MATLAB EXPO

트랙터 캐빈 반능동 서스펜션의 슬라이딩 모드 제어기 개발

김경대 연구원, 서울대학교

MathWorks®

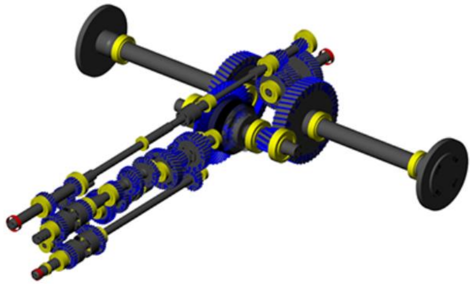
목차

OREDLAB – SNU

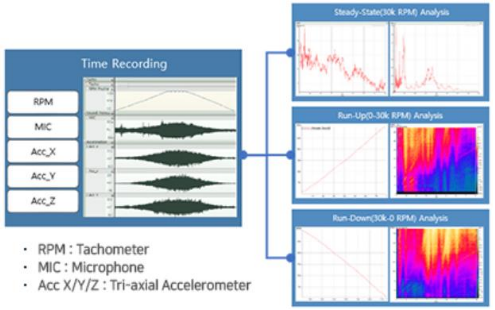
Off-Road Equipment and Soil-Machine Systems Design

Off-Road Equipment

Powertrain Design & Analysis

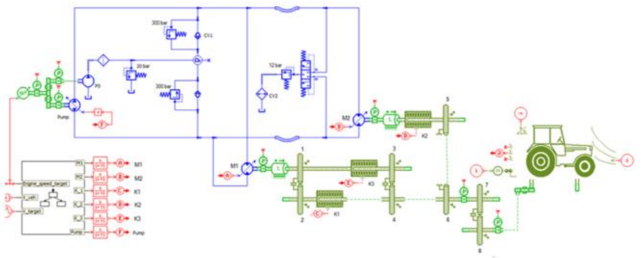


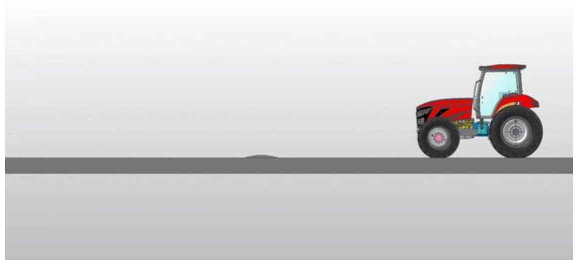
Noise & Vibration



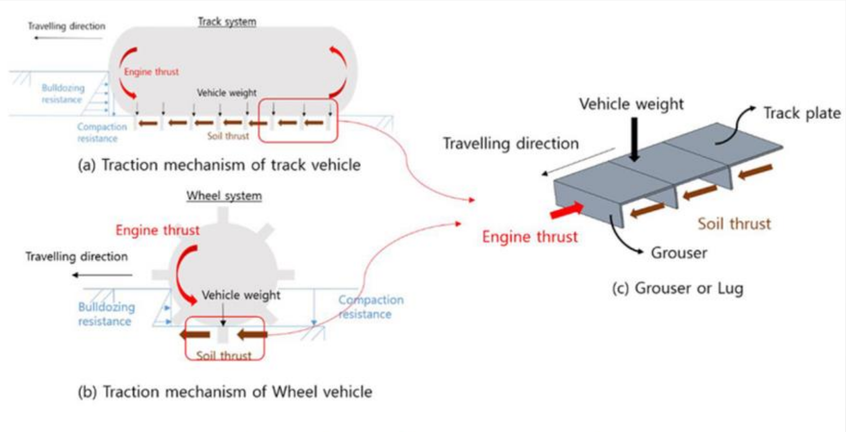
- RPM : Tachometer
- MIC : Microphone
- Acc X/Y/Z : Tri-axial Accelerometer

System Analysis





Soil-Machine Systems



Interaction between off-road vehicle and terrain

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  - 전기구동 트랙터 플랫폼 개발 연구
  - 제어기 HILS 시스템 구축 및 제어 로직 검증
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  - 서울대학교 바이오시스템공학과 박사과정
- 소속
  - 서울대학교 노외기계설계 및 토양기계시스템 연구실(OREDLAB)
  - 전북 한국생산기술연구원 지능형농기계연구그룹

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Project Overview

Tractor Ride Vibration

Serious damages to worker's health

Project Overview

Tractor Ride Vibration

- Paved Road
- Transportation

- Unpaved Road
- Agricultural Tasks

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Project Overview

Semi-active Cabin Suspension

캐빈
현가장치

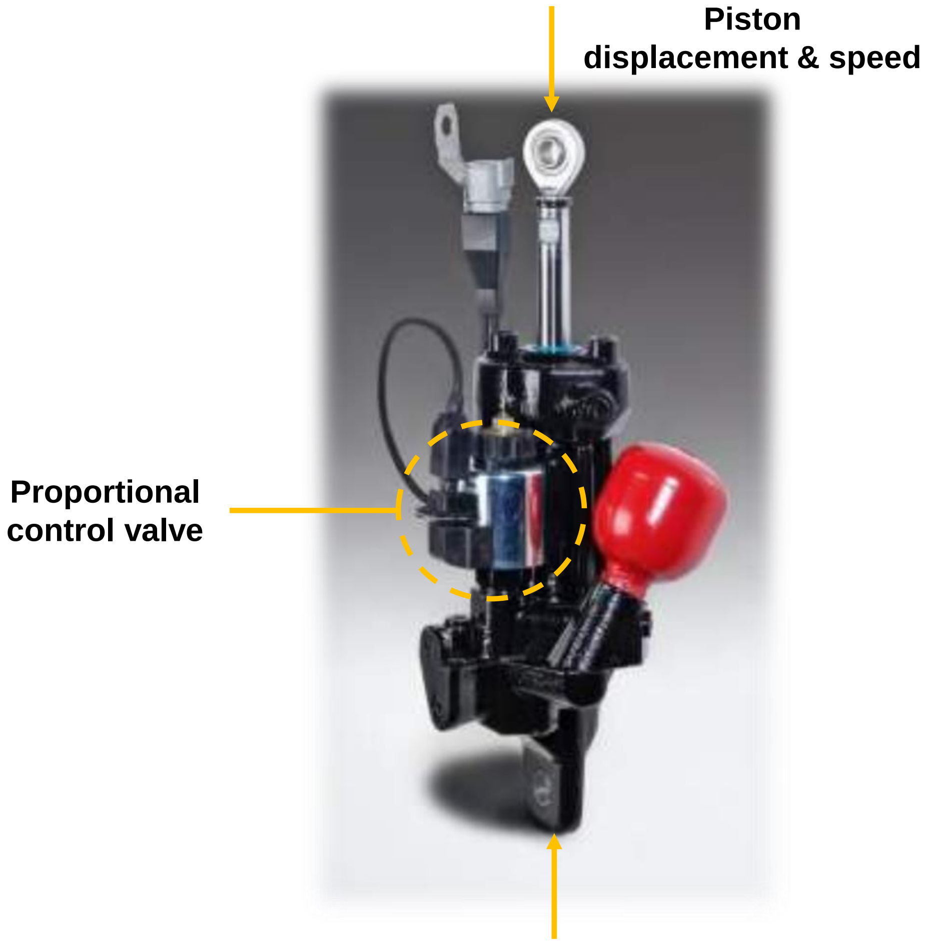
Passive

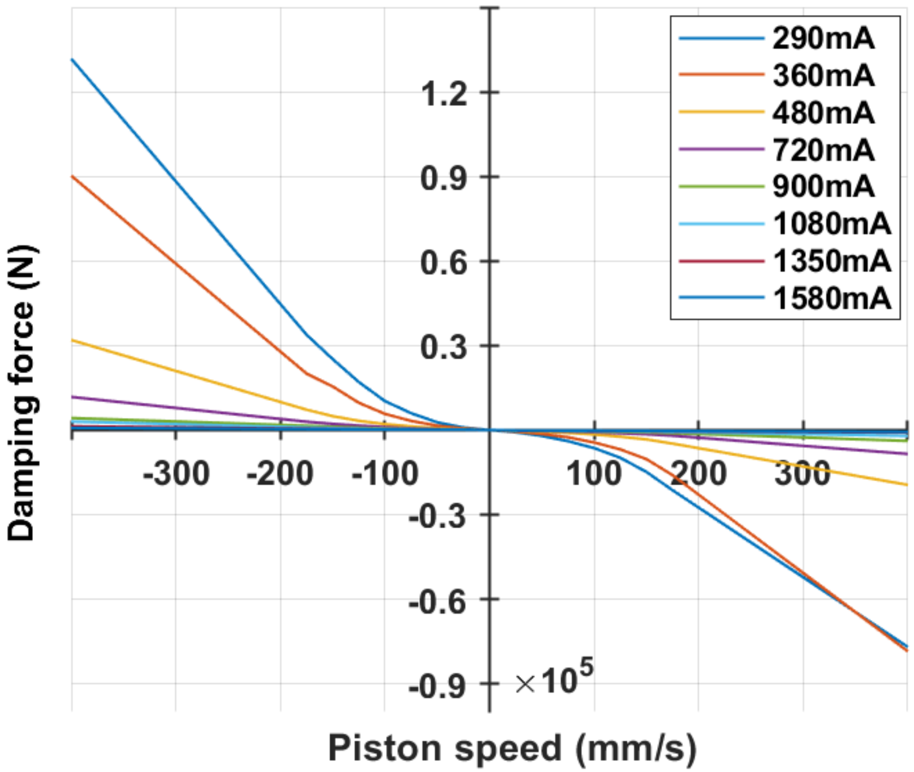
Semi-active

Active

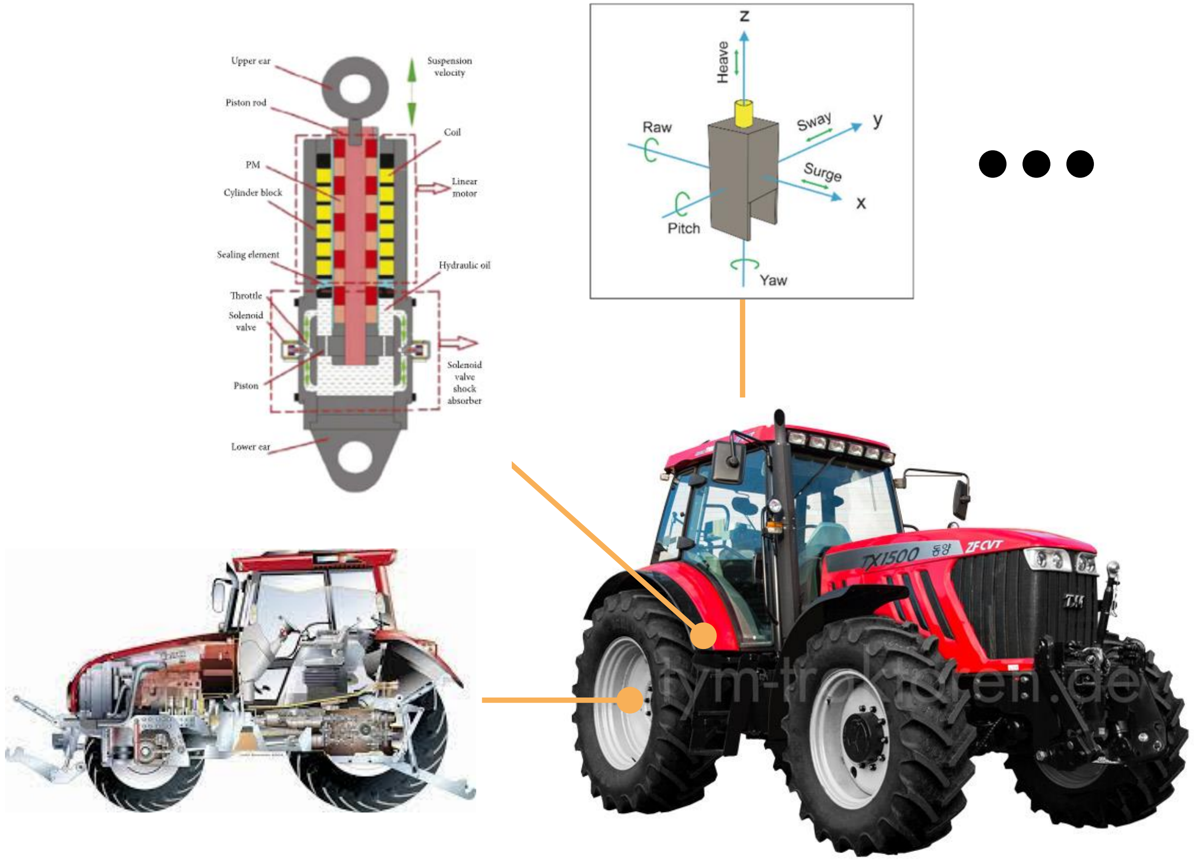
Project Overview

Semi-active Cabin Suspension



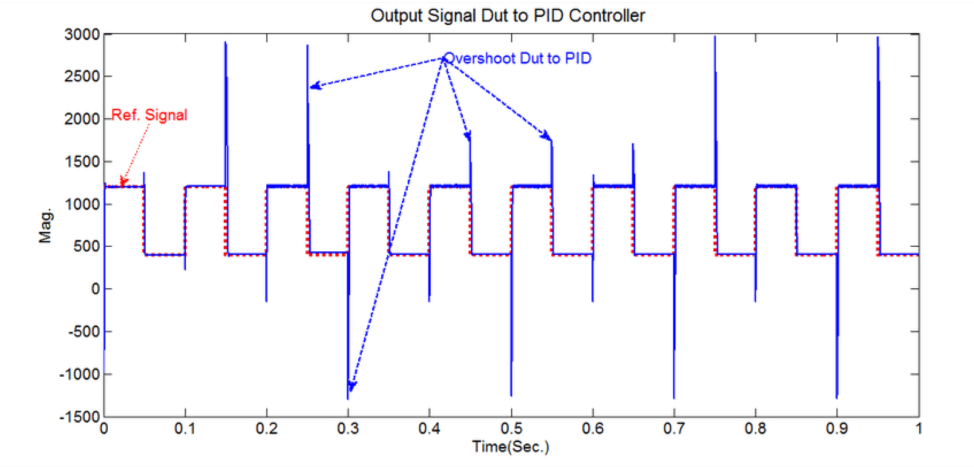


Project Goals and Challenges



- *Model Based Design*
- *Complex System*
- *Non-linear System*
- *Cost & Time*

Project Goals and Challenges



- *Disturbance*
- *Uncertainty*
- *Lack of sensors*

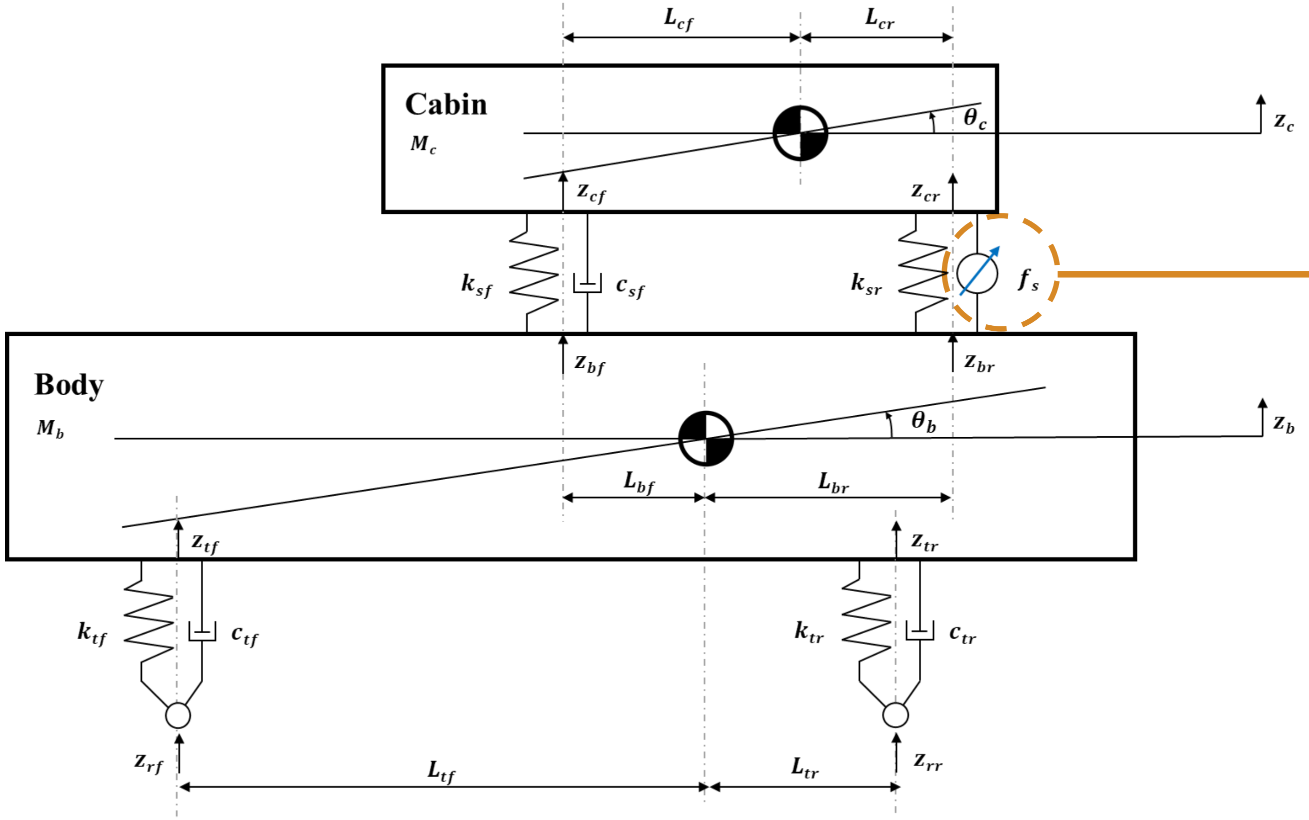
How did we get there and leverage MathWorks

- *LTI System Modeling*
  - Half car model
  - Symbolic math toolbox
  - State space representation

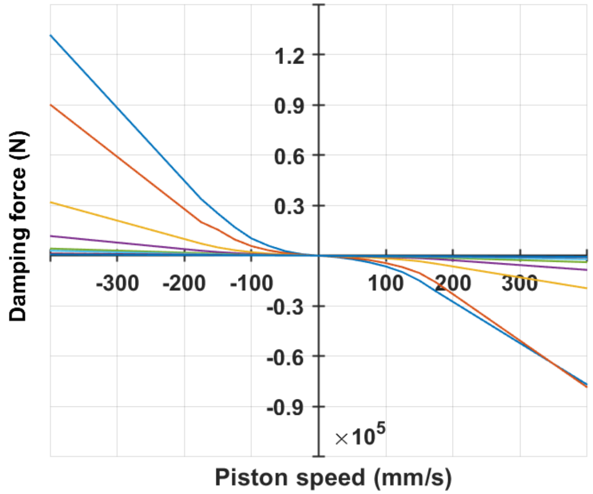
- *Robust Control*
  - Sliding mode

LTI System Modeling

Half car model



$$f_s = -c_{sr}(\dot{z}_{cr} - \dot{z}_{br})$$



$$M\ddot{z} + C\dot{z} + Kz = f_s$$

LTI System Modeling

Symbolic math toolbox & State space representation

Many symbols & Complicated Formula

$$\boldsymbol{M\ddot{z} + C\dot{z} + Kz = f_s}$$

8 X 8 Matrix

8 States

Symbolic math toolbox

Symbolics

```
syms m_c I_c m_b I_b
syms c_s1 c_s2 c_t1 c_t2
syms k_s1 k_s2 k_t1 k_t2
syms L_su1 L_su2 L_sd1 L_sd2 L_t1 L_t2
syms x f
syms z_su1 z_su2 z_sd1 z_sd2 z_t1 z_t2 z_r1 z_r2
syms dz_su1 dz_su2 dz_sd1 dz_sd2 dz_t1 dz_t2 dz_r1 dz_r2
syms ddz_su1 ddz_su2 ddz_t1 ddz_t2
```

M, C, K matrix

```
Mc = eye(2) .* [m_c; I_c];
Mb = eye(2) .* [m_b; I_b];

Ks = eye(2) .* [k_s1; k_s2];
Kt = eye(2) .* [k_t1; k_t2];

Cs = eye(2) .* [c_s1; c_s2];
Ct = eye(2) .* [c_t1; c_t2];

Cs1 = eye(2) .* [c_s1; 0];
Cs2 = eye(2) .* [0; c_s2];
```

A =

$$\begin{pmatrix} 0 & 0 & 1 & 0 & 0 & 0 & -\frac{L_{sd1}}{L_{t1}+L_{t2}} - \frac{L_{t2}}{L_{t1}+L_{t2}} & \frac{L_{sd1}}{L_{t1}+L_{t2}} - \frac{L_{t1}}{L_{t1}+L_{t2}} \\ 0 & 0 & 0 & 1 & 0 & 0 & \frac{L_{sd2}}{L_{t1}+L_{t2}} - \frac{L_{t2}}{L_{t1}+L_{t2}} & -\frac{L_{sd2}}{L_{t1}+L_{t2}} - \frac{L_{t1}}{L_{t1}+L_{t2}} \\ -k_{s1}\,\sigma_8 & -k_{s2}\,\sigma_{11} & -c_{s1}\,\sigma_8 & 0 & 0 & 0 & \sigma_4 + \frac{L_{t2}\,c_{s1}\,\sigma_8}{L_{t1}+L_{t2}} & \frac{L_{t1}\,c_{s1}\,\sigma_8}{L_{t1}+L_{t2}} - \sigma_4 \\ -k_{s1}\,\sigma_{11} & -k_{s2}\left(\frac{{L_{su2}}^2}{I_c} + \frac{1}{m_c}\right) & -c_{s1}\,\sigma_{11} & 0 & 0 & 0 & \sigma_7 + \frac{L_{t2}\,c_{s1}\,\sigma_{11}}{L_{t1}+L_{t2}} & \frac{L_{t1}\,c_{s1}\,\sigma_{11}}{L_{t1}+L_{t2}} - \sigma_7 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ \vdots & & & & & & & \end{pmatrix}$$

Easy & fast
space space representation

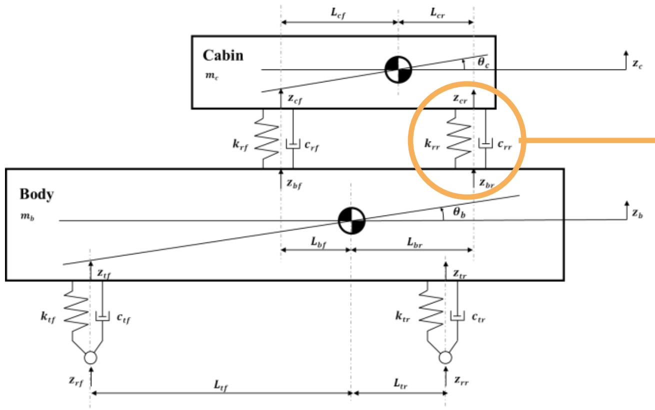
$$\boldsymbol{\dot{x} = Ax + BF_s + L\dot{z}_r}$$

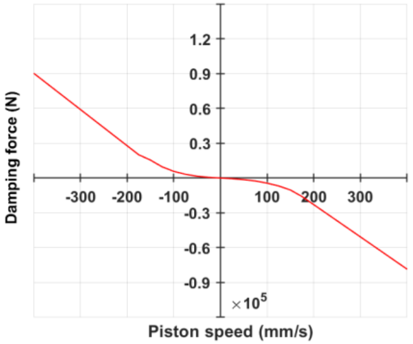
$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$

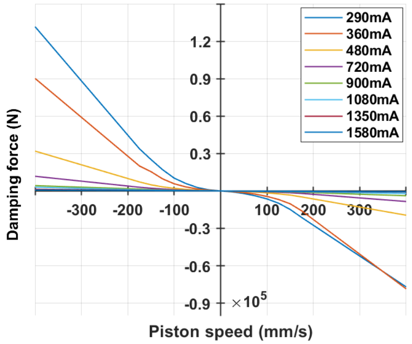
LTI System Modeling

Plant model

- *3 Types of plant model*
  - Rubber mount
  - Semi-active suspension with constant valve current
  - Semi-active suspension with sliding mode controller

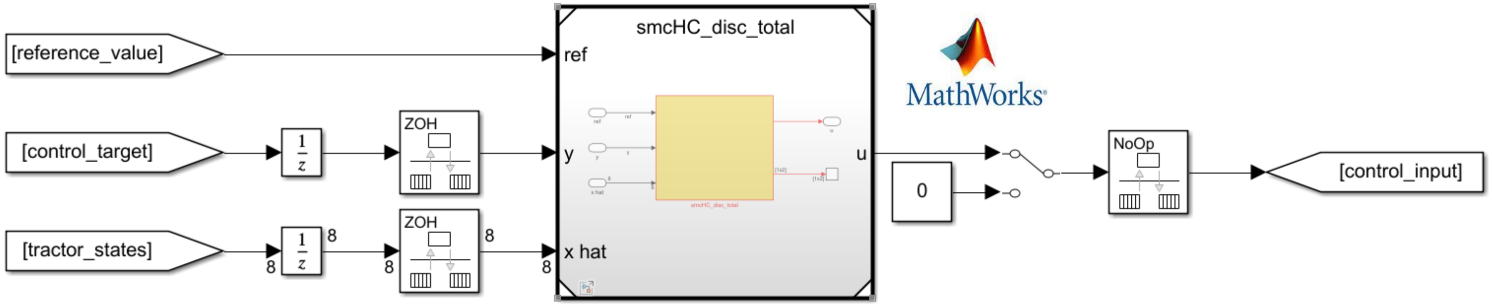






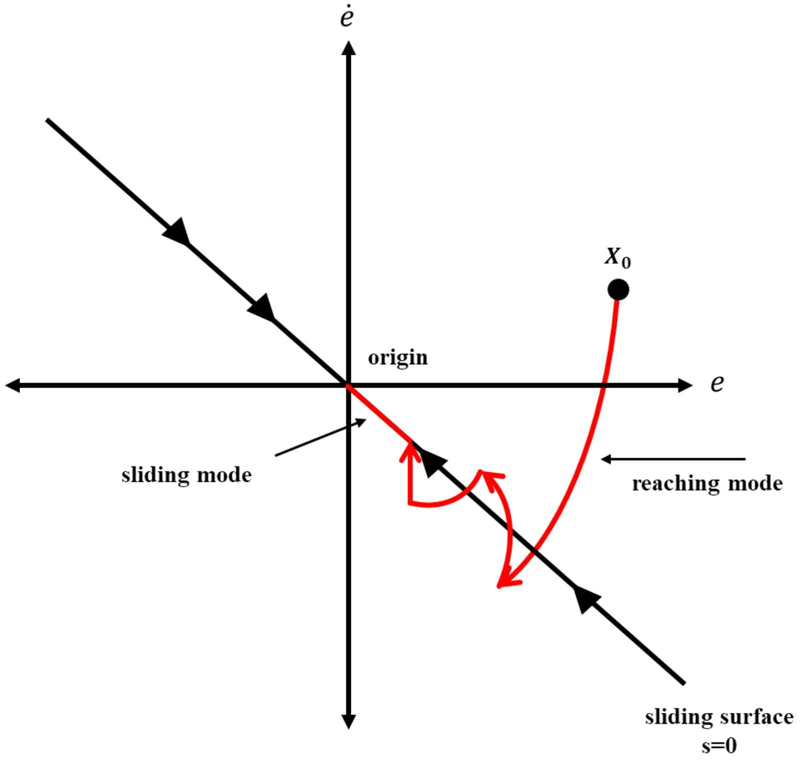
Robust Control
Sliding Mode Controller

- *Sliding mode control?*
  - Nonlinear control method
    - Forces the non-linear system to slide along a sliding surface
  - Strongly robust
    - Mathematically estimate and suppress disturbances & uncertainties
    - Do not need to know precise value, but bounds only
- *Templates*
  - Easy to design



$$e = r - y = 0 - \ddot{z}_c$$

$$s = \dot{e} + \lambda e$$

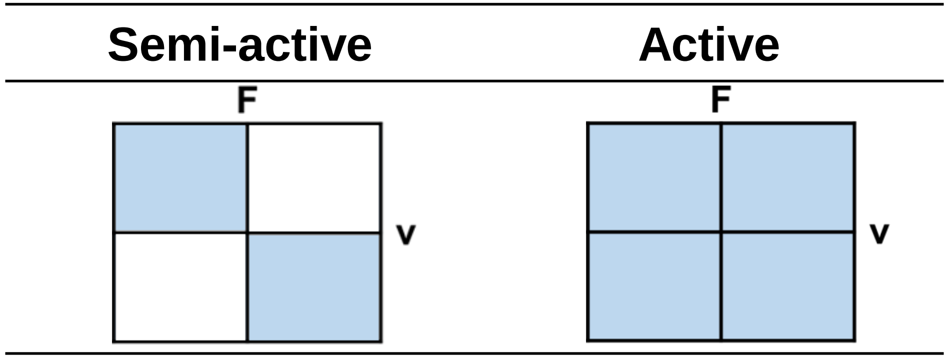


$$Control\ Input = damping\ force, N$$

Robust Control

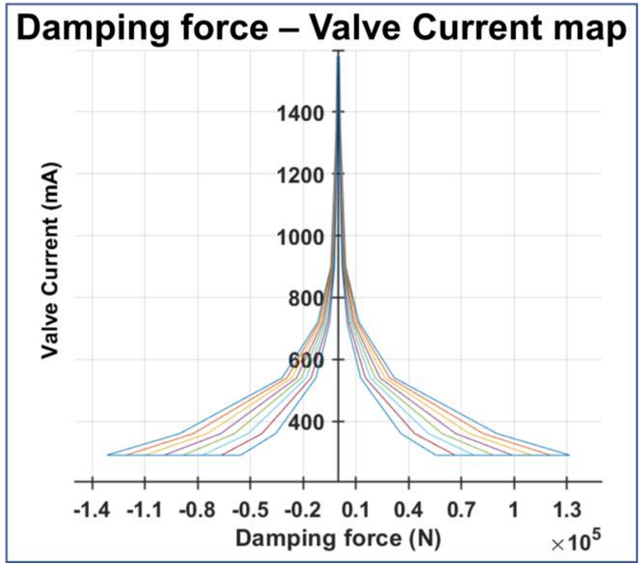
Semi-active suspension constraints

- Magnitude constraints
  - Depends on valve current
- Direction constraints
  - Only to dissipate the system energy



Control damping force, N

Magnitude constraints



Valve control current, mA

Direction constraints

$$
\begin{aligned}
&I_{tgt}(t) = target\ current && \text{if } sign(FV) < 0 \\
&I_{tgt}(t) = I_{tgt}(t-1) && \text{if } sign(FV) \geq 0
\end{aligned}
$$

Valve current command, mA

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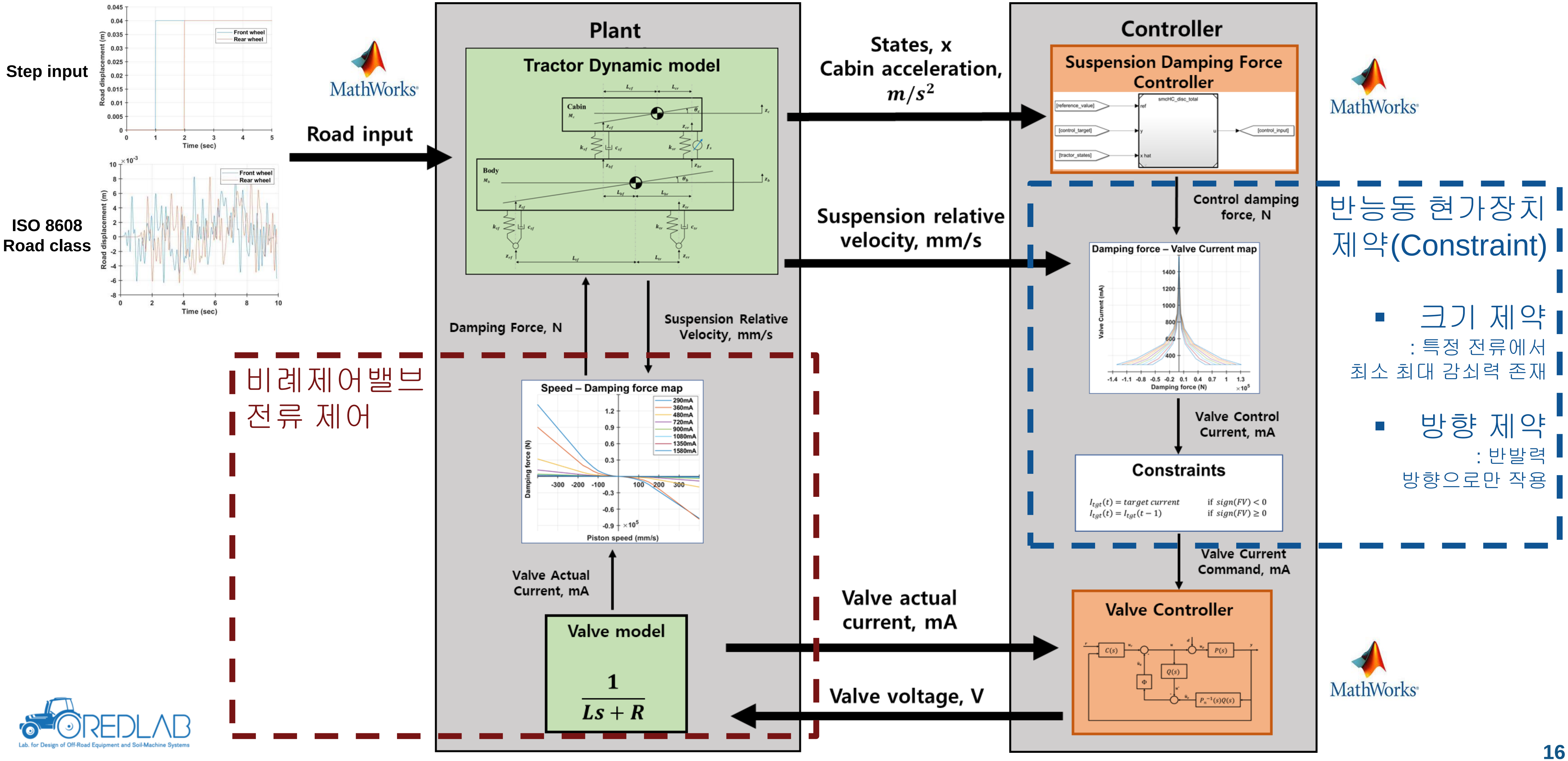
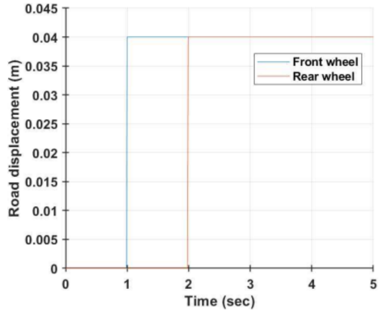
Simulation model

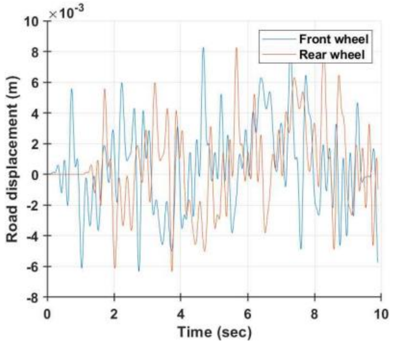


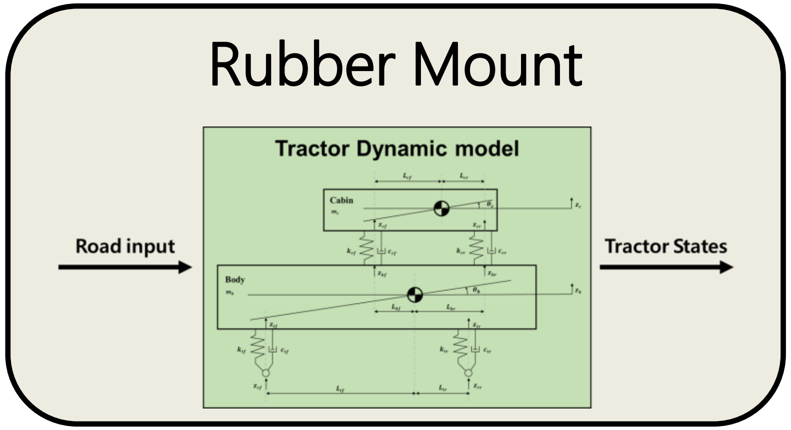
Simulation model

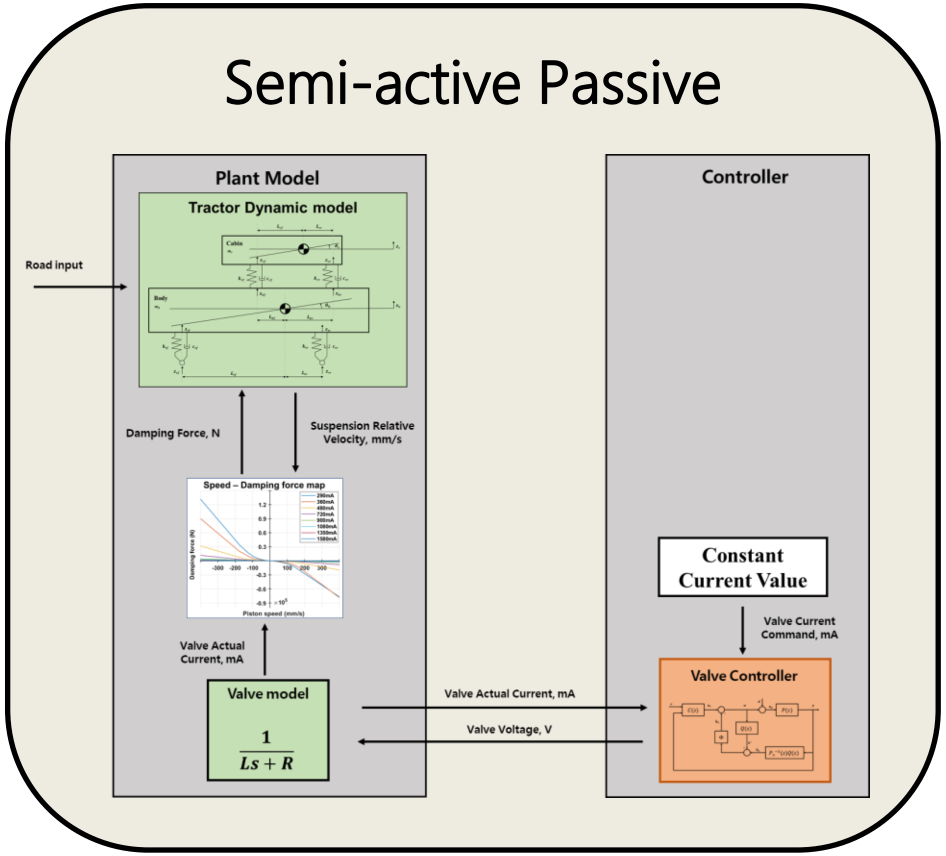
Step input
at 5, 7, 10 km/h

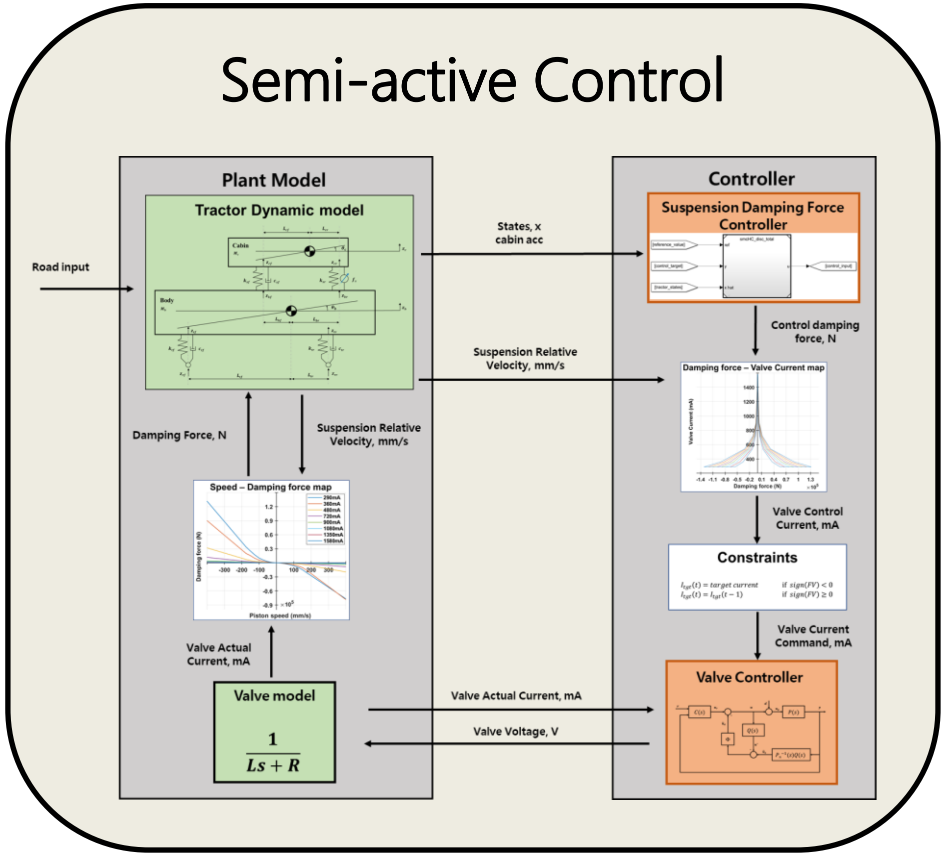


ISO 8608
road class A, B, C
at 5 km/h









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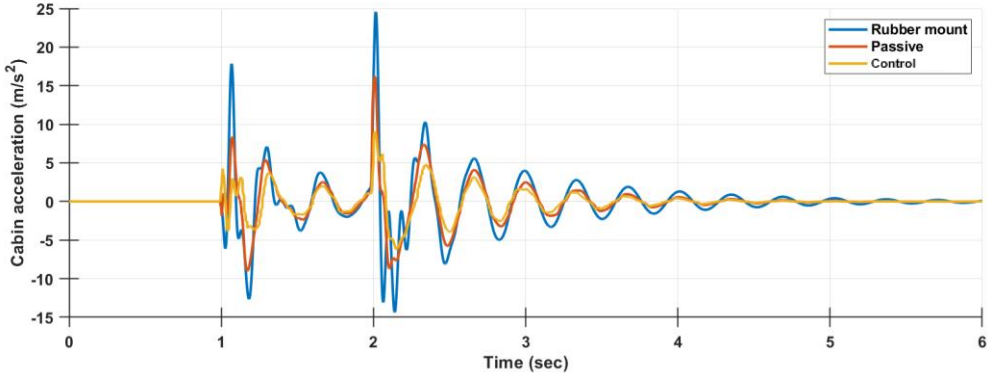
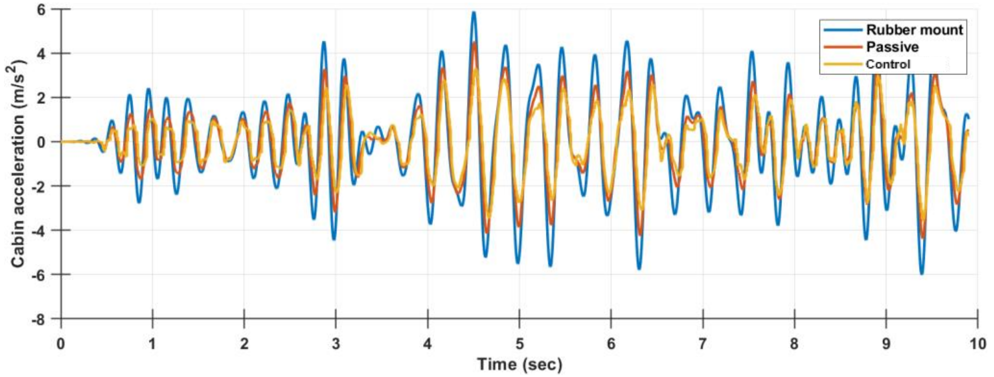
Achievements and outlook

- Semi-active suspension decreases ride vibration better than rubber mount
- With SM controller, shows nearly 60% higher performance than without a controller



< Simulation results for step input at 10 km/h >



< Simulation results for ISO 8608 road class C >

Tractor velocity			Peak value: Rubber mount	Peak value: Passive	Peak value: Control
Step input	$5\,km/h$	Acceleration, m/s^2	23.14	15.06	7.80
		Ratio,%	–	65.06	33.71
	$7\,km/h$	Acceleration, m/s^2	22.27	14.69	8.91
		Ratio,%	–	65.96	40.02
	$10\,km/h$	Acceleration, m/s^2	24.58	16.22	9.07
		Ratio,%	–	65.99	36.89

Tractor velocity			RMS value: Rubber mount	RMS value: Passive	RMS value: Control
Step input	$5\,km/h$	Acceleration, m/s^2	2.52	1.72	1.15
		Ratio,%	–	68.17	45.42
	$7\,km/h$	Acceleration, m/s^2	2.54	1.72	1.19
		Ratio,%	–	67.61	46.73
	$10\,km/h$	Acceleration, m/s^2	2.66	1.83	1.23
		Ratio,%	–	68.90	46.41

< Peak and RMS values for step input >

Road type			Peak value: Rubber mount	Peak value: Passive	Peak value: Control
ISO road input	Class A	Acceleration, m/s^2	3.76	2.81	2.21
		Ratio,%	–	74.86	58.85
	Class B	Acceleration, m/s^2	3.98	2.65	2.05
		Ratio,%	–	66.49	51.45
	Class C	Acceleration, m/s^2	7.01	5.89	4.91
		Ratio,%	–	83.98	69.99

Road type			RMS value: Rubber mount	RMS value: Passive	RMS value: Control
ISO road input	Class A	Acceleration, m/s^2	1.24	0.89	0.77
		Ratio,%	–	72.10	61.85
	Class B	Acceleration, m/s^2	1.47	1.01	0.84
		Ratio,%	–	68.98	57.25
	Class C	Acceleration, m/s^2	2.45	1.77	1.44
		Ratio,%	–	72.03	58.82

< Peak and RMS values for ISO 8608 road class >

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Concluding Remarks and Further plan

- Successfully improved the semi-active suspension’s performance using SM controller
- Learn how to model the LTI systems in a simple and easy way
- Achieve SMC platform which can be applied to various system
- Further plan
  - SM controller HILS, vehicle test
  - Electrical tractor plant model

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Thank you

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