Robotics: Advanced Concepts and Analysis - Web course

COURSE OUTLINE

This course begins by introducing the subject of robotics, presents a brief history, types, classification and usage, and the science and technology of robots. Some of the useful and related links on robotics are mentioned.

Mathematical representations of rigid bodies in 3D space, the concept of a 4 x 4 homogeneous transformations and elementary screw theory, representation of joints, link representation using D-H parameters, different kinds of actuators (stepper, DC servo and AC motors, model of a DC servo motor), sensors (internal and external sensors, common sensors – encoders, tachometers, strain gauge based force-torque sensors, proximity and distance measuring sensors and vision) are presented.

Next the topics under kinematics of serial robot such as the direct and inverse kinematics problems and workspace, and advanced topics such as solution procedures using theory of elimination, inverse kinematics solution for the general 6R serial manipulator, redundant and over-constrained manipulators are discussed in depth.

The topics under kinematics of parallel robots, namely, degrees-of-freedom of parallel mechanisms and manipulators, constraint equations, direct and inverse kinematics problem, closed-form solution using theory of elimination and mobility are

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Mechanical Engineering

Pre-requisites:

- Under-graduate mathematics and basic linear algebra.
- Basic undergraduate kinematics and dynamics.
- Working knowledge of MATLAB or equivalent software.

Additional Reading:

1. Murray, R.M., Li, Z., and Sastry, S. S., A Mathematical Introduction to Robotic Manipulator, CRC Press, 1994.
2. Merlet, J.-P., Parallel Robots, Kluwer Academic, Dordrecht, 2001.
3. Featherstone, R.S., Robot Dynamics Algorithms, Kluwer Academic Publishers, 1987.
4. Haug, E.J., Computer-Aided Kinematics and Dynamics of Mechanical Systems: Basic Methods, Vol. 1, Allyn and Bacon, 1989.
5. Siciliano, B., and Khatib, O. (Editors), Handbook of Robotics, Springer, 2008.
6. Craig, J. J., Introduction to Robotics: Mechanics and Control, 2nd Edition, Addison-Wesley, 1989.
7. *Robotics: Fundamental Concepts and Analysis*, Oxford University Press, Second reprint, May 2008.
8. Research work of my students and recent papers as mentioned in modules.

theory of elimination and mobility are covered next. Several examples such as three-degree-of-freedom parallel manipulators and the Stewart platform manipulator and its variants are discussed in details.

The topics of velocity and static analysis of serial and parallel manipulators are discussed in a unified manner and the concepts of different kinds of singularities are discussed in details.

The course then deals with the dynamics of serial and parallel manipulators, formulation of equations of motion, recursive dynamics, and generation of symbolic equations of motion by a computer. Simulations of robots using software such as MATLAB and commercially available packages are also discussed in this part of the course.

Next, the topic of motion planning and control is discussed in depth. Various robot control techniques for serial and parallel manipulators, position and force control are presented. Both numerical simulation in Matlab and experiments on a five degree of freedom robots are presented.

In the later part of the course several advanced and state-of-art topics are discussed. The first topic deals with modeling and control of flexible serial robots. Next, the topic of wheeled mobile robots, modeling of slip, and design of slip-free wheeled mobile robots are presented.

The third advanced topic deals with Stewart platform and its singularities, use of singularities for fine motion and sensing, and design of Stewart platform based sensors. Next, the topic of over-constrained mechanisms and deployable structures is discussed. Finally the course covers, in brief, topics such as advanced concepts in robot control, nonlinear dynamics and chaos in robot control equations.

COURSE DETAIL

9. Material from other textbooks and robotics journals as mentioned.
10. All modules have **Additional Material** for self-study and reference

Hyperlinks:

1. http://www.mecheng.iisc.ernet.in/~asitava/contents.pdf
2. http://www.mecheng.iisc.ernet.in/~asitava/pub11.html
3. http://www.ai.mit.edu
4. http://robotics.stanford.edu
5. http://www.cs.cmu.edu/~chuck/robotpg/robofaq/TOC.html

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Sl. No	Topic	Number of Lectures
	Module 0: Preface, Information for Students and Teachers, Acknowledgement	
1	**Module 1: Introduction**	1
	Introduction -- brief history, types, classification and usage, Science and Technology of robots, Some useful websites, textbooks and research journals.	
2	**Module 2: Elements of robots – links, joints, actuators, and sensors**	5
	Position and orientation of a rigid body, Homogeneous transformations, Representation of joints, link representation using D-H parameters, Examples of D-H parameters and link transforms, different kinds of actuators – stepper, DC servo and brushless motors, model of a DC servo motor, Types of	

	transmissions, Purpose of sensors, internal and external sensors, common sensors – encoders, tachometers, strain gauge based force-torque sensors, proximity and distance measuring sensors, and vision.		
3	**Module 3: Kinematics of serial robots**	4	
	Introduction, Direct and inverse kinematics problems, Examples of kinematics of common serial manipulators, workspace of a serial robot, Inverse kinematics of constrained and redundant robots, Tractrix based approach for fixed and free robots and multi-body systems, simulations and experiments, Solution procedures using theory of elimination, Inverse kinematics solution for the general 6R serial manipulator.		
4	**Module 4: Kinematics of parallel robots**	5	
	Degrees-of-		

	freedom of parallel mechanisms and manipulators, Active and passive joints, Constraint and loop-closure equations, Direct kinematics problem, Mobility of parallel manipulators, Closed-from and numerical solution, Inverse kinematics of parallel manipulators and mechanisms, Direct kinematics of Gough-Stewart platform.	
5	**Module 5: Velocity and static analysis of robot manipulators**	5
	Linear and angular velocity of links, Velocity propagation, Manipulator Jacobians for serial and parallel manipulators, Velocity ellipse and ellipsoids, Singularity analysis for serial and parallel manipulators, Loss and gain of degree of freedom, Statics of serial and parallel manipulators, Statics and force transformation matrix of a Gough-Stewart platform, Singularity analysis and statics.	
6	**Module 6: Dynamics of**	4

	serial and parallel manipulators		
	Mass and inertia of links, Lagrangian formulation for equations of motion for serial and parallel manipulators, Generation of symbolic equations of motion using a computer, Simulation (direct and inverse) of dynamic equations of motion, Examples of a planar 2R and four-bar mechanism, Recursive dynamics, Commercially available multi-body simulation software (ADAMS) and Computer algebra software Maple.		
7	**Module 7: Motion planning and control**	6	
	Joint and Cartesian space trajectory planning and generation, Classical control concepts using the example of control of a single link, Independent joint PID control, Control of a multi-link manipulator, Non-linear model based control schemes, Simulation and experimental case studies on serial and parallel manipulators,		

	Control of constrained manipulators, Cartesian control, Force control and hybrid position/force control, Advanced topics in non-linear control of manipulators.	
8	**Module 8: Modeling and control of flexible robots**	4
	Models of flexible links and joints, Kinematic modeling of multi-link flexible robots, Dynamics and control of flexible link manipulators, Numerical simulations results, Experiments with a planar two-link flexible manipulator.	
9	**Module 9: Modeling and analysis of wheeled mobile robots**	3
	Introduction and some well known wheeled mobile robots (WMR), two and three-wheeled WMR on flat surfaces, Slip and its modeling, WMR on uneven terrain, Design of slip-free motion on uneven terrain, Kinematics, dynamics and static stability of a three-wheeled	

	WMR's on uneven terrain, Simulations using Matlab and ADAMS.	
10	**Module 10: Selected advanced topics in robotics**	3
	Introduction to chaos, Non-linear dynamics and chaos in robot equations, Simulations of planar 2 DOF manipulators, Analytical criterion for unforced motion. Gough-Stewart platform and its singularities, use of near singularity for fine motion for sensing, design of Gough-Stewart platform based sensors. Over-constrained mechanisms and deployable structures, Algorithm to obtain redundant links and joints, Kinematics and statics of deployable structures with pantographs or scissor-like elements (SLE's).	

References:

1. Ghosal, A., Robotics: Fundamental Concepts and Analysis, Oxford University Press, 2nd reprint, 2008.

2. Fu, K., Gonzalez, R. and Lee, C. S. G., Robotics: Control,

Sensing, Vision and Intelligence¸ McGraw- Hill, 1987.

3. Research papers from Instructors group and other researchers in the field.