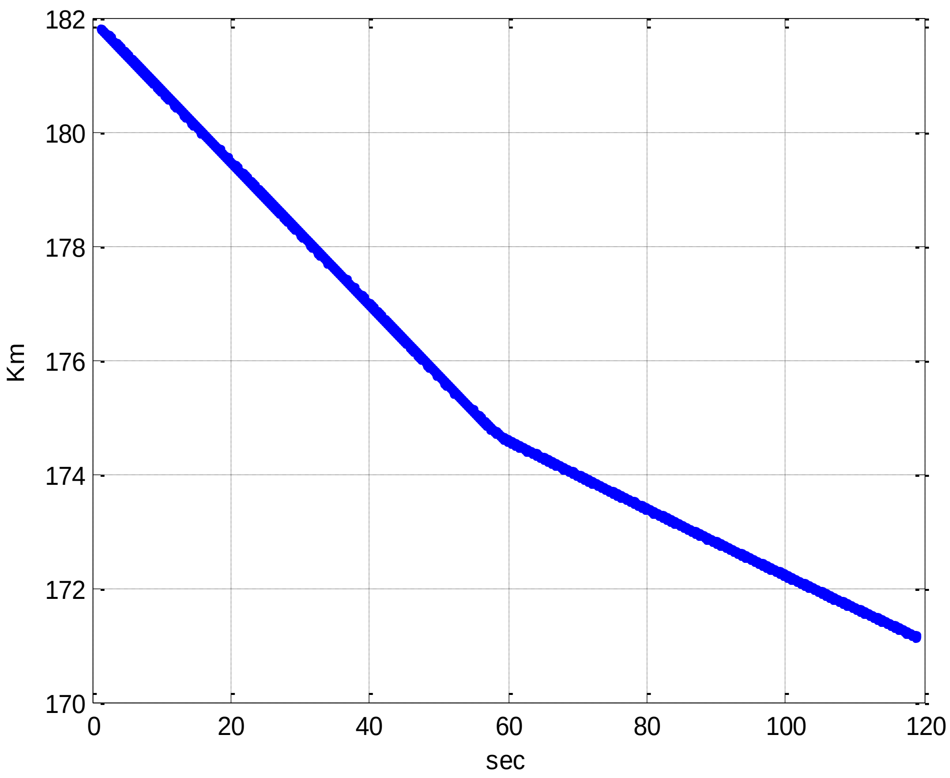
Simulation Results

Proposed Algorithm Response

Non-maneuvering target range



Maneuvering target range



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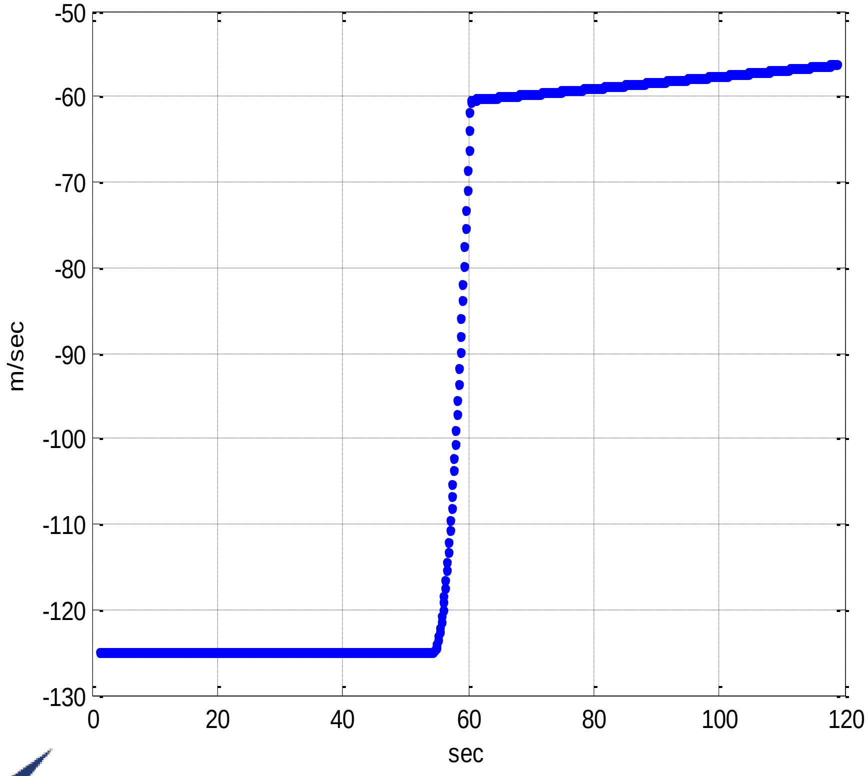
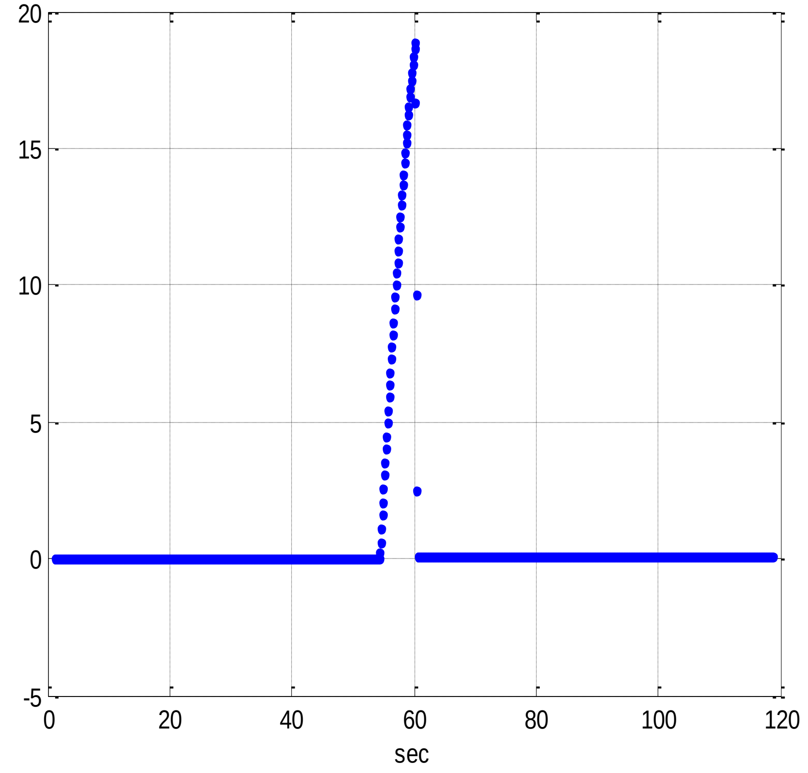
Simulation Results

Proposed Algorithm Response

Maneuvering target range rate



Maneuvering target range acceleration



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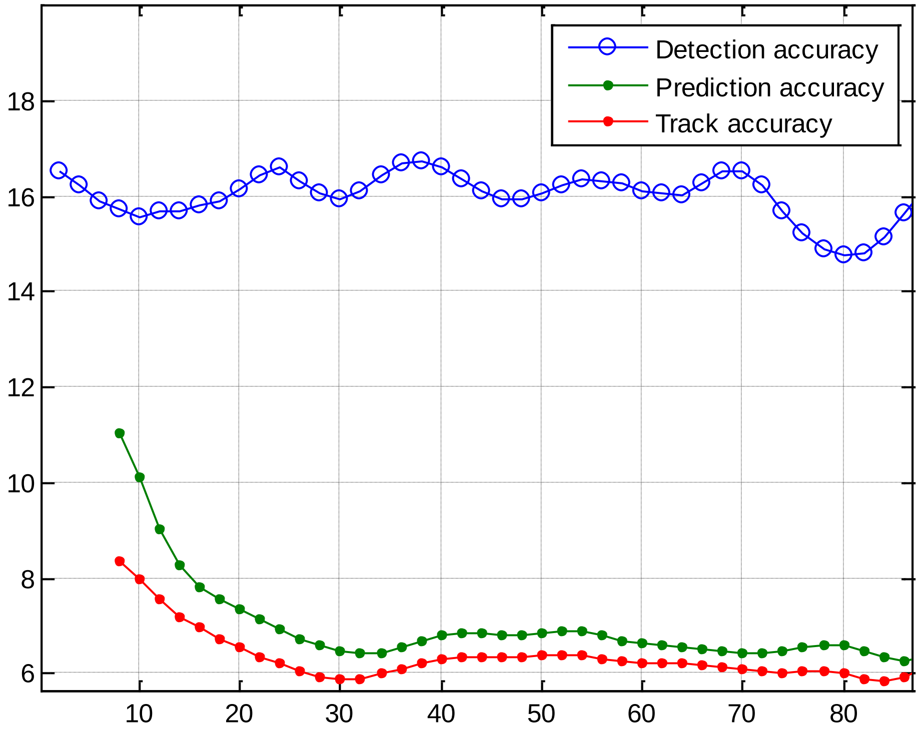
Simulation Results

Proposed Algorithm Response

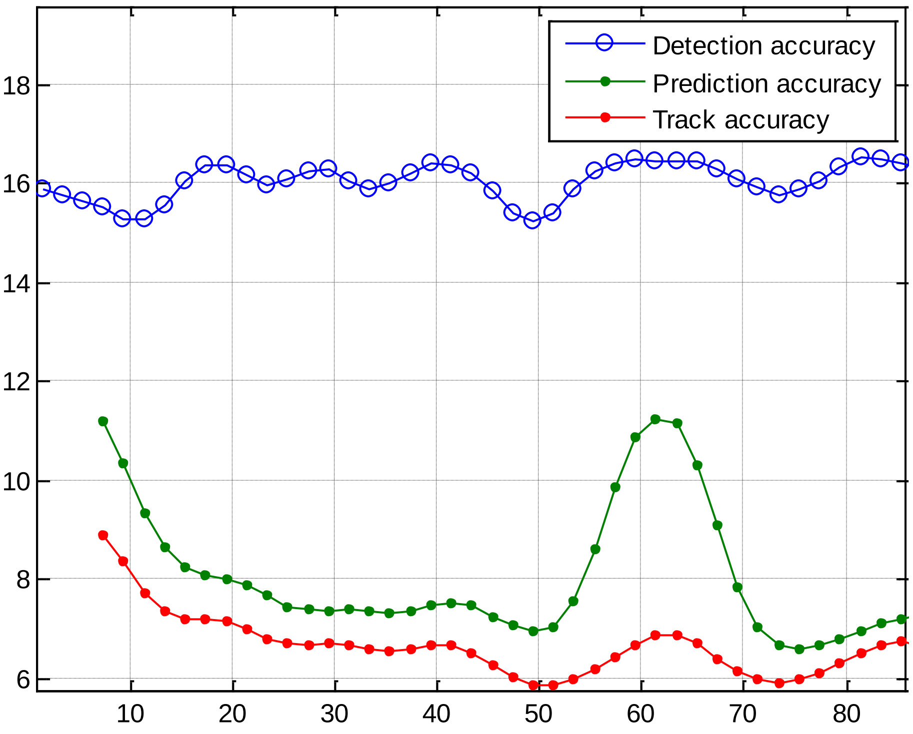
Non-maneuvering target

Range accuracy (m) vs time (sec)



Maneuvering target

Range accuracy (m) vs time (sec)



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How to proceed ?

Possible research directions:

Tracking with 6-component state vector

Target jerk estimation

Dynamic sample rate

Thank you !!