Vehicle Dynamics and Control

Fall 2010

Professor Kyongsu Yi

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Lecture 1: Introduction

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Lectures: Mo/We 11:00-12:15 @301-1512
Office hours: Tue 10:30 to 11:30 or by appointment

Objective: To provide an overview of ground vehicle dynamics through the development, analysis and interpretation of engine, powertrain, automotive chassis and vehicle models.
Analysis and prediction of the dynamics of ground vehicles. Chassis control systems, Vehicle control systems, Human driver model, vehicle-driver closed loop systems, etc.
Lecture 1:

Grading:  Homework 60%
          Final exam 40%
Students absent in a class without instructor’s permission prior to the class would be failed.

Homework: Students will turn in before the end of the class on the due date. Late homework will not be accepted. All homework assignments are to be completed on your own. You are allowed to consult with other students during the conceptualization of a problem but all written and programming work are to be generated by yourself.
Exam: 90-minute final exam on December 13 (Mo) in class, 11:00-12:30
References

The Car and The Future
Vehicle
Engine, Brake, Suspension and Steering
Vehicle-Driver Systems

Environments
World model

Human Driver
Driver Inputs
Throttle brake steering

Vehicle
Vehicle motion
Powertrain and Brake System
Steering Systems

Cadillac STS – Active Front Steer System Diagram

Active Front Steer Actuator
Active Front Steer Controller

Spin axis
Direction of Wheel heading
Slip angle
Slip ratio
Direction of Wheel travel

Direction of Wheel travel

Fz

Spin axis

Ω

Y
X
Z

12
Motor Driven Power Steering Systems

\[ N \cdot (T_{\text{column}} + T_{\text{mot.assist}}) = T_{\text{SAT}} \]

\( N \) : Steering wheel gear ratio

\( T_{\text{SAT}} \) : Self Aligning Torque
Excitation from road (inputs from environment)

Suspension Functions

- Support the vehicle static weight
- Isolate a car body from road disturbances
- Keep road holding on a rough, bumpy, and winding road for improved traction, braking and cornering
Vehicle Dynamic Model

3D Vehicle Model

- 6-DOF Vehicle Body
- 4-Quarter Car Model
- Tire Model

Powertrain Model

- Engine Model
  - Torque Converter
  - Transmission
  - Axle Shaft
  - Differential Gear
Vehicle Longitudinal Dynamics Model

Free Body Diagram of Vehicle Body
Total lateral force including crosswind disturbance

\[ \sum F_y = F_{yf1} \cos \delta + F_{yf2} \cos \delta + F_{yr3} + F_{yr4} + F_{xf} \sin \delta + F_{xf} \sin \delta + F_{cw} + F_{BANK} \]

\( EP = \) equivalent point
\( F_{xfi/ yfi} = \) longitudinal/lateral force of front i-th tire
\( F_{yri} = \) lateral force of rear i-th tire
\( \delta = \) steering angle
Lateral Dynamics

Bank angle

Total lateral force including crosswind disturbance

\[
\phi_{BANK} = \sin^{-1} \frac{\Delta z}{2t_f}
\]

\[
F_{BANK} = m g \sin(\sin^{-1} \frac{\Delta z}{2t_f}) + m_u g \sin \phi
\]

\[
\left( m_u = \text{unsprung mass}, \phi = \text{roll angle} \right)
\]

\[
F_{txi/tyi} = \text{longitudinal/lateral force of i-th tire}
\]

\[
\delta_i = \text{steering angle}, \delta_1 = \delta_2 = \delta, \delta_3 = \delta_4 = 0
\]

\[
\sum F_y = F_{ty1} \cos \delta_1 + F_{ty2} \cos \delta_2 + F_{ty3} + F_{ty4} + F_{nx1} \sin \delta_1 + F_{nx2} \sin \delta_2 + F_{BANK} + F_{CW}
\]
Roll/Pitch/Yaw dynamics

\[ \ddot{\psi} = \frac{\sum M_z - (I_y - I_x) \cdot \dot{\theta} \cdot \dot{\phi}}{I_z} \]

\[ \ddot{\phi} = \frac{\sum M_x - (I_z - I_y) \cdot \dot{\theta} \cdot \dot{\psi}}{I_x} \]

\[ \ddot{\theta} = \frac{\sum M_y - (I_x - I_z) \cdot \dot{\phi} \cdot \dot{\psi}}{I_y} \]

각각의 각각속도로부터 velocity, angle 계산.
Transition from Driver Assistance Systems to IVSS

Past: 100% authority in driver
Present: Assist by Driver Assistance Systems
Future: Smart support by IVSS

Human Driver

Environments (World model)
- Road information
- V2V communication
- V2I communication
- GPS information
- Traffic scene

Integrated System
- Supervisor Controller
  - Environment Monitor
  - Driver Monitor
  - Vehicle Monitor
- Fail-safe Logic
- SCC/CA/CDM
- ESC/AFS
- LDWS/LKS

Vehicle
Vehicle-Driver Systems

Environments
World model

Human Driver

Driver Inputs

Vehicle

Vehicle motion

Throttle brake steering
Vehicle-Driver-IDAS Systems

Environments
World model

Human Driver
Driver Inputs

Vehicle
Vehicle motion

Intelligent Driver Assistance Systems
Major Course Contents

Part 1: Lateral Vehicle Dynamics
  1.1 Vehicle Dynamic Model
  1.2 Planar Model
  1.3 Bicycle Model
    - Bank angle/crosswind
  1.4 Tire Models
  1.5 Understeer/oversteer
  1.6 Dynamic model in terms of error wrt road
  1.7 Lane keeping model
  1.8 Lateral stability Control

Part 2: Longitudinal Vehicle Dynamics
Part 3: Vehicle Control Systems
Part 4: Suspensions
Part 5: Three-dimensional rigid body model of a vehicle
Major Course Contents

Part 2: Longitudinal Vehicle Dynamics
- 2.1 Longitudinal Dynamic Model
- 2.2 Engine model
- 2.3 Transmission
- 2.4 Tire models
- 2.5 Brake

Part 3: Vehicle Control Systems
- 3.1 Driver Model
- 3.2 Lateral Stability Control
- 3.3 Lane Keeping Systems
- 3.4 Adaptive Cruise Control
- 3.5 Autonomous Driving Systems
Major Course Contents (contd.)

(tentative, Optional)
Part 4: Suspensions
   3.1 Fundamental properties of suspensions
   3.2 Invariant properties
   3.3 Ride quality
   3.4 Active/semi-active suspensions

Part 5: Three-dimensional rigid body model of a vehicle
   5.1 Newton/Euler formulation –review
   5.2 14 DOF vehicle model (6+4+4)

Understand the underlying physics and being able to construct models to analyze and predict vehicle behavior
Control system design for safety and maneuverability
End of Introduction

October 6, 2010
안전한 자동차

지능형 안전 자동차

Intelligent Safety Vehicle
주행 안전 장치

수동적 안전 장치
사고 완화

능동적 안전 장치
사고 방지

→ 에어백
→ 안전벨트
→ 목받침

→ ABS Anti-lock Braking System
→ TCS Traction Control System
→ ESP 전자식 주행안정 프로그램
→ Brake Assist 제동 보조 장치
→ 자동주행 (Smart Cruise Control)
→ 충돌방지 (Collision Avoidance)
→ 차선 이탈 방지 (Lane Departure Avoidance)
Vehicle Stability Control (VSC)
Electronic Stability Control (ESC)
Electronic Stability Program (ESP)
1 ESP 동영상 bosch esp exp motor_C
2. Bosch ESP 성능

갑자기 장애물이 나타난 경우

ESP가 장착되지 않은 차량
VSC 작동 원리

ESP는 어떻게 작동하는가?
ESP는 어떻게 작동하는가?

ESP는
→ 운전자가 진행하고자 하는 방향을 인식한다
ESP는 어떻게 작동하는가?

ESP는 자동차의 실제 진행 방향을 감지한다.
ESP는 어떻게 작동하는가?

ESP는

→ 각각의 바퀴를 독립적으로 제어함으로 자동차의 진행 방향을 조정해 준다.
→ 자동차는 더욱 안전하게 도로 위에 머물게 된다.
ESP: 4 wheel independent braking

Can you brake hard on the front wheel, softly on the back left wheel and, at the same time, accelerate the back right wheel to stop the rear of your car losing control in a bend?

1995년 독일 보쉬 개발
2002년부터 Benz 모든 차량에 장착
2011년부터 미국 수출 모든 자동차 장착 의무화
2012년부터 미국에서 생산되는 모든 자동차에 장착 의무화
현대자동차 제네시스 2008년
그랜저 2010년
아반테 2012년
Lane Departure Warning
Lane Keeping Systems
Lane Departure Avoidance Systems
미래의 자동차
Future Vehicles

Hyundai Blue Will – Chicago Auto Show 2010
Toyota Concept Car – 2009 Tokyo Motor Show
Kia Venga – 2010 제네바 모터쇼
Mercedes Benz – New York Auto Show 2007
Honda Puyo – 2007 도쿄 모터쇼
Chevrolet Aveo RS Show Car – Chicago Auto Show 2010
### Future Vehicles: Small and Smart

**Dreaming ...**  
"the car for the 2 kW society"

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m$</td>
<td>1,600 kg</td>
<td>700 kg</td>
</tr>
<tr>
<td>$A_f c_w$</td>
<td>0.70 m²</td>
<td>0.40 m²</td>
</tr>
<tr>
<td>$c_r$</td>
<td>0.013</td>
<td>0.010</td>
</tr>
<tr>
<td>$\eta$</td>
<td>0.2</td>
<td>0.30</td>
</tr>
<tr>
<td>$\text{fuel consumption}$</td>
<td>7.6 l/100km (EU cycle)</td>
<td>2.0 l/100km (117 mpg)</td>
</tr>
</tbody>
</table>

$$1600 \text{ kg}/70\text{ kg} = 23$$
$$700 \text{ kg}/70\text{ kg} = 10$$
Future Vehicle

지능형 안전 자동차 기술
100% 사고없는 안전하고 편안하고 효율적인 자동차
Clean, Safe, Convenient Crash-free Vehicle
NF Sonata 2004
NF Sonata 2004
1. Vehicle Model

3D Vehicle Model

- 6-DOF vehicle body
- 4-Quarter Car Model
- Tire Model

Powertrain Model

- Engine Model
  - Torque Converter
  - Transmission
  - Axle Shaft
  - Differential Gear
1. Vehicle Model
Powertrain and Brake System
3 DOF Vehicle Planar Motion Model

3 DOF linear vehicle model을 위한 가정
1) Roll, Pitch Motion 무시 \( (\phi = 0, \ \psi = 0) \)
2) Suspension Dynamics 무시 \( (F_{z1} = F_{z2} = F_{z3} = F_{z4}) \)

운동방정식

\[
m(\ddot{v}_x - \gamma v_y) = F_{xr} + F_{xf} \cos \delta_f - F_{yf} \sin \delta_f \quad (1)
\]

\[
m(\ddot{v}_y + \gamma v_x) = F_{yr} + F_{yf} \cos \delta_f - F_{xf} \sin \delta_f \quad (2)
\]

\[
I_z \dot{\gamma} = l_f F_{yf} \cos \delta_f - l_r F_{yr} - l_f F_{xf} \sin \delta_f ...
\]

\[
+ \frac{d}{2} (\Delta F_{xr} + \Delta F_{xf} \cos \delta_f) \quad (3)
\]
Motivation and Auto Industry

Korean Automotive Industries
(1) Volume – No. 5 in the World (3.2 Million, 2001)
(2) 10% of GNP
(3) Export $2.33 billion,
    balance in the black: $1.96 billion
    99% of parts are home products
(4) Manufacturer 50,000.
    Suppliers 100,000.
    Auto Related Service 250,000.

TOTAL: 400,000 Jobs and 1,600,000 peoples

(5) Technology – Not Competitive
Motivation and Auto Industry

Technology Trends
(1) Environment-Friendly Vehicles
(2) Intelligent Vehicles

Transition of Vehicles
Transportation → “Safe”, “Comfort”, “Convenient” and “Entertaining”
Mobile Office
Automobile Engineering

1. Body
2. Engine
3. Transmission
4. Chassis
   - Suspension
   - Brake
   - Steering
   - Wheel assembly
5. Automotive Electronics