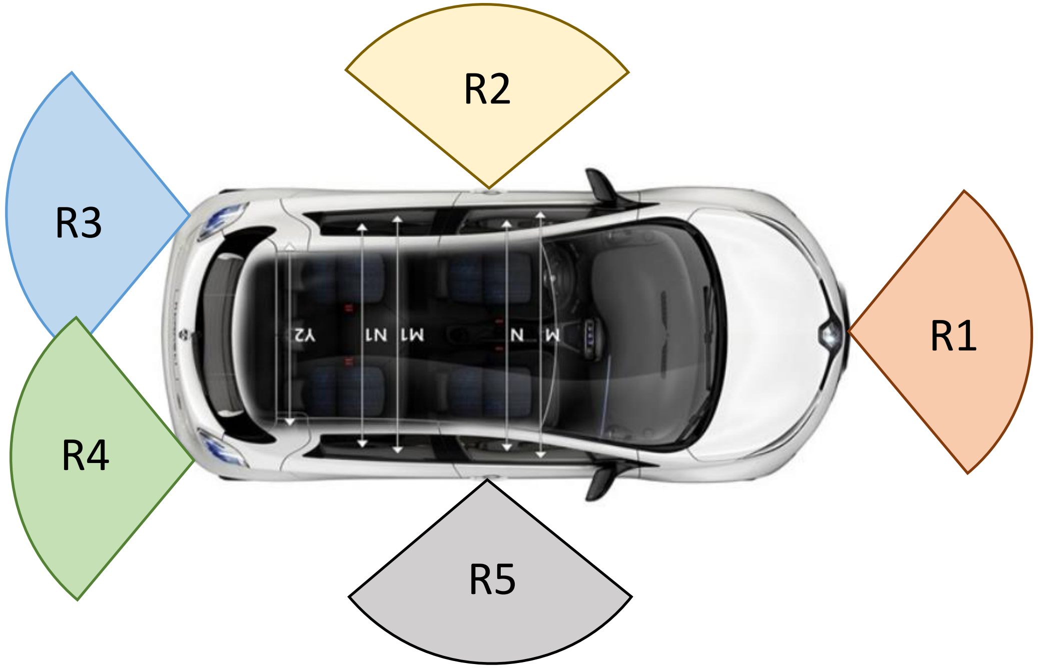
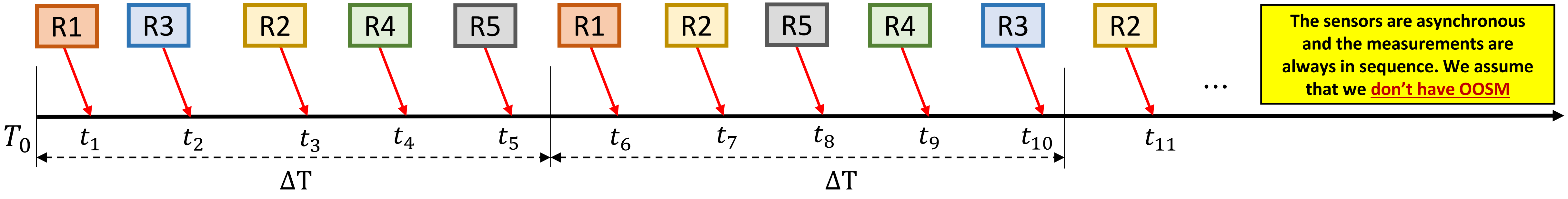
Ego motion estimation by radar sensor : Measurements in cartesian coordinates

Contents

Sensor Setup

Sensor/ Parameter	Mount x coordinate	Mount y coordinate	Mount yaw angle	Max range	cycle
Radar 1	$+3.4$	0	$0°$	250 m	13 Hz
Radar 2	$+2.4$	$+0.8$	$+90°$		
Radar 3	-0.56	$+0.62$	$+180°$		
Radar 4	-0.56	-0.62	$-180°$		
Radar 5	$+2.4$	-0.8	$-90°$		





Inputs Considered

Measuremets from radar *i* at time t in sensor frame

$$\mathrm{Z}_{\mathrm{t}}^{\mathrm{radar_i}} = \{\mathrm{z}_1 \quad \mathrm{z}_2 \quad \cdots \quad \mathrm{z}_{\mathrm{m_k}}\}$$

$$\mathrm{z_i} = \left[px, py, vx, vy, \sigma_{px}, \sigma_{py}, \sigma_{vx}, \sigma_{vy}\right]^{\mathrm{T}}$$

$(px, py) \rightarrow$ measurement position

$(vx, vy) \rightarrow$ measurement relative velocity

$(\sigma_{px}, \sigma_{py}, \sigma_{vx}, \sigma_{vy}) \rightarrow$ noise std

Radar *i* mount info w.r.t rear wheel base centre

installation coordinates $\rightarrow \left(\mathrm{x}_{\mathrm{m}}^{\mathrm{radar_i}} \quad \mathrm{y}_{\mathrm{m}}^{\mathrm{radar_i}}\right)$

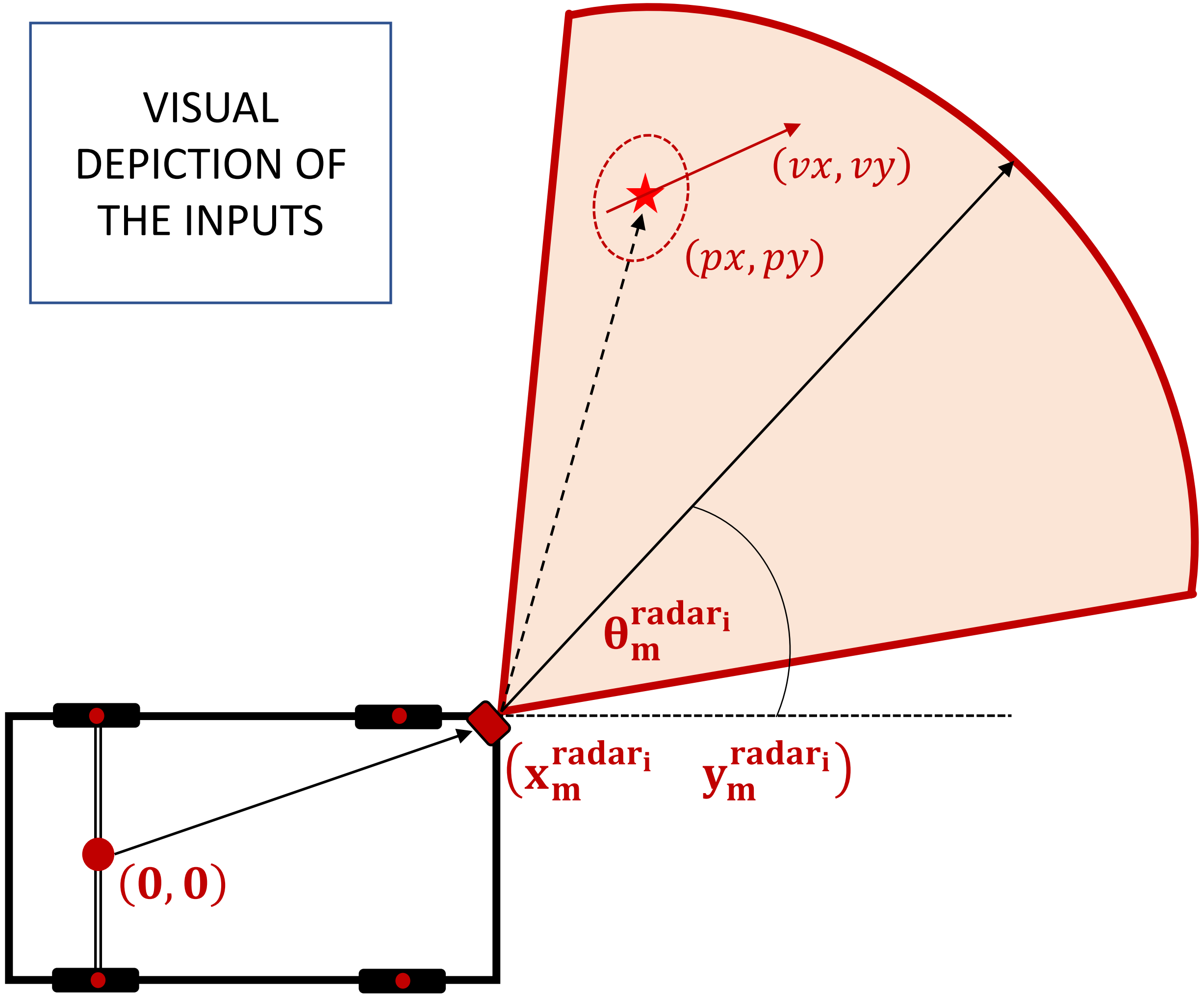
mounting angle $\rightarrow \theta_{\mathrm{m}}^{\mathrm{radar_i}}$

Ego vehicle odometry at time t w.r.t rear wheel base centre (optional)

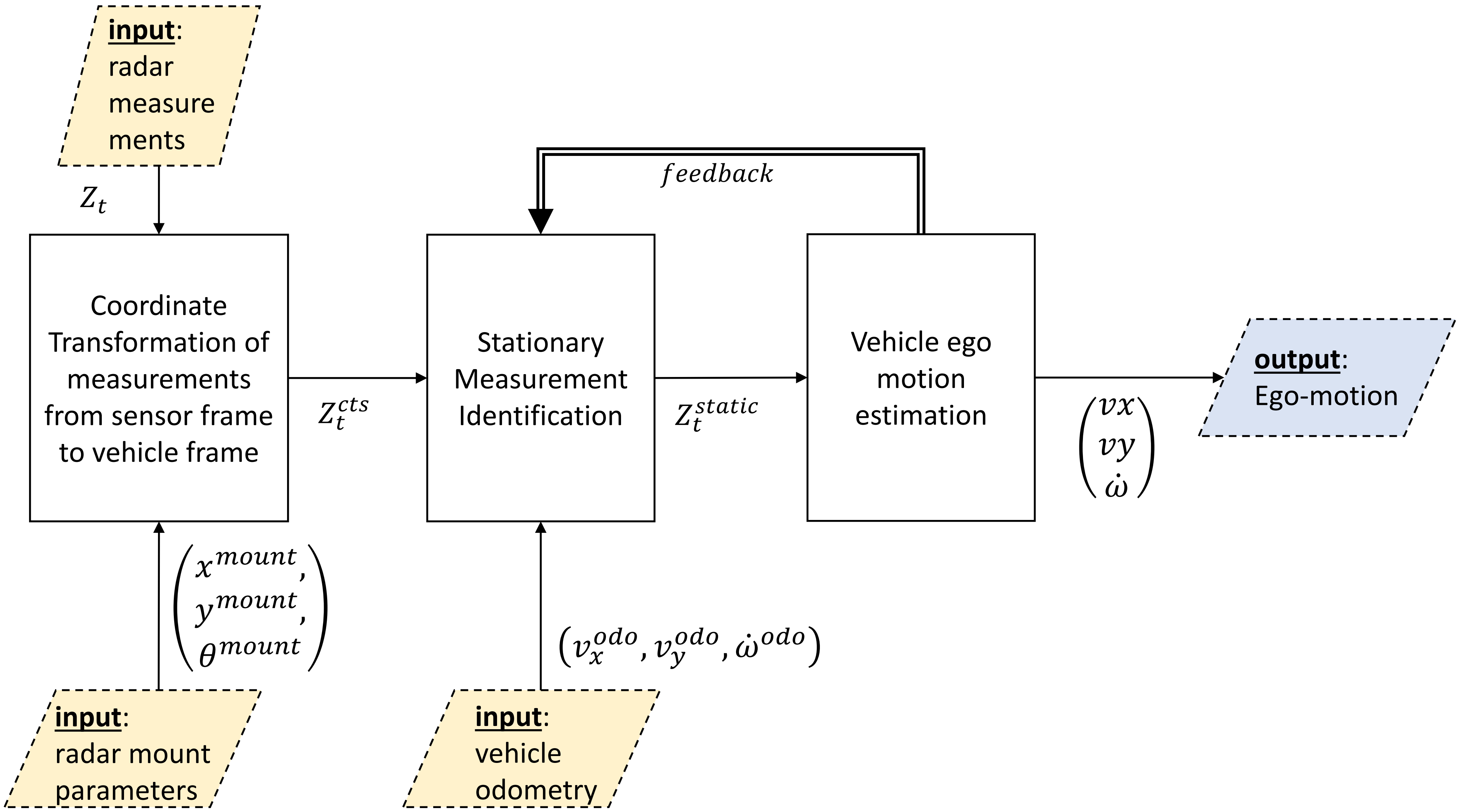
$\mathrm{v}_{\mathrm{t}}^{\mathrm{x}} \rightarrow$ lateral velocity

$\dot{\omega}_t \rightarrow$ yaw rate

VISUAL DEPICTION OF THE INPUTS



High Level Architecture



Coordinate Transformation

input:
Radar mount parameters

$$\begin{pmatrix} t_x^{mount}, \\ t_y^{mount}, \\ \theta^{mount} \end{pmatrix}$$

Construct Rotation matrix and Translation vector

$$R = \begin{bmatrix} \cos(\theta^{mount}) & -\sin(\theta^{mount}) \\ \sin(\theta^{mount}) & \cos(\theta^{mount}) \end{bmatrix} \quad T = \begin{bmatrix} t_x^{mount} \\ t_y^{mount} \end{bmatrix}$$

R, T

input:
radar measure ments

$$\begin{pmatrix} p_x \\ p_y \\ v_x \\ v_x \end{pmatrix}$$

Measurement vector transformation

$$\begin{bmatrix} p_x^{cts} \\ p_y^{cts} \end{bmatrix} = R * \begin{bmatrix} p_x \\ p_y \end{bmatrix} + T$$

$$\begin{bmatrix} v_x^{cts} \\ v_y^{cts} \end{bmatrix} = R * \begin{bmatrix} v_x \\ v_y \end{bmatrix}$$

$$X = \left(p_x^{cts}, p_y^{cts}, v_x^{cts}, v_y^{cts}\right)$$

input:
radar measure ments

$$\begin{pmatrix} \sigma_{px} \\ \sigma_{py} \\ \sigma_{vx} \\ \sigma_{vy} \end{pmatrix}$$

R

Measurement covariance transformation

$$\Sigma_p = \begin{bmatrix} \sigma_{px}^2 & 0 \\ 0 & \sigma_{px}^2 \end{bmatrix}$$

$$\Sigma_v = \begin{bmatrix} \sigma_{vx}^2 & 0 \\ 0 & \sigma_{vx}^2 \end{bmatrix}$$

$$\Sigma_p^{cts} = R \Sigma_p R^T$$

$$\Sigma_v^{cts} = R \Sigma_v R^T$$

$$\Sigma_{meas}^{cts} = \begin{bmatrix} \Sigma_p^{cts} & O \\ O & \Sigma_v^{cts} \end{bmatrix}$$

Σ_{meas}^{cts}

output: radar meas in the vehicle frame : $\boldsymbol{\Sigma_{meas}^{cts}}, \mathbf{X}$

Stationary Measurement Identification

input: Radar meas positions

(r_x^i, r_y^i) $\Sigma_{\mathrm{p}}^{\mathrm{cts}}$

input: Predicted ego motion

Σ_X $(v_x^{ego\_pred}, v_y^{ego\_pred}, \dot{\omega}^{ego\_pred})$

for each of the locations corresponding to radar measurements compute the predicted velocity as if it was stationary

$$\begin{bmatrix} \mathrm{v_x^{i\_pred}} \\ \mathrm{v_y^{i\_pred}} \end{bmatrix} = -\begin{bmatrix} 1 & 0 & -\mathrm{r_y^i} \\ 0 & 1 & \mathrm{r_x^i} \end{bmatrix} \begin{bmatrix} \mathrm{v_x^{ego\_pred}} \\ \mathrm{v_y^{ego\_pred}} \\ \dot{\omega}^{\mathrm{ego\_pred}} \end{bmatrix}$$

$\Sigma_X, \Sigma_{\mathrm{p}}^{\mathrm{cts}}$

Compute predicted measurement covariance by sigma point approximation

$v_x^{i\_pred}, v_y^{i\_pred}$

Σ_v^{pred}

input: Radar meas velocity

(v_x^i, v_y^i) Σ_v^{cts}

Compare the predicted range rate with the measurement range rate

$$\mathrm{error^i} = \sqrt{V^T \Sigma^{-1} V}$$

$$V = \begin{pmatrix} v_x^{i\_pred} - v_x^i \\ v_y^{i\_pred} - v_y^i \end{pmatrix} \quad \Sigma = \Sigma_v^{cts} + \Sigma_v^{pred}$$

$error^i$

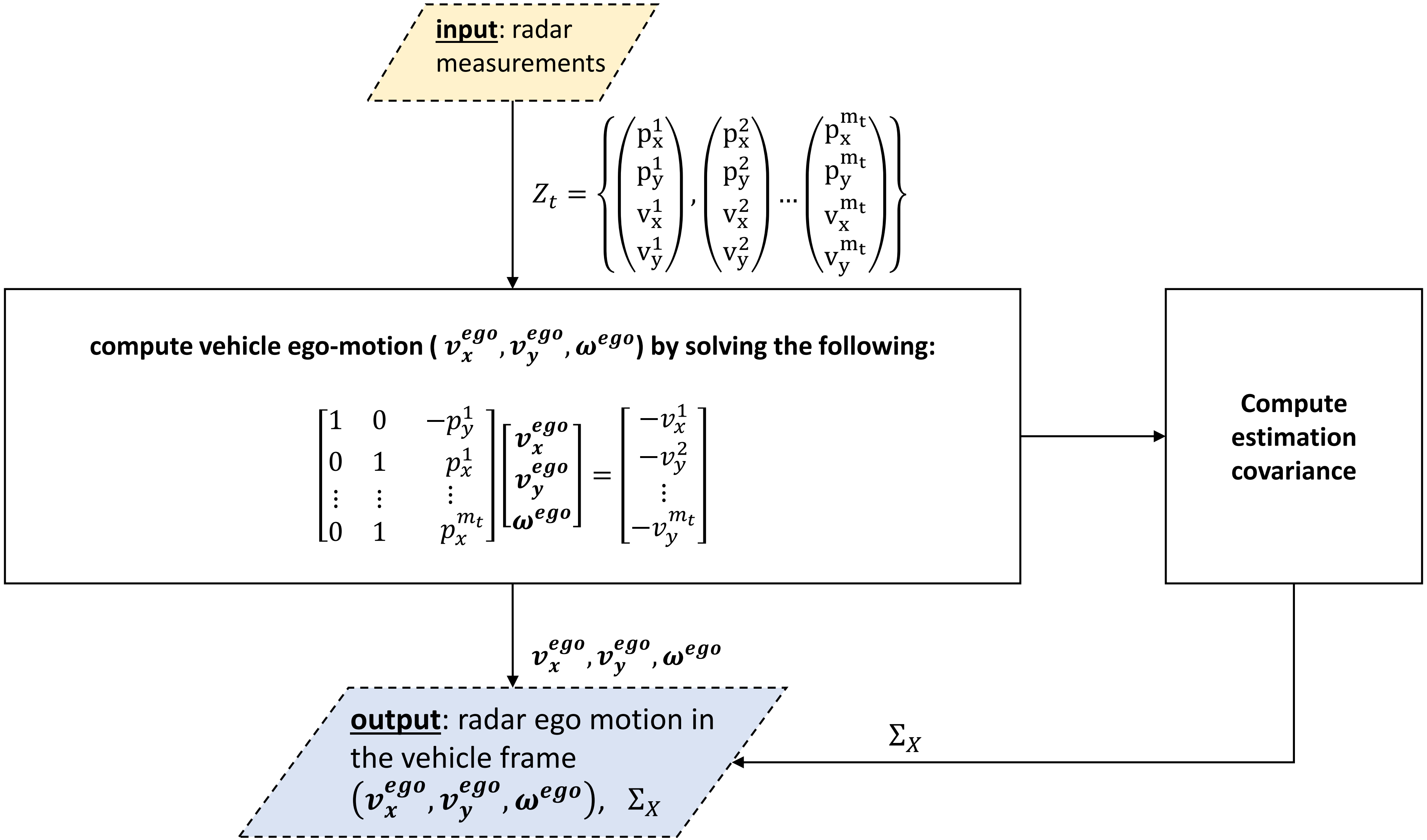
Stationary measurement selection

if $\mathrm{error^i} \leq threshold$,
then $\mathrm{Z^i}$ is considered stationary

$Z_{stationary}^i$

output: preliminary list of stationary measurements

Vehicle Ego-Motion Estimation



Present Challenges and Limitations

- The results clearly indicate that a time varying bias exist in the output. The probable cause and the bias compensation steps are not yet explored

Alternative methods

- Other alternative methods exist such as maintaining a history of clutter free stationary measurements, followed by spatially and temporally aligning the measurements and finally solving a least squares problem to estimate the ego-motion.

- Utilizing the positions only by ICP, some variant of ICP (Iterative closest point algorithm), NDT, or some graph optimization based techniques.

- The above techniques are not explored in this project since the radar measurements are quite sparse and the above techniques are computationally expensive

Use-cases

- Short-term odometry from radar ego-motion
- Radar only perception for AD/ADAS

etc …

References

1. *https://www.researchgate.net/publication/269332200_Instantaneous_ego-motion_estimation_using_Doppler_radar*

2. *Probabilistic ego-motion estimation using multiple automotive radar sensors*

The End