Università degli Studi di Padova – Dipartimento di Ingegneria Industriale

Corso di Laurea in Ingegneria Meccanica

Relazione per la prova finale «Traction Control System Design for an All-Wheel-Drive Electric Vehicle»

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TRACTION CONTROL SYSTEM

WHAT?

Avoiding excessive slip at each wheel.

WHY?

- Providing better steering control and stability of the vehicle;
- Enhancing performance of the vehicle by allowing maximum traction.

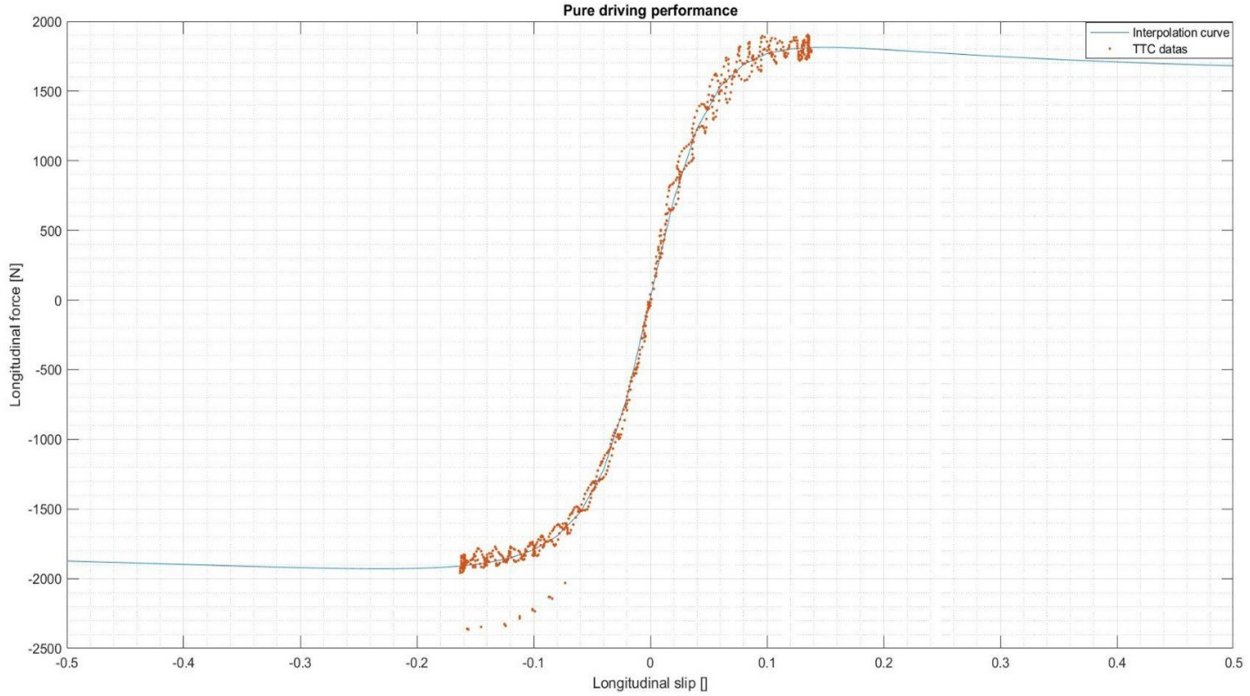
HOW?

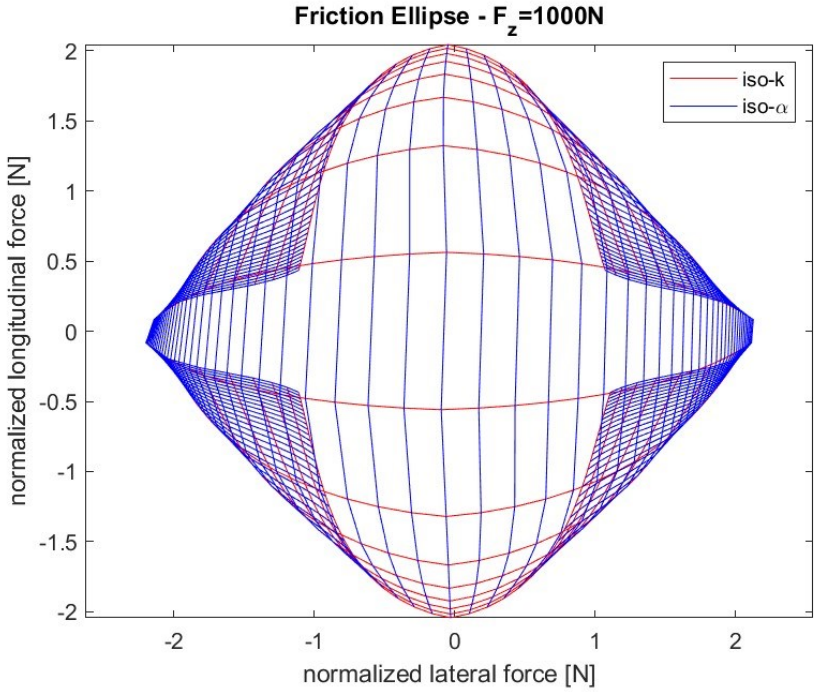
By reducing the provided torque whenever the longitudinal slip exceeds a suitable upper threshold.

INTRODUCTION: TIRE LONGITUDINAL SLIP & FORCE

LONGITUDINAL SLIP: $k = \frac{V_r - V_c}{V_c} = \frac{\omega R_e - V_c}{V_c}$ → desired working range: $k \in [-0.1;\ 0.1]$

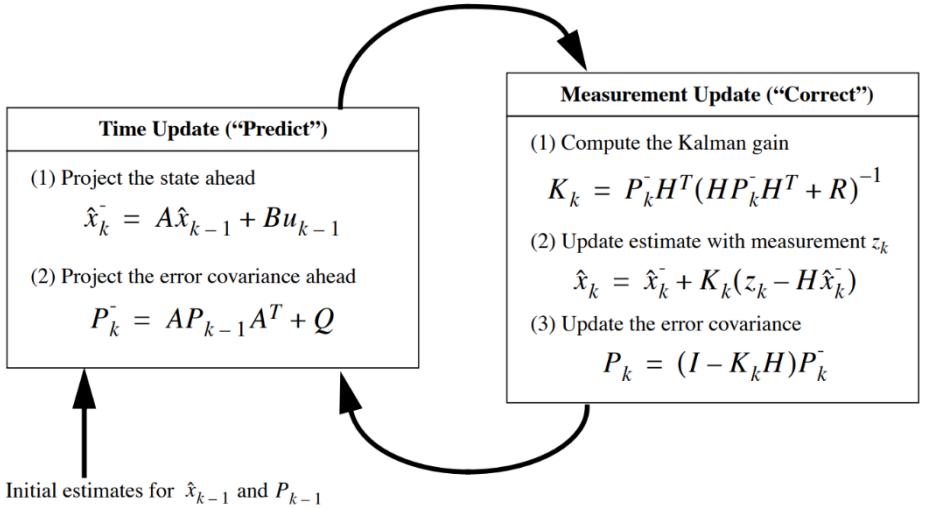
Fitting experimental data on Hoosier 18x7.5-10 R25B provided to us by Formula SAE Tire Test Consortium (FSAE TTC) and Calspan Tire Research Facility (TIRF):

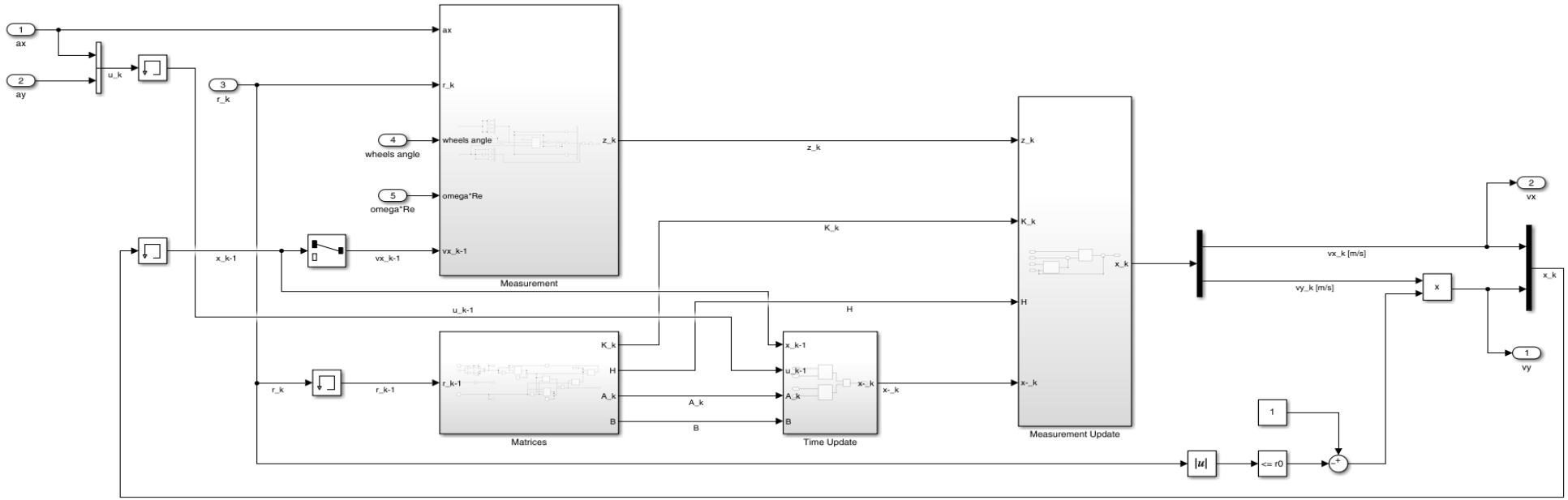




THE MODEL: VEHICLE VELOCITY ESTIMATION

Vehicle velocity estimation trough a **kinematic model-based Kalman filter**





THE MODEL: VEHICLE VELOCITY ESTIMATION

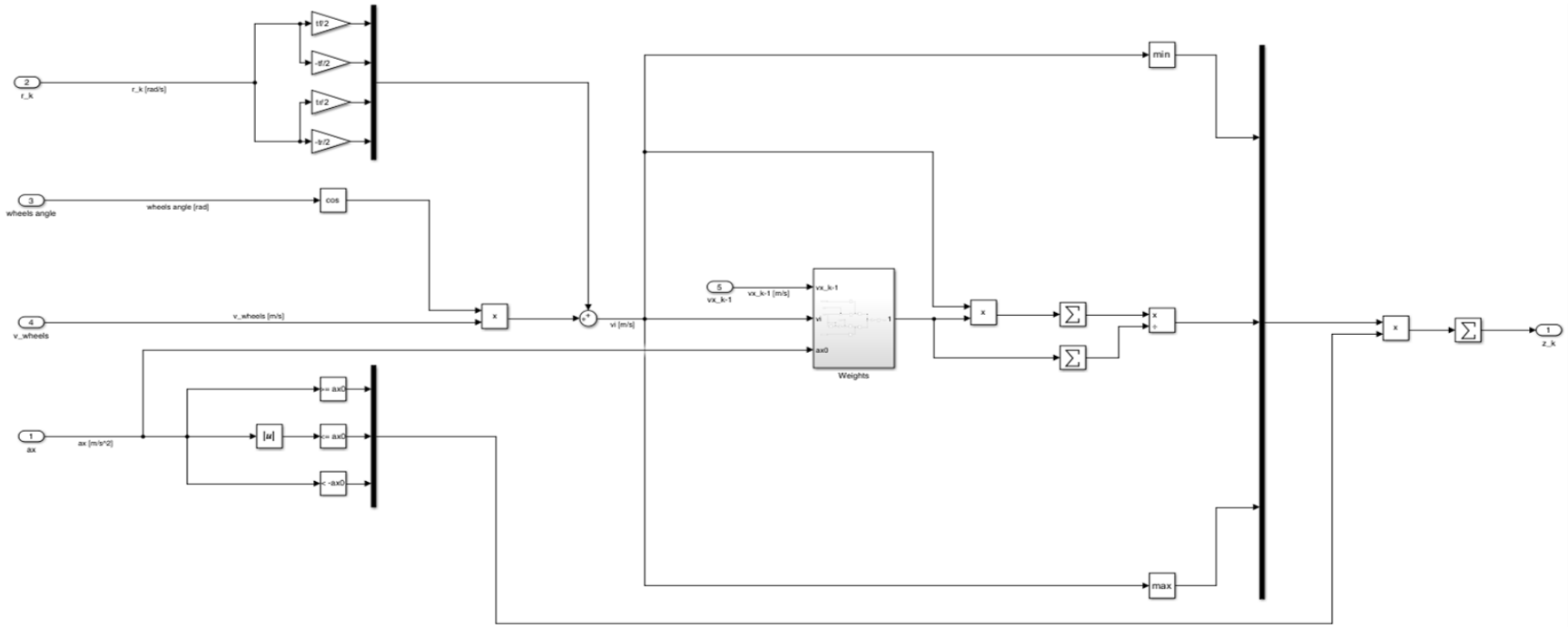
Kinematic model equation and parameters:

$$\begin{bmatrix} \dot{v}_x \\ \dot{v}_y \end{bmatrix} = \begin{bmatrix} 0 & r \\ -r & 0 \end{bmatrix} \begin{bmatrix} v_x \\ v_y \end{bmatrix} + \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} a_x \\ a_y \end{bmatrix} \rightarrow \begin{bmatrix} \hat{v}_{x_k}^- \\ \hat{v}_{y_k}^- \end{bmatrix} = \begin{bmatrix} 0 & r_{k-1}T \\ -r_{k-1}T & 0 \end{bmatrix} \begin{bmatrix} v_{x_{k-1}} \\ v_{y_{k-1}} \end{bmatrix} + \begin{bmatrix} T & 0 \\ 0 & T \end{bmatrix} \begin{bmatrix} a_{x_{k-1}} \\ a_{y_{k-1}} \end{bmatrix}$$

$$\boldsymbol{x} = \begin{bmatrix} v_x \\ v_y \end{bmatrix}; \quad \mathbf{A} = \begin{bmatrix} 0 & r_{k-1}T \\ -r_{k-1}T & 0 \end{bmatrix}; \quad \mathbf{B} = \begin{bmatrix} T & 0 \\ 0 & T \end{bmatrix}$$

Measurement equation and parameters:

$$z = \mathbf{H}\boldsymbol{x} = v_x;$$
$$\mathbf{H} = [1 \quad 0]$$

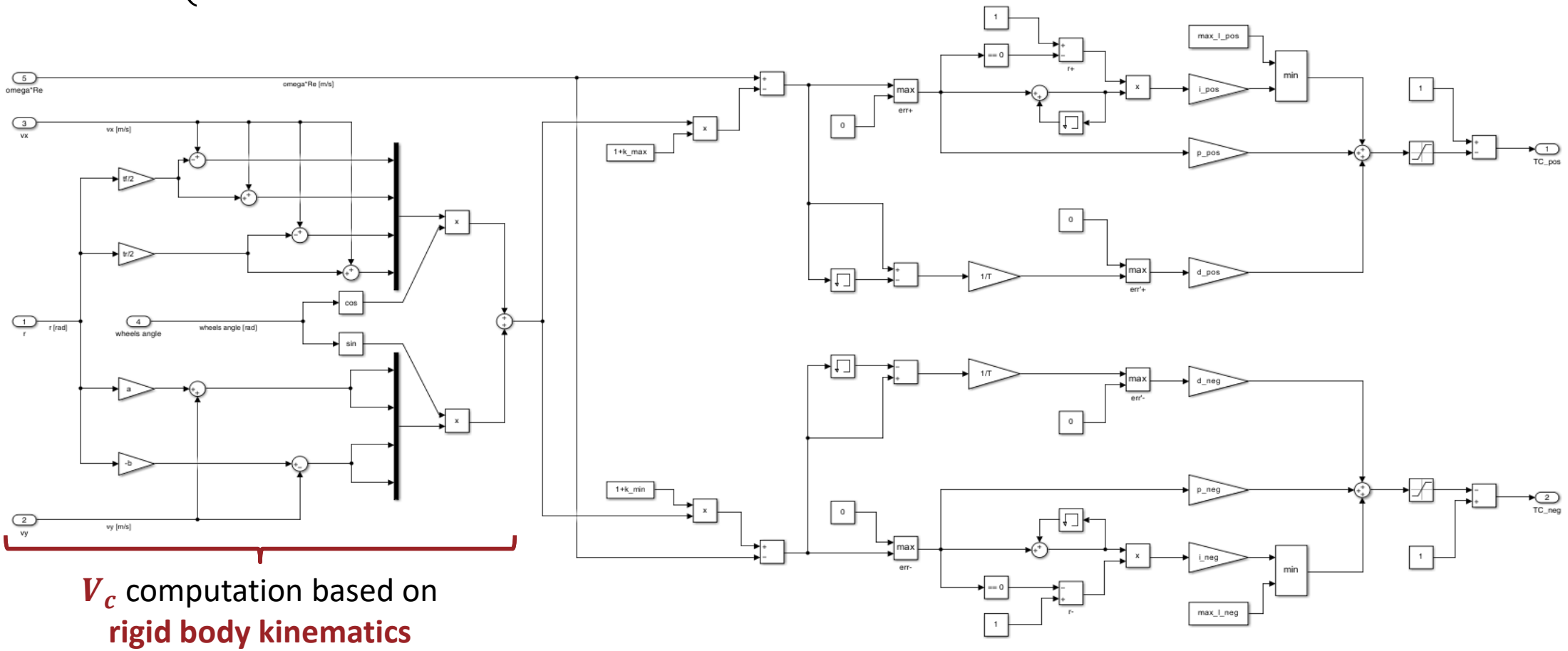


THE MODEL: PID CONTROLLER

To avoid:

$$\begin{cases} \frac{V_r - V_c}{V_c} > k_{max} \Rightarrow \frac{V_r - (1+k_{max})V_c}{V_c} > 0 \\ \frac{V_r - V_c}{V_c} < k_{min} \Rightarrow \frac{(1+k_{min})V_c - V_r}{V_c} > 0 \end{cases}$$

$$\epsilon^+ = \min(0, \omega R_e - (1 + k_{max})V_c)$$
$$\epsilon^- = \min(0, (1 + k_{min})V_c - \omega R_e)$$



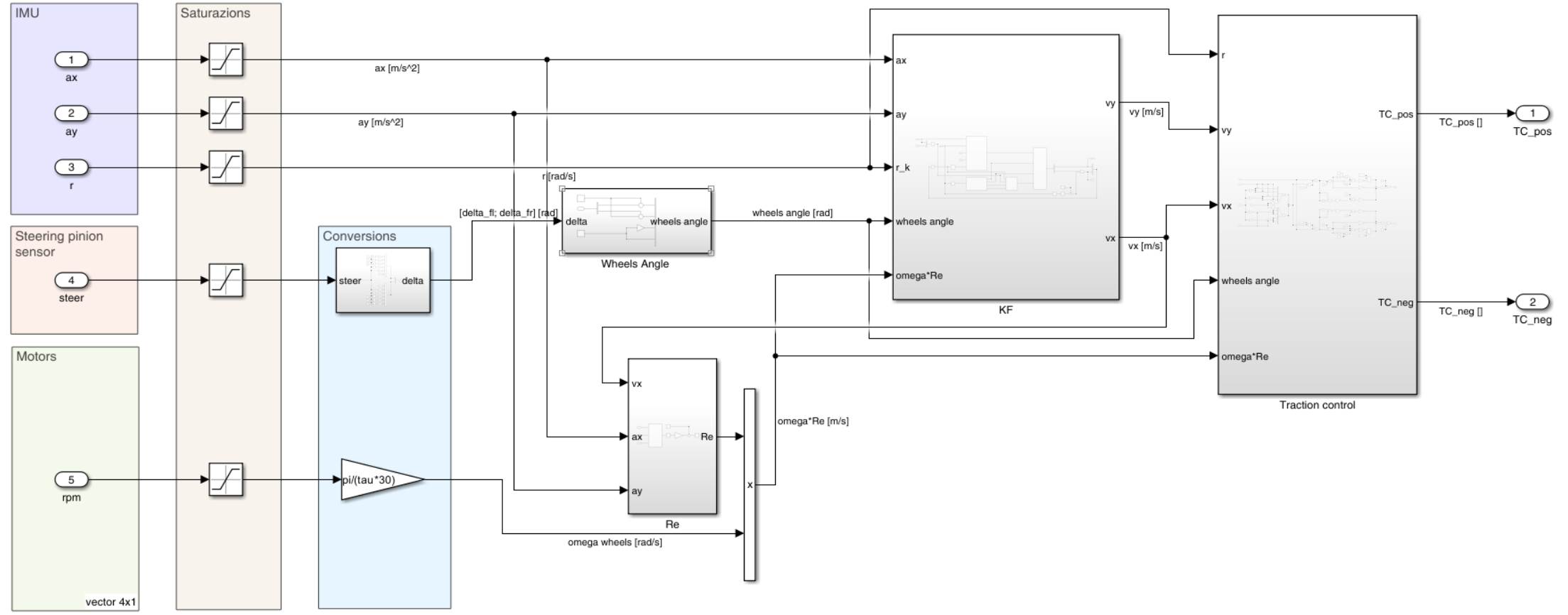
V_c computation based on **rigid body kinematics**

THE MODEL: OVERVIEW

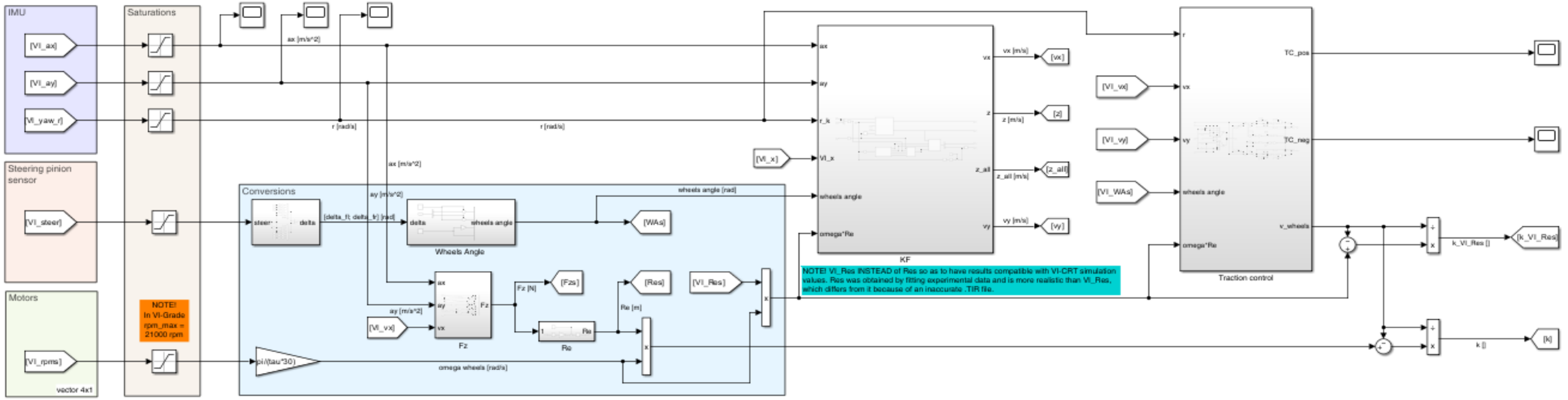
Inputs saturation and **initial computations**

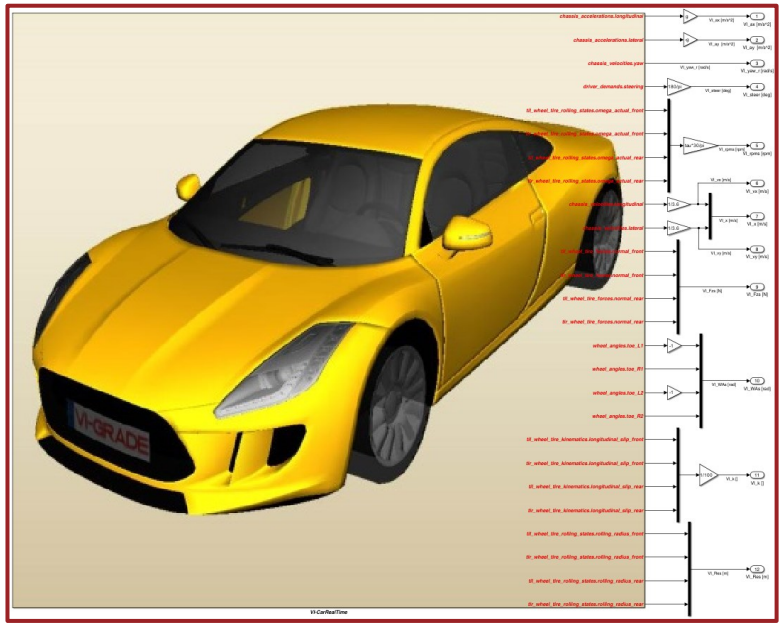
Vehicle velocity estimation trough **KF**

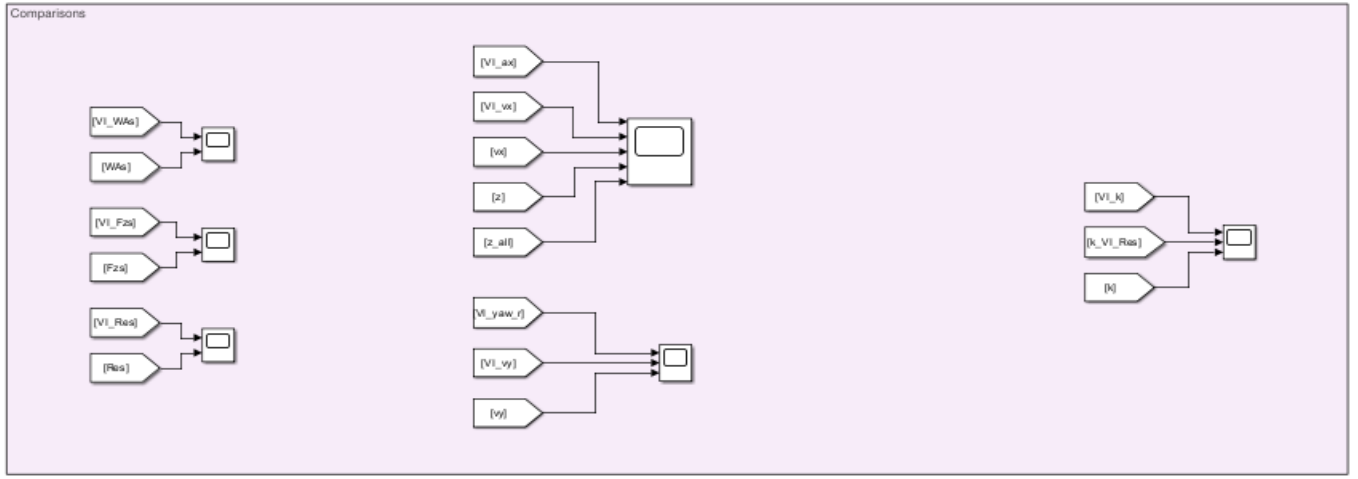
PID longitudinal slip **controller**



VALIDATION & RESULTS: VI-CARREALTIME

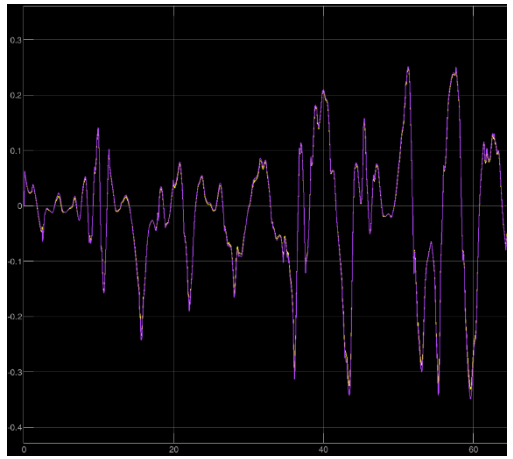




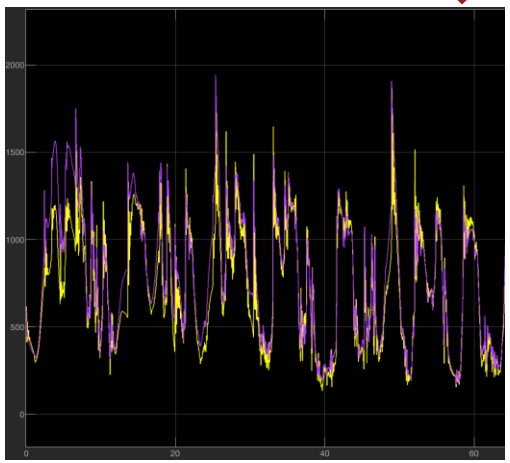


VALIDATION & RESULTS: VI-CARREALTIME

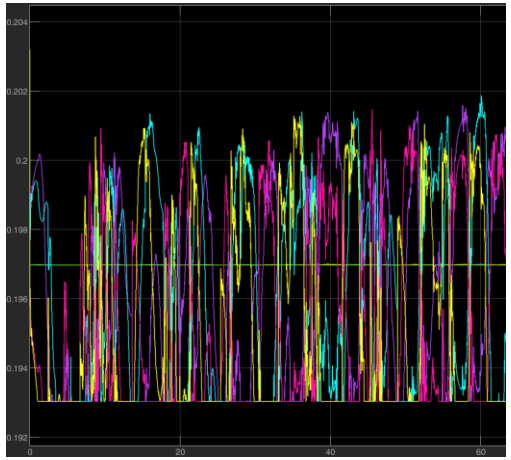
Wheels angles [rad]: ✓



Normal load F_z [N]: ✓

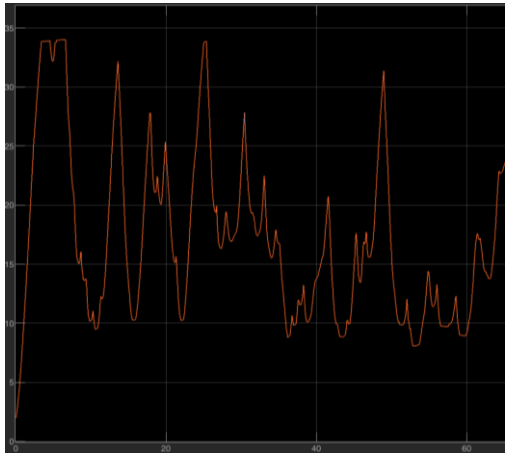


Effective rolling radius R_e [m]: ✗

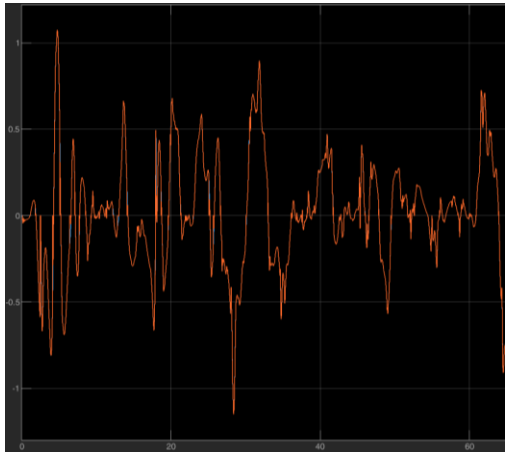


Kinematic model design: ✓

$\mathbf{v}_x$[m/s]

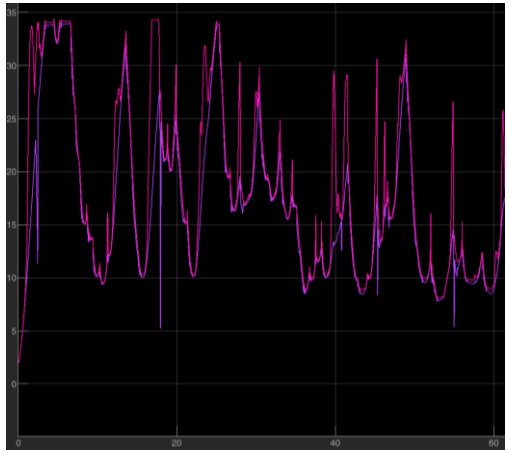


$\mathbf{v}_y$ [m/s]

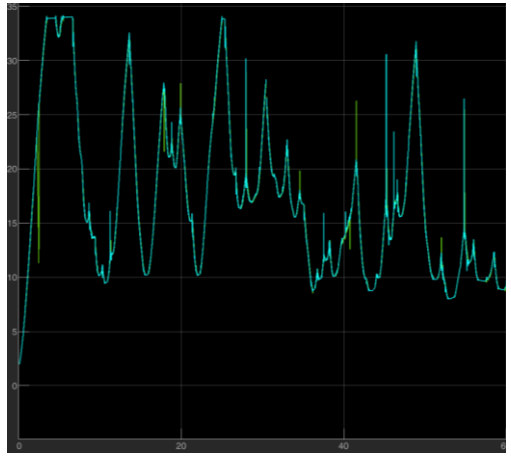


Measurement constants tuning: ✓

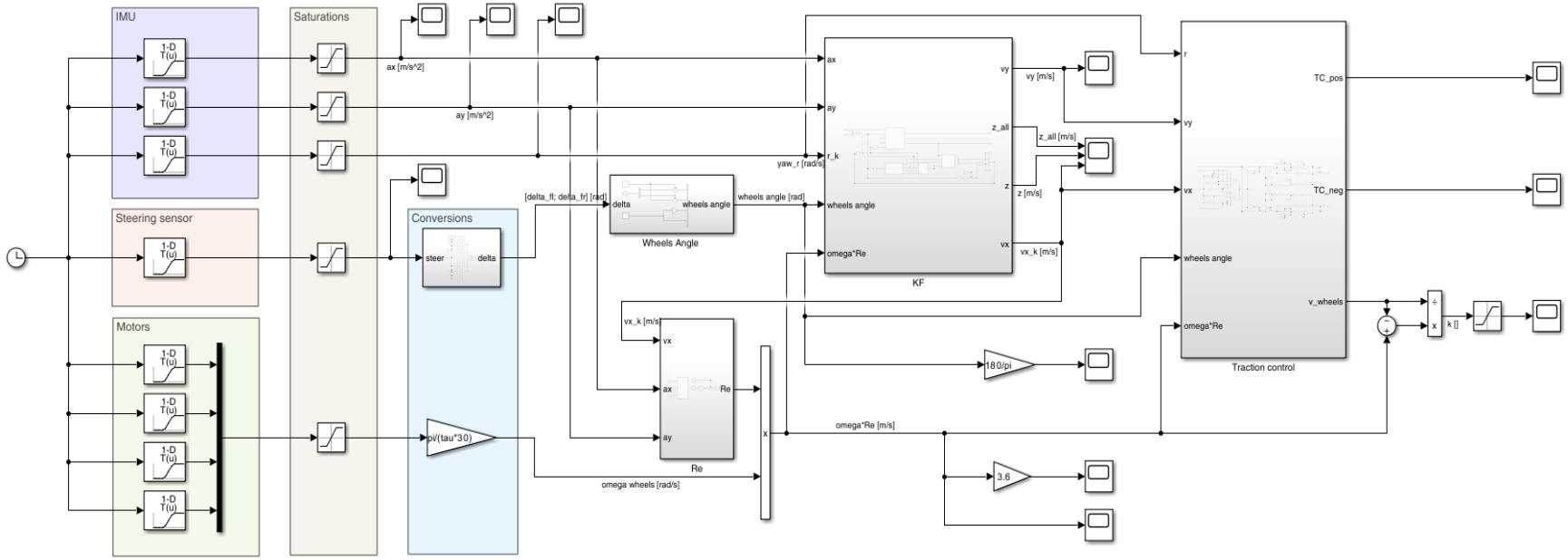
z_{min} **vs** z_{max} [m/s]



z_{avg} **vs** z [m/s]



VALIDATION & RESULTS: SGE-05 TRACK TEST DATA

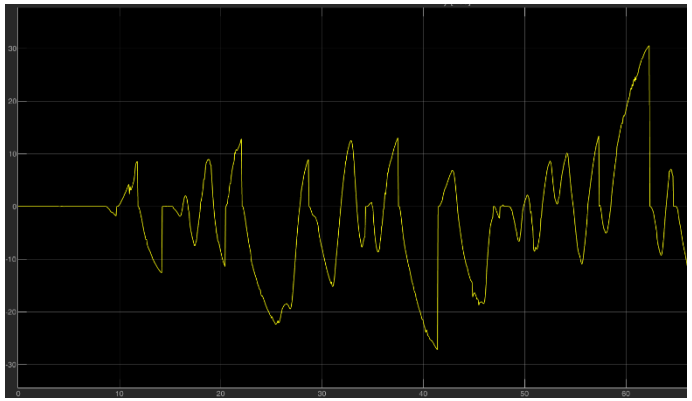


Measurement z to be **trusted more**:

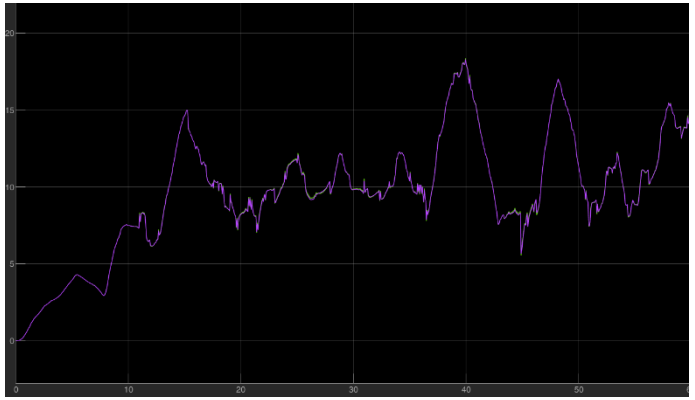
$$\mathbf{Q} = 0.1\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix};$$

$$R = 0.01$$

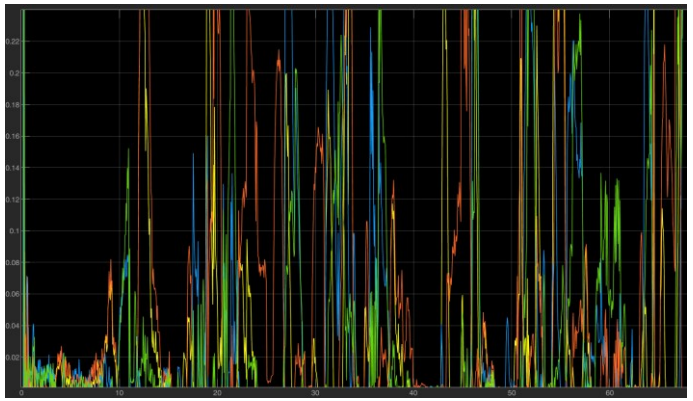
$\mathbf{v_y}$ [m/s]



$\mathbf{v_x}$ [m/s]



$\boldsymbol{k}$ []



CONCLUSION

Model properly designed:

1. Wheels angles & F_Z;
2. Kinematic model design;
3. Measurement;

→ **VI-CarRealTime**

4. Kalman filter loop. → **SGe-05 track test data**

WIP:

1) .TIR file; → R_e
2) VI-CarRealTime loops; → **KF** validation & **PID controller** tuning
3) Sensor sampling frequency.

?

Combined model-based vehicle velocity estimator

Thank you for your attention!