DYNAMICS AND CONTROL OF MECHANICAL SYSTEMS

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PRE-REQUISITES : Basic UG level mathematics and engineering mechanics and basic programming knowledge.

INTENDED AUDIENCE : Primarily first year Master's and Ph D student in Mechanical Engineering and final year Undergraduate students as an elective.

INDUSTRY SUPPORT : Ashok Leyland, Chennai; Altair, Bangalore, L&T Technology Services,Vadodara; Government organizations such as ISAC-ISRO (Bangalore), BARC (Mumbai), HAL Bangalore, CAIR-DRDO (Bangalore); Educational institutions such NITs, IIST, and other engineering colleges.

COURSE OUTLINE :
This course deals with dynamics and control of mechanical systems. The main contents of the dynamics portion of the course are modeling and representation of rigid bodies in 3D space using position and orientation (rotation matrices, Euler angles, quaternions), system of rigid bodies with constraints, linear and angular velocities and accelerations of connected rigid bodies, inertia and external forces and moments acting on a rigid body, derivation and numerical solution of equations of motion obtained using Newton-Euler and Lagrangian approach, and small or ``linearized'' motion. The control part of the course starts with modeling and analysis of single-input-single-output (SISO) systems using state-space methods following naturally from the linearized equations of motion of the mechanical systems. The course also deals with design of controllers using state-space methods and the key concepts of stability, controllability and observability in linear systems. The control part also shows the connection to the traditional root locus and Bode plots used in analysis and design of single-input-single-output linear systems. This course involves use of Matlab for numerical simulations and introduces multi-body modeling and simulation tools such as Simscape.

ABOUT INSTRUCTOR :
Prof. Ashitava Ghosal is a Professor of Mechanical Engineering with joint appointments at the Centre for Product Design and Manufacturing and Robert Bosc Centre for Cyber Physical System at IISc, Bangalore since 1988. He completed his PhD from Stanford University, California, M.S from University of Florida, Gainesville, Florida and B.Tech from Indian Institute of Technology, Kanpur. His broad research area is in robotics and other computer controlled mechanical systems, nonlinear dynamics and product design. He is the author of "Robotics: Fundamental Concepts and Analysis" by Oxford University Press (2006) which is used as a textbook in many UG and PG programs in India and abroad. He has 5 patents, published 78 archival journal papers and 80 papers in national and international conferences. He has guided 16 PhDs and more than 70 Masters students at the Indian Institute of Science, Bangalore. He is currently Associate Editor of the international journals Mechanism and Machine Theory (Elsevier), Journal of Mechanisms and Robots (ASME), International Journal of Advanced Robotic Systems (SAGE) and has been an Associate Editor of ASME Journal of Mechanical Design (2006-2013) and Mechanics Based Design of Structures and Machines (Taylor & Francis) (2013 – 2020). He is currently a member of the Executive Committee of IFToMM (International Federation for the Promotion of Mechanism and Machine Science) and was elected as a fellow of the Indian National Academy of Engineering in 2010. More information is available at
https://mecheng.iisc.ac.in/~asitava

COURSE PLAN :

Week 1: Rigid body and coordinate systems, position and orientation, rotation matrices and their properties, Euler angles, quaternions, homogeneous transformation matrices and their properties, examples
Week 2: Linear and angular velocity of a rigid body, skew symmetric angular velocity matrix, space fixed and body fixed angular velocity, linear and angular acceleration, Coriolis/centripetal acceleration, velocities and accelerations in terms of Euler angles/ quaternions, examples
Week 3: Joints in multi-body systems, joint variables, Degree-of-freedom and constraints due to a joint and in multi-body systems, holonomic and non-holonomic constraints, velocity and acceleration of rigid bodies in a multi-body system, alternate system of coordinates and resulting constraints, examples
Week 4: Mass and inertia of a rigid body, Properties of inertia matrix, external forces and moments acting on a rigid body -- gravity, friction, actuator torque/forces, angular momentum – example of spinning top and gyroscope.
Week 5: Free-body diagram, Newton-Euler formulation and equations of motion, Introduction to recursive formulations, examples.
Week 6: Equations of motion using Lagrangian formulation – rolling of a thin disk in 3D, two link robot and 4-bar mechanism, solution of equations of motion in Matlab, comparison between Newton-Euler and Lagrangian formulation.
Week 7: Modeling and simulation of multi-body systems using computer tools, examples using Simscape.
Week 8: Linearization of equations of motion, state space formulation, state variables, solution of state equations
Week 9: Stability, controllability and observability in SISO systems, examples
Week 10: Root locus and Bode plots, relationships between classical and state space approaches
Week 11: Design of controllers using state space and root locus.
Week 12: Case studies in modeling and control – planar robot, pendulum on a cart, stabilization using gyroscope etc.