University Of California, Berkeley
Department of Mechanical Engineering

ME 131 – Vehicle Dynamics & Control (4 units)

Undergraduate Elective

Syllabus

CATALOG DESCRIPTION

Physical understanding of automotive vehicle dynamics including simple lateral, longitudinal and ride quality models. An overview of active safety systems will be introduced including the basic concepts and terminology, the state-of-the-art development, and basic principles of systems such as ABS, traction control, dynamic stability control, and roll stability control. Passive, semi-active and active suspension systems will be analyzed. Concepts of autonomous vehicle technology including drive-by-wire and steer-by-wire systems, adaptive cruise control and lane keeping systems. Design of software control systems for an actual 1/10 scale race vehicle. Upon completion of this course, students should be able to follow the literature on these subjects, perform independent design, be able to design vehicle dynamics control systems for a 1/10 scale vehicle.

COURSE PREREQUISITES

Math 53, 54, Physics 7A-7B. Programming (E7) Ordinary differential equations (Math 1B, Math 54) Elementary linear algebra (M54), ME 132

TEXTBOOK(S) AND/OR OTHER REQUIRED MATERIAL

Class Slides

Vehicle Dynamics and Control, R. Rajamani, Springer, 2006

COURSE OBJECTIVES

Present and motivate the appropriate level of dynamic modeling that is required to analyze the performance of vehicle control systems. The development of such models is as much of an art as a science in that the models must be kept as simple as possible so that real-time controller implementation can be achieved while retaining the fundamental stability and dynamic response characteristics. Develop the analytical skills necessary to quantitatively predict the behavior of open-loop and closed-loop systems. Feedback control systems will be presented that are currently being used in active safety systems, the student will be expected to design feedback control systems for an actual 1/10 scaled vehicle platform which will be distributed to every group of two students in the class. Experimental design will be complemented with a careful analysis of the performance by simulation. Develop skills in using professional computer-aided control system design and analysis tools, e.g, Matlab/Simulink and ROS, to explore properties of dynamic systems composed of a large number sub-systems such as sensors and actuators.

DESIRED COURSE OUTCOMES

At the end of the course the students should be able to:

a. Formulate simple but accurate dynamic models for automotive longitudinal, lateral and ride quality analysis.
b. Assess the stability of dynamic systems using differential equation theory, apply frequency-response methods to assess system response to external disturbances, sensor noise and parameter variations.
c. Have a basic understanding of modern automotive safety systems including ABS, traction control, dynamic stability control and roll control.
d. Follow the literature on these subjects and perform independent design, research and development work in this field.
e. Expected to design feedback control systems for an actual 1/010 scaled vehicle platform which will be distributed to every group of two students in the class

TOPICS COVERED

Rigid body dynamics review, MATLAB review, vehicle coordinate systems, vehicle dynamic models (longitudinal, lateral, vertical), tire modeling, human driver modeling, active safety systems, stability analysis, ride quality analysis, suspension systems analysis.

CLASS/LABORATORY SCHEDULE

Three hours of lecture and two hours of lab per week.

CONTRIBUTION OF THE COURSE TO MEETING THE PROFESSIONAL COMPONENT

Students learn the basic properties of automotive control systems, and should be able to immediately and successfully develop and analyze the performance of current and future systems. Students also develop modest proficiency in computer-aided tools, specifically ROS and Matlab Control System Toolbox and Simulink, both of which are used ubiquitously in the industry.

RELATIONSHIP OF THE COURSE TO ABET PROGRAM OUTCOMES

(a) an ability to apply knowledge of mathematics, science, and engineering

(b) an ability to design and conduct experiments, as well as to analyze and interpret data

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

(d) an ability to function on multi-disciplinary teams

(e) an ability to identify, formulate, and solve engineering problems

(g) an ability to communicate effectively

(j) a knowledge of contemporary issues

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

ASSESSMENT OF STUDENT PROGRESS TOWARD COURSE OBJECTIVES

40%: homework assignments
40%: term project
20%: final exam

SAMPLE OF WEEKLY AGENDA

3 hours of lecture

2 hours of lab
Weekly homework (theory)
Weekly lab assignment (related to the 1/10 race car platform)

PERSON(S) WHO PREPARED THIS DESCRIPTION

Professor Francesco Borrelli
9/27/17

WEEKLY SCHEDULE OF TOPICS

(See attached)

ABBREVIATED TRANSCRIPT TITLE (19 SPACES MAXIMUM): VEH DYN AND CTR
TIE CODE: LECS
GRADING: Letter
SEMESTER OFFERED: Fall and/or Spring
COURSES THAT WILL RESTRICT CREDIT: None
INSTRUCTORS: Borrelli
DURATION OF COURSE: 15 Weeks
EST. TOTAL NUMBER OF REQUIRED HRS OF STUDENT WORK PER WEEK: 12
IS COURSE REPEATABLE FOR CREDIT? No
CROSSLIST: None

Course Sylalbus: ME 131, Spring 2018

1. *Modeling of Dynamic System*

(a) Modeling of dynamic systems
- physics based models
- black box models
- gray box models
- complex models for evaluation (CarSim)
- simplified models for real-time control (Simulink)

2. *3D Rigid body dynamics review*

3. *Feedback Control Systems*

(a) Open-loop vs closed- loop systems

(b) Hierarchical control structure

(c) Model-based vs non-model-based control design

(d) PID control design
- "magic" numbers of Nichols-Ziegler

(e) Sliding Control Design

4. *Longitudinal vehicle dynamics*

(a) Longitudinal dynamics

(b) Longitudinal tire forces

(c) Driveline dynamics & spark ignition systems

5. *Longitudinal control II*

(a) Hierarchical structure: upper / lower layers

(b) Upper layer design: application to adaptive cruise control

(c) Lower layer design: drive & brake-by-wire systems

(d) Adaptive cruise control (ACC)
- Constant spacing control
- Constant headway control

6. *Longitudinal control III*

(a) ACC continued

(b) ABS and Traction control systems

- Automated highway systems
- Platoons
- “String stability”

7. *Lateral dynamics*
    - Lateral dynamics Bicycle model, steady state cornering
    - Use of error coordinates
    - Models for roadway geometry

    (a) Understeer / oversteer

    (b) Transient behavior

    (c) Load transfer

8. *Electronic stability control systems I*

    (a) Combined lateral / longitudinal dynamics
    - 7 DOF model
    - Combined lateral / longitudinal tire forces
    - Friction circle, Dugoff model, magic formula)

9. *Electronic stability control systems II*

    (a) Yaw moment control

    (b) Differential braking

    (c) Differential traction

    (d) Steer-by-wire control

10. *Overview of Autonomous Driving Control Systems*

    (a) Sensor and actuators

    (b) Architecture

    (c) Control Systems

Weekly Schedule: ME 131, Spring 2018

- *Week 1*
    - Modeling of Dynamic System
        - physics based models
        - black box models
        - gray box models
- *Week 2*
    - Modeling of Dynamic System
        - complex models for vehicle dynamics (CarSim)
        - simplified models for real-time control of vehicles (Simulink)
- Week 3
    - 3D Rigid body dynamics review
- Week 4
    - Feedback Control Systems Review
        - Open-loop vs closed- loop systems
        - Hierarchical control structure
        - Model-based vs non-model-based control design
        - PID control design
        - Sliding Control Design
- Week 5
    - Longitudinal vehicle dynamics
    - Longitudinal tire forces
    - Driveline dynamics & spark ignition systems
- Week 6
    - Longitudinal vehicle control
    - Hierarchical control structure: upper / lower layers
- Week 7
    - Longitudinal vehicle control
        - Upper layer design: application to adaptive cruise control
        - Lower layer design: drive & brake-by-wire systems
- Week 8
    - Adaptive cruise control (ACC), Constant spacing control, Constant headway control
- Week 9

    - ABS and Traction control systems
- Week 10
    - Automated highway systems
    - Platoons, String stability
- Week 11
    - Lateral dynamics
        - Lateral dynamics Bicycle model, steady state cornering
        - Use of error coordinates
        - Models for roadway geometry
- Week 12
    - Lateral dynamics
        - Understeer / oversteer
        - Transient behavior
        - Load transfer
- Week 13
    - Electronic stability control systems I
    - Combined lateral / longitudinal dynamics
        - 7 DOF model
        - Combined lateral / longitudinal tire forces
        - Friction circle, Dugoff model, magic formula
- Week 14
    - Electronic stability control systems II
        - Yaw moment control
        - Differential braking
        - Differential traction
        - Steer-by-wire control
- Week 15
    - Overview of Autonomous Driving Control Systems
        - Sensor and actuators
        - Architecture
        - Control Systems