ME161/ME261 - Dynamic Systems: Class and lab information

Instructor	Paul Mitiguy	LeAnn Duong	Holly Liske
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Instructor	Alex Perkins	Paul Csonka	
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Mechanics advisors	Katy Keenan	Apoorva Rajagopal	
Class location/time	Bldg 530 Room 127	Tues/Thurs 2:15-3:45	
Lab location/time	Terman 577/573A	Sign up	
Web site	www.stanford.edu/class/me161	(Webmaster: **Alex Perkins**)	
Holidays	Saturday Nov. 21 - Sunday Nov. 29, 2009		
Reading material	Distributed in class		

Course description and prerequisites

Modeling, analysis, and measurement of mechanical and electromechanical systems. Numerical and analytical solutions of linear/nonlinear algebraic and ordinary differential equations governing the behavior of single and multiple degree of freedom systems. Stability, resonance, amplification, and control system design. Demonstrations and laboratory examples. Requires familiarity with dynamics, differential equations, linear algebra, and basic electronics.

Course objectives

Dynamic Systems is a prerequisite for ENGR105/ME105 (feedback control design), ME227 (vehicle dynamics), and is useful for ME281 (biomechanics of human movement) AA242/ME331 (advanced dynamics) and ME309 (finite element analysis). The course objectives are to:

- Model, introduce mathematical identifiers, analyze, and interpret dynamic systems
- Understand the roles of analytical methods and computational tools, including designing feedback control systems with professional software e.g., Matlab, **M**otion**G**enesis, and Working Model
- Develop intuition about the time-dependent nature of dynamic systems
- Gain physical insights into basic principles with experiments
- Develop a hands-on, minds-on, can-do attitude

ABET (Accreditation Board of Engineering & Technology) outcomes – in order of relevance

- Ability to identify, formulate, and solve engineering problems
- Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice
- Ability to apply knowledge of mathematics, science, and engineering
- Ability to design and conduct experiments, as well as to analyze and interpret data
- Ability to design a system, component, or process to meet desired needs

Topics covered

History of math & mechanics	Computational tools and ODEs	Computation & algebraic equations
Math review	Investigating $e^{p\,t}$	Classification of ODEs
Numerical solution of ODEs	Analytical solution of 1^{st}-order ODEs	Analytical solution of 2^{nd}-order ODEs
Root and root locus	Newton/Euler laws of 3D motion	Power/energy-rate principle
Harmonic forcing	Inhomogeneous 1^{st} and 2^{nd}-order ODEs	Motors, sensors, and circuits
Complex numbers	Laplace transforms	PID control
Linearization and stability	Linear algebra review	Eigenanalysis and coupled ODEs
State-space and coupled ODEs	State-space and PID control	System identification laboratories

[5] Paul prefers meeting students in office hours, scheduling a weekend or evening appointment, or talking on the telephone rather than corresponding by e-mail (particularly on technical matters).

Learning by design

The word ***educate*** is from the Latin ***educare*** - "to draw out" (not "to stuff in"). Please provide suggestions, comments, criticism, ideas, and creative brainstorming about lectures, labs, homeworks, classroom interaction, office hours, software, hardware, etc. With 150^+ classes of experience and a significant financial investment in your education, you are both learning experts and customers. **We appreciate your input!**

Office hours (start Sunday September 27)

Day	Time	Location	Instructor
Sun	7:30 - $9{:}00^+$	Terman 529	LeAnn Duong
Mon	5:30 - $7{:}30^+$	Terman 529	Apoorva Rajagopal
Mon	6:30 - $8{:}00^+$	Terman 529	Alex Perkins & Katy Keenan
Mon	8:00 - $9{:}30^+$	Terman 529	Alex Perkins & Katy Keenan
Tues	3:45 - $4{:}15^+$	Classroom/Terman 527	Alex Perkins / Holly Liske
Tues	4:00 - $5{:}30^+$	Terman 527	Paul Mitiguy / Holly Liske
Thurs	3:45 - $4{:}15^+$	Classroom/Terman 527	Alex Perkins
Thurs	4:00 - $5{:}30^+$	Terman 527	Paul Mitiguy

Lab sessions

Day	Time	Group	Instructor
Thursday	4:00-6:00	A	LeAnn Duong & Paul Csonka
Thursday	6:00-8:00	B	LeAnn Duong & Holly Liske
Friday	11:00-1:00	C	Paul Csonka
Friday	1:00-3:00	D	Paul Csonka
Friday	3:00-5:00	E	Holly Liske
Monday	9:00-11:00	F	Holly Liske
Monday	4:30-6:30	G	LeAnn Duong & Alex Perkins

Grading

- **Homework: 25%** Weekly homework is due at the **start** of class on the schedule specified in the syllabus. Homework is graded with a $\surd^{++}$ (100), $\surd^{+}$ (93), $\surd$ (85), $\surd^{-}$ (78), $\surd^{--}$ (70), or no credit (0). There is a strong correlation between high homework scores and high exam scores - and there are few reasons to do poorly on the homework.
  - Late homework that is passed in less than one lecture day late and before the end of that lecture day's office hours is penalized **15 points**.
  - Late homework that is passed in less than two lecture days late (before the end of office hours on that late 2^{nd} lecture day) is penalized **30^+ points**, and is not thoroughly examined - only checked for completeness by an instructor.
  - Late homework that is passed in later than two lecture days is penalized **50^+ points** and is not thoroughly examined - only checked for completeness by an instructor.
  - To accommodate ill or overtired students, or students who need an extension for ***any*** other reason, ***one class lecture*** homework extension is permitted during the quarter. For example, a homework due Tuesday may be passed in on Thursday without penalty or a homework due Tuesday may be passed in on the following Tuesday with a **15^+ point** penalty.
  - Homework is not accepted after the last day of class.
  - Occasionally, homework solutions are covered in class. Homework solutions are not posted. Homework is practice and you are ***encouraged*** to work with your classmates and instructors.
  - Submit your work and answers on separate sheets of paper (not on homework assignments).
  - **Staple** homework/Pre-Lab questions with your submitted homework.
- **Laboratory: 15%** Each of the three parts of the lab is graded with a $\surd^{++}$, $\surd^{+}$, $\surd$, $\surd^{-}$, $\surd^{--}$, or 0. Some pre-lab questions are included (and submitted) with homework. Submit post-lab **separate** from homework. Staple and **submit Working Model pre-lab questions with the post-lab.**

  - 4% **Pre-lab**: Completing pre-lab questions before the lab session
  - 5% **Lab**: Participation in your ***regularly*** scheduled lab session
  - 6% **Post-lab**: On-time completion of post-lab questions.

  Labs are conducted in groups of 3 students, depending on class size. Each lab session is less than 2 hours and has at most 4 groups. Some labs may be done in class. Lab write-up consists of writing short answers to a few questions. The labs are intended to be ***fun***. We hope you enjoy getting an intuitive feel for dynamic systems and concepts learned in class.

- **Midterm: 25%** The midterm exam is in-class, open-book, open-note, and requires a calculator. **No makeup exam** will be given for the midterm.
- **Final: 35%** The final exam is in-class, open-book, open-note, and requires a calculator. The final exam covers the entire course (both before and after the midterm). No makeup exam will be given without university authorization.
- **Graded material:** Student → Holly Liske (alphabetize) → Graders → Holly Liske (Coursework/Excel) → Holly Liske (Photocopy, ABET) → Student (in class or outside Paul's office).

  Holly Liske is the grader intermediary. Consult **Holly** for questions about homework/test/lab scores. Verify your scores at https://coursework.stanford.edu ***each week*** to ensure no grades were overlooked.

  When **you** choose to use computational tools (e.g., MotionGenesis, Matlab, C, etc.) to **avoid tedious calculations**, make sure **you** know what the computer is doing (it is not magic). Print out and submit the appropriate computational files (e.g., `.all` files) and include both input and ***output***.

Class participation and music

Class participation (and music) is facilitated by **LeAnn Duong** and **Alex Perkins** who will call on students to participate in demos, answer questions, and work out problems on the board.

Computer facilities

The symbolic manipulator MotionGenesis is used for various homework problems. e.g., **generating** and **solving** equilibrium equations. Alternately, you may choose to do numerical analysis with C, Fortran, or Matlab. The plotting capabilities in MGPlot, Matlab or Excel are useful for generating graphs. Student PC (Windows) and MAC (OSX) versions of MotionGenesis and MGPlot are available on the class website. Instructions for using these computer programs will be distributed in class. The software Working Model 2D may be used in several lab and in-class experiments.

Course conduct and the Stanford University Honor Code and Fundamental Standard

Students are required to uphold Stanford University's Honor Code and Fundamental Standard. Makeup exams are not given without university authorization. Exam grades are non-negotiable and exams will not be regraded. Exams, homework, labs, and other submitted material may be photo-copied by an instructor. Other than with an instructor, there is to be **no** class-related communication (no exchange of electronic devices, notes, homework, written material, or other information) during exams. Although you are ***encouraged*** to work with other students on homework and lab problems, it is expected that each student pass in his/her own homework and lab. Copying other students' homeworks or labs is a violation of the Honor Code.

Students with documented disabilities

Students who may need an academic accommodation based on the impact of a disability must initiate the request with the Student Disability Resource Center (SDRC) located within the Office of Accessible Education (OAE) 563 Salvatierra Walk (phone: 723-1066). SDRC staff will evaluate the request with required documentation, recommend reasonable accommodations, and prepare an Accommodation Letter for faculty dated in the current quarter in which the request is being made. Students should contact the SDRC as soon as possible since timely notice is needed to coordinate accommodations.

Dynamic Systems Syllabus

Date	Who	Assignment	Topic
09/22 Tu	P	Hw 1 assigned Lab groups	**Music: TBD by TAs.** Course introduction. What is a "dynamic system". **Demo: Babyboot**. **Class photos.** MIPSI problem solving methodology. Class road map in the context of ODEs. Math review: complex plane, logs, and trigonometry (circles, triangles, sine, cosine, amplitude-phase formula, and atan2 function).
09/24 Th	P		**Music: TBD by TAs.** Math review: differentiation, integration, the *good* product rule. Solutions of *first-order* ODEs by separation of variables and integration. Initial value problem for first-order ODE. Time constant. **Demo: Computer solution of nonlinear algebraic equations.**
Thurs-Mon	TAs	**Prelab due** **Go to lab**	**Motor spin-down test and first order response.** Experimentally determine the damping constants associated with a DC motor with dry Coulomb friction and/or viscous damping. **Hardware/software to be announced.**
09/29 Tu	P	**Hw 1 due** **Lab due** Hw 2,3 assigned	Classification of algebraic and differential equations. Knowing when to surrender to a computer. **Demo: Computer solution of nonlinear, inhomogeneous, ODEs for the babyboot.** This lecture brought to you by the letter e. The origins of e (e is for Euler, e is for engineer, e is for excellent). What is meant by "a solution to an ODE." Solutions of *first-order* and *second-order* ODEs by assumed solution.
10/01 Th	P		Mathematical and physical significance of ζ, ω_n, ω_d, period of vibration, decay ratio, logarithmic decrement, rise time, peak time, overshoot, settling time, and picking related control constants. **Demo: Slinky with numbers, ruler, scale, and stop watch.**
Thurs-Mon	TAs	**Prelab due** **Go to lab**	See the effect of varying ω_n, ζ, mass, spring constant, damping constant, or initial deflection on a dynamic system. Notice that period is unaffected by the initial displacement! Measure the decay ratio, damping ratio, damping constant, period, ω_n, ω_d, overshoot, and settling time. Experimentally determine m, b, and k. **Hardware/software to be announced.**
10/06 Tu	P	**Hw 2,3 due** **Lab due** Hw 4,5 assigned	Review of class road map. What is a mechanical engineer? Newton and thermodynamics. Design engineers and analysts. **Question of the day: Is the fundamental law of motion** $\mathbf{F} = \frac{dm\mathbf{v}}{dt}$ **or** $\mathbf{F} = m\mathbf{a}$**.** Aristotle and fundamental laws of *translational* motion: $\mathbf{F} = m\mathbf{v}$. **Demo: Nerf football**. Dissecting $\mathbf{F} = m\mathbf{a}$. Kinematics and vector review: dot-products, simple rotation matrices. The golden rule for vector differentiation. **Demo: Demonstrating the derivative of a vector with a bike pump.** Understanding translational and rotational kinematics via the inverted pendulum on a cart. Extending Newton's law to rigid bodies. Forces: Gravity, translational springs and dampers, and linear actuators (motors). **Demo: Bike pump as nonlinear spring/damper.** Springs in parallel and series. **Demo: Slinky.**

10/08 Th	P		**Question of the day: What is the fundamental law of rotational motion?** Torques: rotational springs/dampers, DC motors. **Demo: Metronome, rotational spring.** Fundamental laws of 2D and 3D *rotational* motion: Euler $\mathbf{T} = I\boldsymbol{\alpha}$? **Discussion of e-mails from engineers at Loral/Lockheed. Demo: Spinning book. Demo: Spin stabilization with gyroscope. Demo: Rattleback.**
Thurs-Mon	TAs	**Prelab due** **Go to lab**	**Bifilar pendulum.** Experimental determination of mass, center of mass, and moment of inertia of a physical object.
10/13 Tu	P	**Hw 4,5 due** **Lab due** Hw 6 assigned	**Demo: Energy exchange for translational motion with slinky and person-particle.** Power/energy-rate method for one DOF problems. Gear problems. **Demo: Energy exchange for rotational motion with powerbee.** Equivalent systems. **Demo: Harmonic forcing slinky experiments.**
10/15 Th	P		Solution and interpretation of 1st/2nd order, *inhomogeneous*, linear, constant-coefficient ODE. Harmonic forcing, resonance, the beat phenomenon. **Question of the day: Is resonance good?** Steady state amplitude and phase response to harmonic forcing. Real world application to whirl-flutter on XV22 Osprey. **Demo: Scotch-yoke/harmonic forcing. Demo: Harmonic forcing with an eccentric particle - earthquakes. Music Demo: DynamicSystemsSongCaltechNobelLaureateDavidPolitzer.mp3**
Thurs-Mon	TAs	**Prelab due** **Go to lab**	**Harmonic forcing.** Observe the effects of changing the mass m, damping constant b, spring constant k and forcing frequency Ω. **Hardware/software to be announced.**
10/18 Sun	TAs	**Review**	**Midterm exam review** in Terman 556, 6:15-7:45 p.m. (before E15 review)
10/20 Tu	P	**Hw 6 due** **Lab due**	***Midterm exam***. Exam room is Terman 556 for last names starting with A-M.
10/22 Th	P	Hw 7 assigned	Midterm solutions. Stability and interpretation of e^{pt} for real and/or complex values of p. Stability and roots to third and higher order ODE. Root locus.
Thurs-Mon	—	***No lab***	Halloween lab-vacation. Do not forget short homework due Tuesday!
10/27 Tu	P	**Hw 7 due** Hw 8 assigned	Basic electrical elements: resistors, capacitors and inductors and their measurement units. Parallel between electrical and mechanical elements? Torque motors and linear actuators as electrical elements (back-EMF and motor constants). Motor data sheets. Generating equations for electrical systems. Kirchoff current law. **Demo: Resistors, capacitors, inductors, motor with lamp.** Generators. **Demo: Generator radio and generator flashlight.** Sensors as electrical systems. **Demo: UFO Ball**. **Question of the day: Is God an EE, ChemE, ME, or CE? Question of the day: Is there a naturally occurring substance on Earth that is hotter than the sun's surface? Human sensors - how many fingers on back? Miracle ball - sensing human contact**

10/29 Th	P		Review of complex numbers. Engineering "proof" that all odd numbers are prime. Introduction to Laplace transforms. Converting an ODE in t (time) to an algebraic equation in s Laplace variable. Final value theorem and transfer functions. Generating rough sketches of time response using initial values, pole location, and the Final Value Theorem. Laplace transforms and steady state amplitude and phase response to harmonic forcing. **Demo: Working Model for MIPSI.**
Thurs-Mon	TAs	**Prelab due** **Go to lab**	**Electromechanical systems: Motors**. Observe the interactions between input voltage, armature resistance, motor damping, back-EMF, current, and motor RPM. Experimentally determine a motor's torque constant k_m and observe the relationship between motor voltage and motor speed.
11/03 Tu	P/P	**Hw 8 due** **Lab due** Hw 9 assigned	**Demo: MacScope demo of Fourier Series - amplitude vs. frequency for Soprano and Bass with good and raspy voices.** High-pass and low-pass electrical and mechanical devices. Understanding mechanical and electrical filters. **Demo of an electromechanical system: speakers and filters**. Simple RC circuits that act as high and low-pass filters of an audio signal.
11/05 Th	P		Understanding PID control system design. Block diagrams. Picking PID control constants by root locus and pole placement. **Demo: P and PI cruise control of a car on a hill with wind. Demo: Feedback control.**
Thurs-Mon	TAs	**Prelab due** **Go to lab**	**Working Model: PID control of dynamic systems.**
11/10 Tu	P	**Hw 9 due** **Lab due** Hw 10 assigned	**Demo: Simple particle pendulum.** Comparison of experimental and analytical results for small-angle approximation. **Demo: Car spinout.** Linearization of ODEs about a solution. **Demo: Rolling disk, Euler disk, Swinging Spring.**
11/12 Th	P/L		Review of matrix algebra: Determinants, inverse, solving sets of linear equations, eigenvalues/eigenvectors. Solutions of 2nd order, undamped, **coupled**, homogeneous, linear, constant-coefficient, ODEs. **Go Stanford. Beat CAL.**
Thurs-Mon		**Prelab due** **Go to lab**	**MIPSI on a dynamic system - counts as two labs.** Model, introduce identifiers, simplify, solve, and interpret a dynamic system of your own choosing.
11/17 Tu	A	**Hw 10 due** Hw 11,12,13 assigned	Solutions of **coupled** undamped ODEs continued. Eigenvalues and eigenvectors. Initial values. **Demo: Rotor modes**. **Demo: Wilbur force pendulum. Demo Tarm's FEA Bell**.
11/19 Th	P	**Lab due**	Modal damping. State matrix solution of **damped coupled** ODEs. **Demo: Spinning book/condensed milk revisited. Demo: Two particle slinky with damping.** Life lesson on suffering. Inscribed in WWII death camp. "I believe in the sun, even when it's not shining. I believe in love, even when I can't feel it. ..." Quote from movie Princess Bride: "Life is pain. Anyone who tells you differently is selling something." Country-western song: "Love's the only house big enough for all the pain in this world." **Job talk**.

Thurs-Mon	TAs	**Prelab due** **Go to lab**	**Controlling dynamic systems.** Conceptual understanding of feedback control of multi-degree of freedom systems. **Working Model: Inverted pendulum on a cart**. **Hardware/software to be announced.**
11/24 Tu	—	***Have fun***	Thanksgiving Holiday
11/26 Th	—	***Have fun***	Thanksgiving Holiday
12/01 Tu	P	**Hw 11,12,13 due** **Lab due**	State-space feedback control of multi-degree of freedom systems. **Demo: Student control of inverted pendula on a cart (pointer, ruler, broom-stick, croquet mallet with center of mass**. **Demo: Balancing Bear.**
12/03 Th	P		Course review. Course evaluations. Computer programs, e.g., **MotionGenesis**, Matlab, Working Model, and MSC.Adams, and their use in dynamic systems. **Class review:** Number line, algebra, trigonometry sine/cosine, amplitude-phase formulas, atan2, calculus (good product rule and fundamental theorem of calculus), behavior of e^{pt}, classification of algebraic and differential equations, uncoupled/coupled, linear/nonlinear, homogeneous/inhomogeneous, ... computer solution of linear/nonlinear algebraic equations, computer solution of linear/nonlinear ODEs, ODE solution via separation of variables and integration, ODE solution via assuming e^{pt}, damping constant, damping ratio, logarithmic decrement, decay ratio, undamped, underdamped, critically damped, overdamped, natural frequency, damped natural frequency, period of vibration, rise time, peak time, maximum overshoot, settling time root locus, stable, neutrally stable, unstable, kinematics (rotation matrices, angular velocity, golden rule of vector differentiation), dynamics (F=ma, M=dH/dt) Power/Energy-rate principle, Homogenous, particular, transient, and steady-state solutions, Harmonic forcing, resonance, motors, sensors, electrical circuits (voltage, current, resistors, inductors, capacitors, motor constants, back-EMF) complex numbers, complex algebra and exponentiation, Laplace transforms, transfer functions, sinusoidal transfer function, PID control of dynamic systems, Linearization (small angle approximations and Taylor series), Matrices and linear algebra (determinants, inverse, eigenvalues, eigenvectors), Undamped and damped coupled linear ODEs. State-space and control of multi-DOF systems. **Next classes:** E105 Controls; ME227 Vehicle Dynamics (Gerdes); ME281 Biomechanics of Human Movement (Delp); ME331B Advanced Dynamics (Mitiguy); ME309 FEA (Sheppard); CME200/ME300A Linear algebra; EE263 (Boyd). **Demo: Mode dance and physical significance of eigenvalues/vectors.**
12/06 Sun	TAs	**Review**	**Final exam review** in Terman 556, 6:30-8:30 p.m.
12/09 Wed	P	**Final exam**	***Final exam 7:00-10:00 p.m.*** Exam room is Terman 556 for last names N-Z.