Event-triggered Robust Output Feedback Controller for a Networked Roll Control System

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Fernando Viadero-Monasterio is a Ph.D. student from the University Carlos III de Madrid (UC3M). He received his M.S. degree in industrial engineering in 2020 from UC3M. Before that, he received his B.S. degree in industrial engineering in 2018 from Universidad de Cantabria (UNICAN). He joined the Department of Mechanical Engineering in 2018, where his research is focused on vehicular dynamics and autonomous vehicles.

Publications

- Simultaneous Estimation of Vehicle Sideslip and Roll Angles Using an Integral-Based Event-Triggered $H\infty$ Observer Considering Intravehicle Communications. IEEE Transactions on Vehicular Technology. **First revision passed.** 2022
- $H\infty$ dynamic output feedback control for a networked control active suspension system under actuator faults. Mechanical Systems and Signal Processing. 2022
- Project ARES: Driverless transportation system. challenges and approaches in an unstructured road. Electronics. 2021

- Development of a control system that enhances **stability** and **confort** by reducing lateral motion of the vehicle
- **Low-cost** architecture
- Network saturation avoidance. **Event-triggered** data transmission
- Robust control solution towards **network delays**

- System states: $x = [\varphi, \dot{\varphi}]^T$
- Observed measurement: $y = \dot{\varphi}$
- Controlled output: $z = [\varphi, \dot{\varphi}]^T$
- Control input: $u = M_x$
- System disturbances: $\omega = [a_y, \varphi_r, d_s]^T$

φ: roll angle (rad)

$\dot{\varphi}$: roll rate (rad/s)

M_x: anti-roll moment (Nm)

a_y: lateral acceleration of the vehicle (m/s^2)

d_s: unknown vector disturbance

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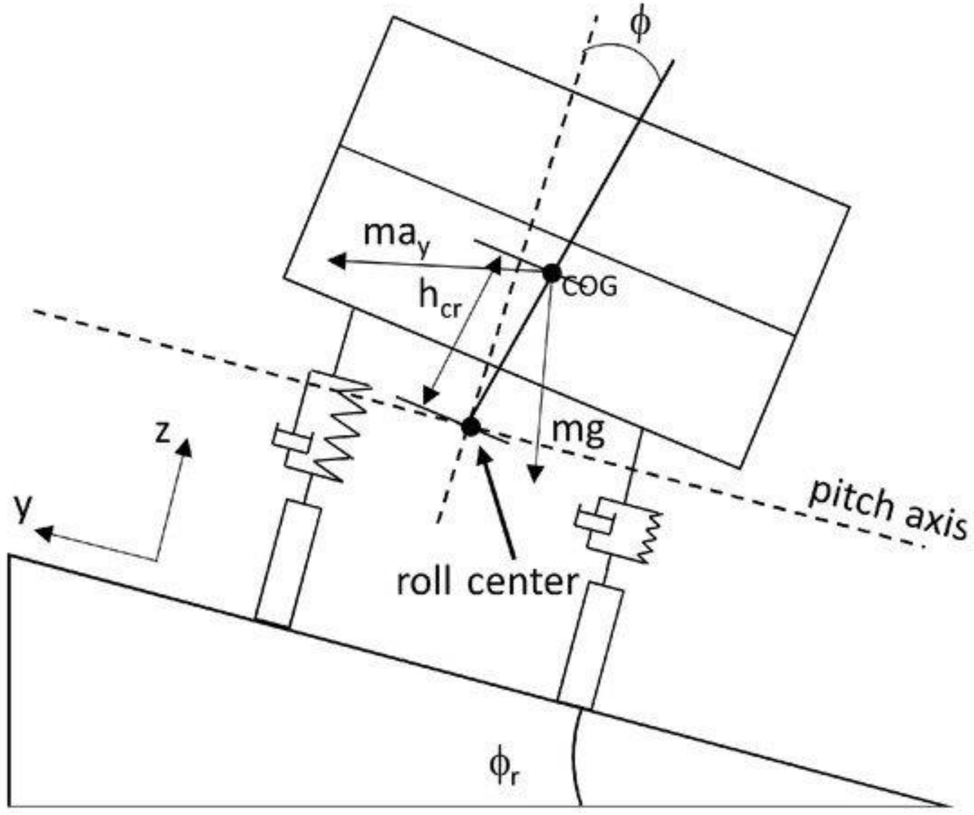


- Reduce the **Transmission Rate (TR)** over the communication network

$$TR = \frac{Transmitted\ data}{Total\ measured\ data} = \frac{Transmitted\ data}{f_s t} \leq 1$$

- Evaluate the difference between the current vehicle measurement and the last transmitted one, $\boldsymbol{e(t) = y(t) - \tilde{y}(t)}$

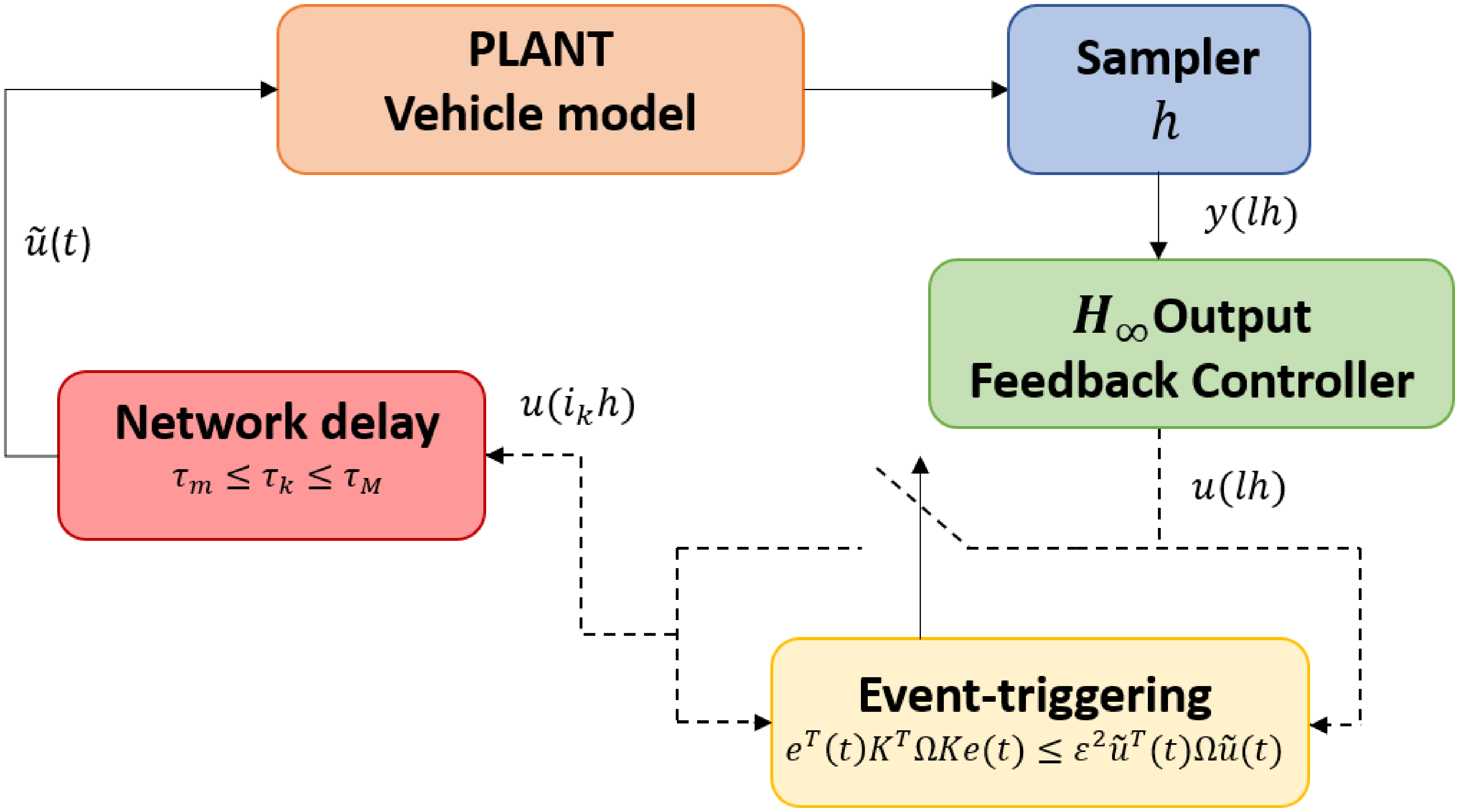
$\tilde{y}(t)$: last transmitted plant measurement

- Design an **event-triggering rule**, so that a change in the control signal sent to the actuators is made only when required:

$$e^T(t)K^T\Omega K e(t) \geq \varepsilon^2 \tilde{y}^T(t)K^T\Omega K \tilde{y}(t)$$

Ω, ε: event-triggering parameters to desing

- $y(t)$ is sampled every h milliseconds and a control signal is evaluated
- The event-triggering mechanism decides whether to neglect this information or to update the control input that the actuators must supply
- Every time a new data package is transmitted, a delay will appear through this communication, $\tau_m \leq \tau_k \leq \tau_M$
- The actuators generate an anti-roll moment depending on the control signal received from the network


PLANT
Vehicle model
Sampler
h
$y(lh)$
H_∞ Output
Feedback Controller
$\tilde{u}(t)$
Network delay
$\tau_m \leq \tau_k \leq \tau_M$
$u(i_k h)$
$u(lh)$
Event-triggering
$e^T(t)K^T\Omega K e(t) \leq \varepsilon^2 \tilde{u}^T(t)\Omega\tilde{u}(t)$

- Control signal: $u(t) = \boldsymbol{K}y(t)$ — K: control gain to design
- The **closed-loop $\boldsymbol{H_\infty}$ performance** is guaranteed if

$$\|z^T(t)z(t)\|_2 < \gamma^2\|\omega^T(t)\omega(t)\|_2$$

γ: positive scalar to minimize

- The **event triggering** must be taken into account, as it affects system stability
- **Communication delays** must be taken into account, as they affect system stability

- Lyapunov stability analysis:

$$V(t) = V_1(t) + V_2(t) + V_3(t)$$

$$V_1(t) = x^T(t)Px(t)$$

$$V_2(t) = \int_{t-\tau}^{t} \dot{x}^T(s)C_1^T K^T S K C_1 x(s)ds$$

$$\tau = \tau_M + h$$

$$V_3(t) = \int_{t-\tau}^{t} (s-(t-\tau))\dot{x}^T(s)C_1^T K^T R K C_1 \dot{x}(s)ds$$

S, R: real positive symmetric matrices to design

- User constrained values: $\boldsymbol{h = 20\,ms, \tau_M = 20\,ms, \tau_m = 10\,ms, \varepsilon = 0.1}$
- The control gain $\boldsymbol{K}$ is obtained through the minimization problem

min γ^2

subject to $P > 0, R > 0, S > 0, \Omega > 0$

- A feasible solution is found using the MATLAB LMI solvers

$$\gamma^2 = 16.96$$

$$P = \begin{bmatrix} 14.306391 & 0.607416 \\ 0.607416 & 0.464377 \end{bmatrix}$$

$$R = 3.4 * 10^{-9}$$

$$S = 1.25 * 10^{-10}$$

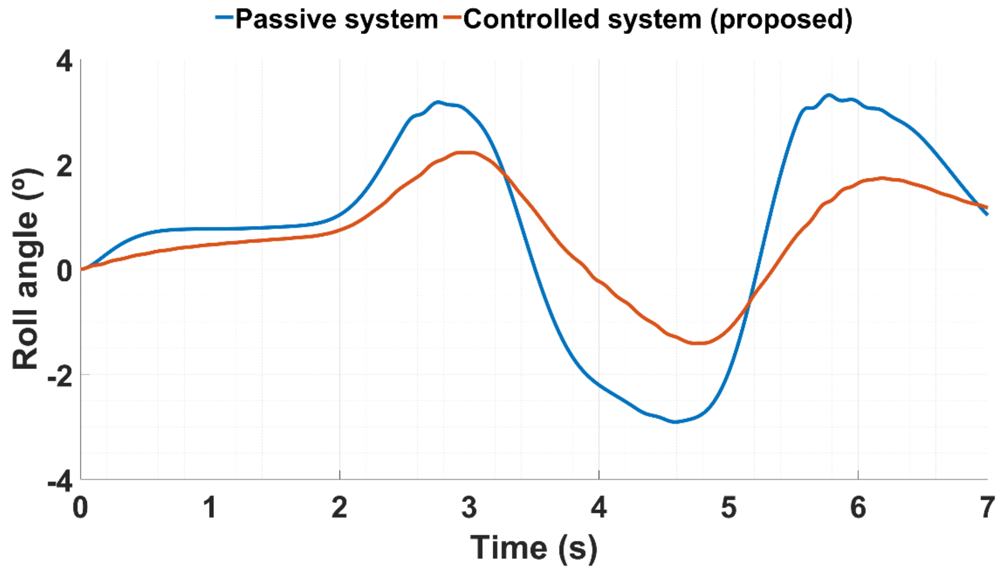
$$K = -13552.53$$

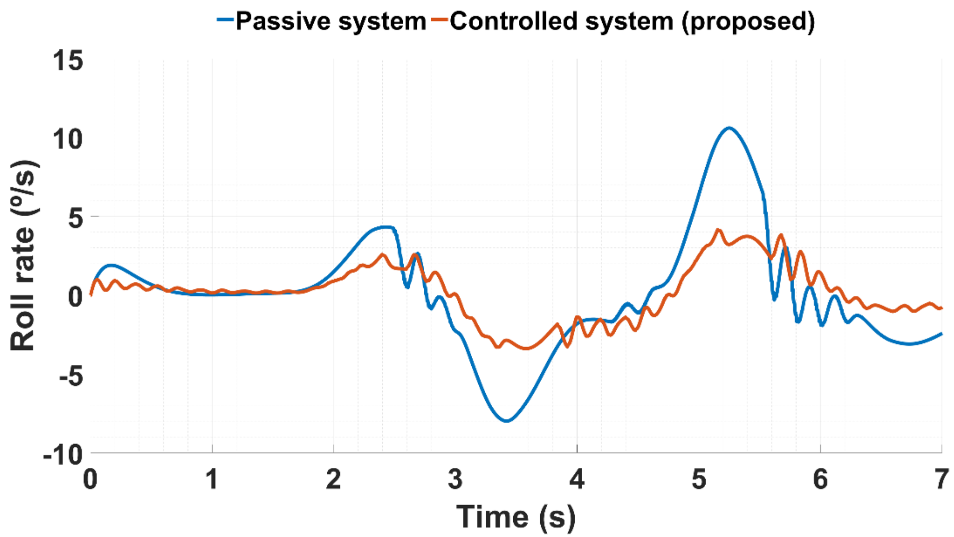
$$\Omega = 1$$

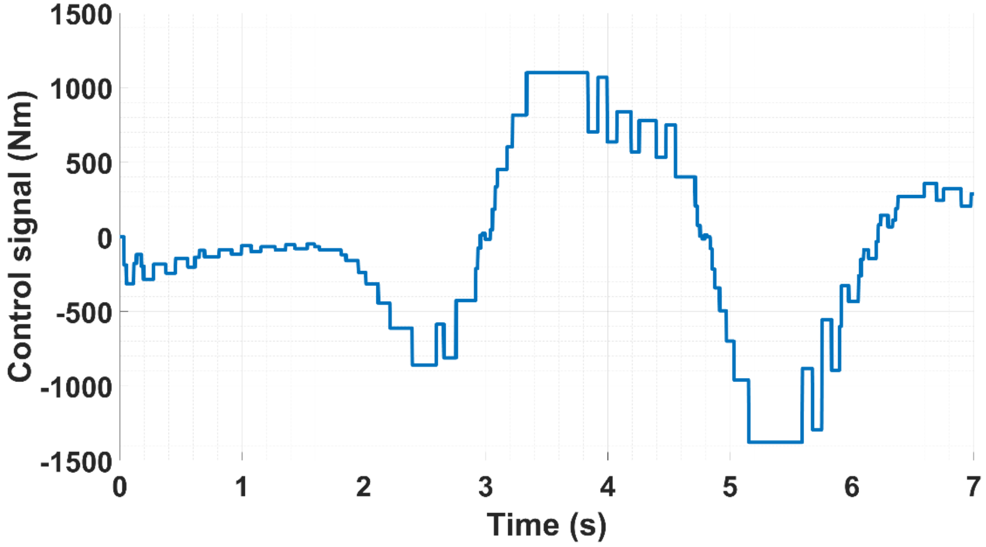
- **Experiment 1**. Double line change at 100 km/h

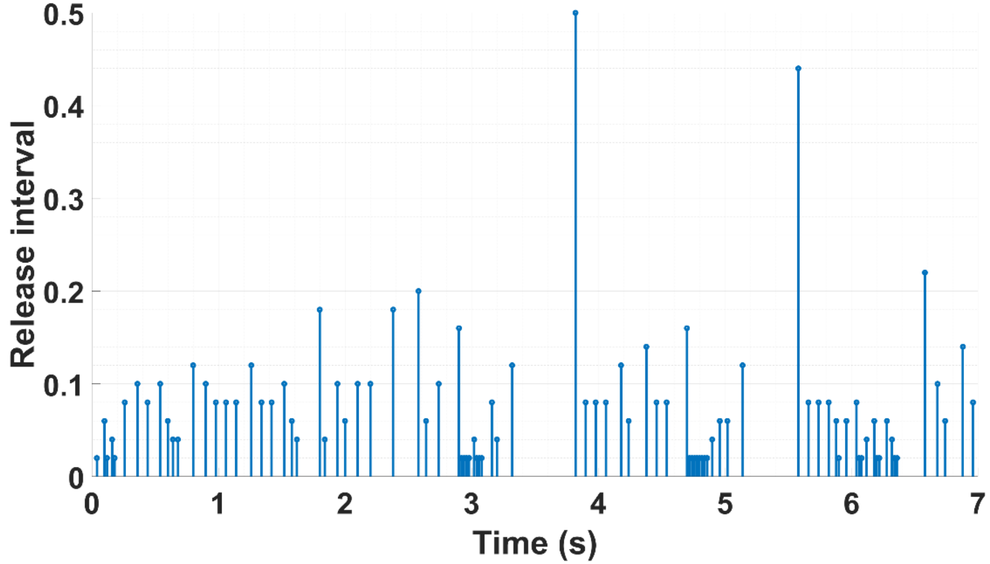
	RMS Roll Rate (º/s)	MAX Roll Rate (º/s)	RMS Roll Angle (º)	MAX Roll Angle (º)
Passive system	3.57	4.15	1.97	3.31
Active system (proposed)	**1.70**	**3.31**	**1.14**	**2.22**

6. CarSIM Simulation results





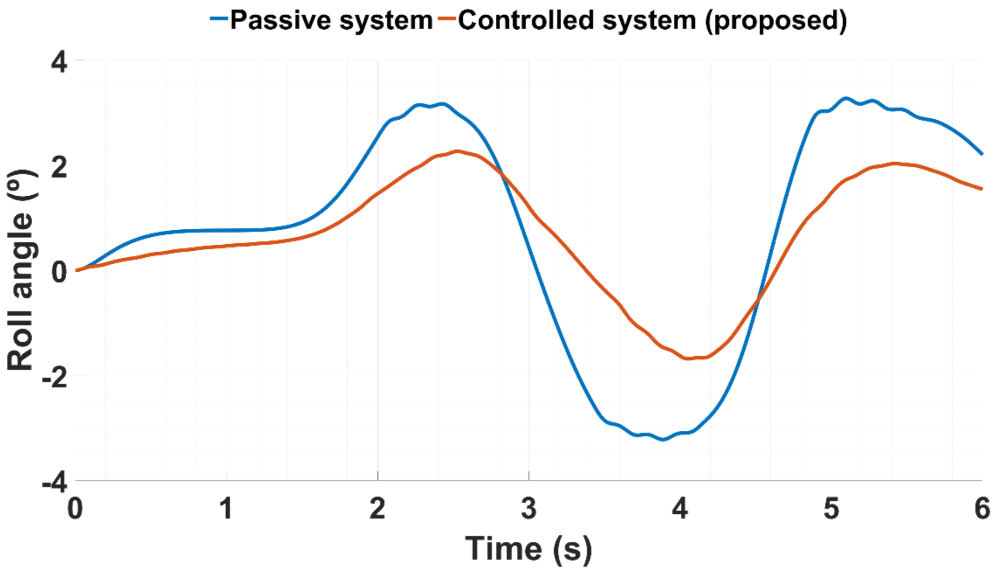


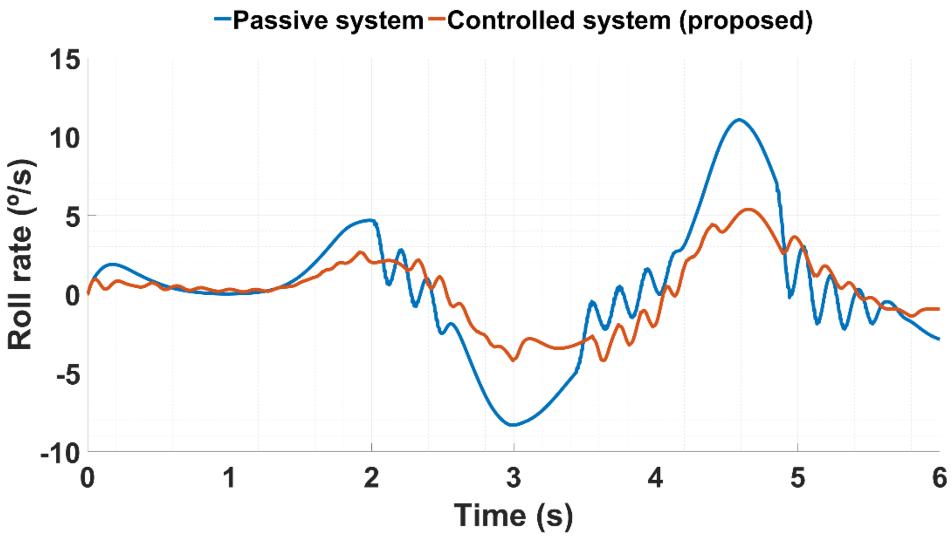


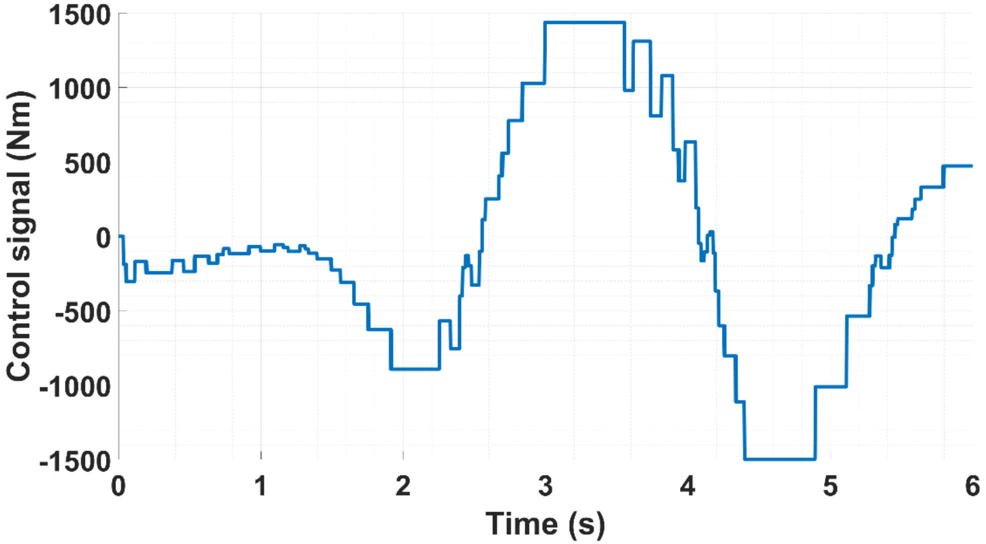
- **Experiment 2**. Double line change at 120 km/h

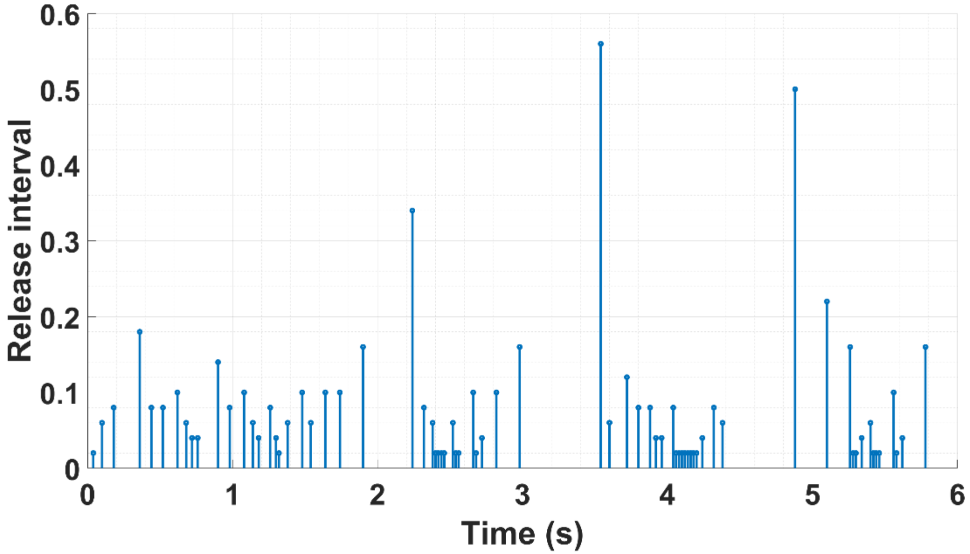
	RMS Roll Rate (º/s)	MAX Roll Rate (º/s)	RMS Roll Angle (º)	MAX Roll Angle (º)
Passive system	4.13	11.05	2.18	3.27
Active system (proposed)	**2.21**	**5.38**	**1.30**	**2.26**

6. CarSIM Simulation results









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- To analyze the performance of the proposed controller, the RMS and MAX values of the roll rate and angle are compared, leading to a reduction of up to 50% of the roll rate and angle in the worst cases
- The Event-Triggered mechanism reduces the network communication resources usage by up to 70%
- Future works may include the consideration of actuator and sensor faults

8. References

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