Robotics and Mobility Systems (RMS)

1. Introduction

Robotics is an interdisciplinary field that cuts across domains of software, control, mechanics, sensing and electronics. With the emergence of high-speed computers, energy-efficient and responsive actuation and sensing systems and artificial intelligence, the field of robotics has made a long stride in the past decade toward achieving greater autonomy. Robots have found widespread applications not only in conventional industrial setups but also in service, medical, transport and many other industries. This has resulted in substantial growth in both usage of robots and demand for engineers with relevant specialisation.

The broader domain of Mobility is witnessing a change through the research and development of Electric Vehicles (EVs) and alternate green fuel driven mobility systems . The EV ecosystem is supported through significant research in battery technology and drive train design advancements. The newer chemistry in battery technology supported by advancements in manufacturing technology has led to a significant reduction in cost, weight and energy density of the batteries, and thus EVs have poised as a significant alternative to conventional vehicles. It is envisaged that different subsystems of EVs, and in particular, battery technology, continue its improvement cycle for the next several years and this fuels the penetration of EVs. With advancements in technology and broader applications, there has also been significant interest in developing unmanned aerial vehicles (UAVs) with small to large payload as a subclass of mobility systems. These mini flying vehicles offer the advantage of portability. Hence, it can be carried near the mission area for its deployment and gather necessary information about the surrounding terrain. Apart from surveillance, these UAVs with small payload capacity will help law enforcement, defense applications, agricultural survey, forestry, environmental monitoring etc.

In order to meet this increasing demand for engineers with diverse backgrounds in the field of robotic and mobility systems, and to support relevant research and development, an M.Tech. Programme in Robotics and Mobility System is designed. The proposed M.Tech. the programme will provide interdisciplinary learning opportunities to participate in one of the most challenging advanced technology areas. It is also envisaged that this programme will serve as a platform to test innovative ideas in the design, development, and testing of the Robotics and Mobility systems.

Eligible Branches: Mechanical Engineering, Electrical Engineering, Electrical and Communication Engineering, Computer Science and Engineering, Instrumentation and Control, Aerospace Engineering, Automobile Engineering, Aeronautical Engineering, Engineering Physics or Equivalent.

2. Objectives of the Program

The objectives of the programme are to

- produce competent engineers who can model, develop and control Robotics and Mobility systems
- impart in-depth knowledge and analytical and experimental research skills to handle Robotics and Mobility Systems problems
- provide knowledge of several tools for the design and analyses of Robotic and Mobility Systems.
- develop the ability to cultivate technological solutions for addressing growing demands of autonomy in robotic systems, electric vehicles, drones, and other next-generation mobility systems.

3. Graduate Attributes:

The graduates of this program will have:

1. The graduates of this program will have strong fundamentals in Robotic and Mobility systems.
2. Ability to understand methods of modelling, sensing, electronics, control, energy management, navigation and planning for robotic and Mobility systems.
3. Ability to design and analyze robotic and Mobility systems for individual and mass transportation, surveillance and manipulation.
4. Understanding of cutting-edge research on autonomous navigation, sensing and decision making, Communication and Battery Technology.
5. Ability to innovate and contribute towards the development of next-generation robotics and mobility systems.
6. High-quality technical communication skills.
7. Appreciation and adherence to norms of professional ethics.
8. Ability to plan and manage technical projects.

4. Learning Outcomes:

At the end of the program, a student is expected to have,

1. Understanding of the fundamentals related to modelling, control, and embedded computing of Robotics and Mobility systems
2. Knowledge of working principles of Robotics and Mobility robotic systems.
3. Knowledge of Autonomous Navigation of Robotics and Mobility Systems

4. Understanding of manipulation, motion planning and decision making, and teleoperation of Robotic Systems as a part of a micro specialization.
5. Understanding of battery technology, communication, IoT, and Associated EV Technology as a part of a micro specialization.
6. Developing awareness about recent trends such as machine learning, artificial intelligence, Computer Vision and networked systems.
7. Ability to apply the acquired knowledge for design, analysis and control of robotic and mobility systems.
8. Critical thinking and scientific problem-solving.
9. Skill to communicate scientific ideas and /or application systems.
10. Acquire basic project management skills

5. Topic Cloud for core courses

S. no.	Topics	Name of courses
1	General mobility principles, power /energy sources for the mobility, control and actuation, communication, modeling of traffic flow, vehicle to grid communication	Introduction to Mobility systems
2.	Classification and modeling of unmanned vehicles, Control of aerial, ground, and underwater unmanned vehicles, Sensors for unmanned vehicle development, Sensor data processing and fusion, Actuators for unmanned vehicles, Intra-vehicle and inter-vehicle communication technologies	Unmanned Vehicles
3.	3D Transformation, Position Kinematics, Jacobian, EL, NE Formulation, Motion Planning, Vision-based, control, Joint Control, Model-based control, Force Control	Robotics
4	Embedded system design process, processors architecture, Memory system and Memory management, Multicore Architecture,Programming of Embedded processors , Hardware software co-design, real time operating systems, scheduling algorithms	Embedded system Design
	Programming processors, Interfacing with i/o devices , interaction with processors, Interfacing sensors	Embedded system design lab
5	Introduction to Autonomous Systems, Agent Architectures, real-time systems, design of autonomous vehicle, planning, navigation, localization, multi-agent systems, game theory	Autonomous systems

5.2 List of core courses:

S. No.	Name of the course	L-T-P	Contact hours	credit
1	Introduction to mobility systems	3-0-0	3	3
2	Unmanned vehicles	3-0-0	3	3
3.	Mobility system and Unmanned vehicle Lab	0-0-2	2	1
4.	Robotics	3-0-2	5	4
5.	Embedded system design	3-0-0	3	3
6.	Embedded system design lab	0-0-2	2	1
7.	Autonomous system	3-0-0	3	3
	Total	**15-0-6**	**21**	**18**

6. Program's Structure for M.Tech. (Robotics And Mobility System)

S.N.	Course Type	Credits
1	M.Tech. Compulsory (MC)	18

2	M.Tech. Micro Specialization Core (MSC)	9
3	M.Tech. Electives (ME)	7
4	M.Tech. Open (MO)	6
5	M.Tech. Project (MP)	16
	Total Graded	**56**
6	Non-Graded (NG)	4
	Total	**60**

*It is mandatory to do a minimum of 9 credits in one of the microspecialisations.
*All Microsecipalization electives will also be available to students as program electives

6.1 Course Structure: Semester wise distribution of credits

Cat	*Course Title*	*L-T-P*	*Cr*		*Cat*	*Course Title*	*L-T-P*	*Cr*
I Semester					**II Semester**			
MC	RML 7020 Introduction to mobility systems	3-0-0	3		MC	EEL7xx Embedded system Design	3-0-0	3
MC	RML 7030 Unmanned vehicles	3-0-0	3		MC	EEP7XX Embedded system Design lab	0-0-2	1
MC	RMP 7020 Mobility systems and Unmanned vehicles Lab	0-0-2	1		MC	CSL 7650 Autonomous systems	3-0-0	3
MC	MEL 7080 Robotics	3-0-2	4		ME/MSC	*Program Elective/Microspecilazation Core*	3-0-0	3
ME/MSC	*Program Elective/Microspecilazation Core*	3-0-0	3		ME/MSC	*Program Elective /Microspecilazation Core*	3-0-0	3
NG	*Technical Communication*	3-0-0	1		NG	*Professional Ethics*	1-0-0	1
Total (Graded+Non-graded)			**14+1**		*Total (Graded+Non-graded)*			**13+1**
III Semester					**IV Semester**			
MP	Project	0-0-5	5		MP	Project	0-0-11	11
ME/MSC	*Program Elective /Microspecilazation Core*	3-0-0	4		MO	*Open Elective*	3-0-0	3
ME/MSC	*Program Elective/Microspecilaz atiCore*	3-0-0	3		NG	*IP Management and Exploitation*	1-0-0	1
MO	*Open Elective*	3-0-0	3					
NG	*Systems Engineering and Project Management*	1-0-0	1					
Total (Graded+ Non-graded)			**15+1**		*Total (Graded+Non-graded)*			**14+1**

7 Microspecializations

1. Autonomous Mobile Robots [AMRs]
2. Unmanned Aerial Vehicles [UAVs]
3. Electric Vehicles (EVs)

7.1 Topic cloud of Microspecializations core

Microspecializations in Autonomous Mobile Robots

	Topic Cloud	Course
1	Kinematics of wheeled mobile robots, Dynamic model of differential drive robot, Reference position control, Trajectory tracking control,, Feedback linearization, Lyapunov-based control design, Collective coordination and control, Basic principles of navigation, Model-based robot path planning, robot localization and mapping	Mobile Robots [3]
2	Introduction to AI, Propositional logic , Search, Predicate logic, Rule-based systems, Constraint satisfaction problems,Planning, Uncertain Reasoning: Fuzzy logic	Artificial Intelligence [3]
3	Formation, Filtering, Transformation, Image Restoration, Geometry , Segmentation, Feature Description and Matching, Deep Learning based Segmentation and Recognition	Computer vision [3]

Microspecializations in UAVs

	Topic Cloud	Course
1	Modelling techniques, dynamics of fixed-wing, rotary-wing and flapping wing vehicles.	Flight Mechanics
2.	Feedback control of UAV, Motion planning, Linear and Nonlinear control law, Distributed control, Swarm dynamics and control, Stability	UAV Control
3.	Random Processes, Least-Squares Problems, Kalman Filter, INS, GPS, Vision based navigation, Guidance	Estimation navigation and guidance

Microspecializations in EVs

	Topic Cloud	Course
1	Characteristics and limitations of power semiconductors, Mathematical modeling of power converter topologies including resonant converters, PWM Techniques in power electronics, Soft switching techniques, Drive circuits, Input and output filter design for power converters, Feedback loop compensation and stability analysis, Design of Magnetic components, Thermal Consideration for Power converter design, Introduction to Electro-Magnetic Compatibility: EMC Basic knowledge, PCB layout, Failure analysis Techniques	Automotive Electronic Design
2	Introduction, Configurations and components of electric drives, Architectures of EVs, DC Series Motor, Brushless DC Motor, Permanent Magnet Synchronous Motor, Three Phase AC Induction Motor, Switched Reluctance Motors, Synchronous Reluctance Motor	Special Drives for Electric Vehicles
3.	Cell models, SOC estimation, SOH estimation, Battery pack balancing	Battery Management System

7.2 Summary of Microspecialization core courses

s.No.	Microspecialization	Microspecialization core course
1.	Autonomous Mobile Robots	RML7220 Mobile Robots [3] CSL7XX Artificial Intelligence [3] CSL7xx Computer Vision [3]
2.	Unmanned Aerial Vehicles	RML 7250 Flight Mechanics [3] RML 7260 UAV Control [3] RML 7270 Estimation navigation and guidance [3]

3.	Electric Vehicles	EEL7XX Automotive Electronic Design [3] EEL7XX Special Drives for Electric Vehicles [3] CHL7XX Battery Management System (BMS) [3]

8. Program Electives Topic cloud

8.1 Robotics

	Topic Cloud	Course
1	Kinematics and Dynamics Branched Robotic systems, Redundancy, Task Level Control, Contact Modelling, Grasping, Cooperative Manipulation, Human-Robot Interaction	Advanced Robotic Manipulation [3]
2	Fundamentals of probability, Optimization-based Control, Markov Decision Processes, Motion Planning, Kalman Filtering, KF parameter estimation, Particle Filters, Introduction to Reinforcement Learning and Deep RL, Value and policy gradient-based methods, Deep RL for Motion Planning	Planning and Decision Making for Robots [3]
3	ROS Architecture, Environment, Nodes, ROS Topics, Messages, Publisher, Subscriber, ROS Services and Actions, Debugging Tools, Plotting and Data Visualization. Unified Robotic Description Format (URDF), Integration with various Libraries such as OpenCV, Creating ROS Drivers	Robot Operating System [3]
5	Basic Aerial Robot Flight Concepts, Micro-aerial vehicle, Frame Rotations and Representations, Aerial robots equations of motion, State-Space Form, Time, Motion, and Trajectories, Linearization, 2-D and 3-D control of Aerial robots, PID Control, LQR control, Motion planning, Collision-free Navigation, Sensing and Estimation, Vision-based Guidance for aerial robots	Aerial Robots [3]
6	Telerobotics, teleoperation, haptics, Applications: minimally-invasive surgery, surgical simulators, exoskeletons and assistive devices, computer-aided design, space teleoperation, and entertainment, Telerobotic control architectures, Haptics in teleoperation, Mathematics of teleoperation and haptics, Internet-based teleoperation	Tele-Robotics [3]
7	Vision of Sociable Robots, Anthropomorphism, and Design, Intentions, Intentionality, and Perceiving other Minds, Social Learning, Human-compatible Perception, Robots and ethics, Human Robot Interaction, Designing of Sociable Robot,	Social Robotics [3]
8	Feedback control, observer dynamics, stability results, Event-triggered control, robust and optimal control laws, Multi-agent control	Advanced Control Systems [3]
9	Supervised Learning, Unsupervised Learning, Generative Models, Computational Learning Theory and Deep Neural Networks	Machine Learning [3]

8.2 Mobility Ststems

	Topic Cloud	Course

1.	Unsteady lift mechanisms; Kinematics of flapping flight; Governing equations and scaling laws; rigid wing and aeroelasticity;	Flapping and rotary-wing aerodynamics
2	Introduction to vehicular networks and applications, Intra-vehicle Communications, V2X Communications, Medium Access Control Protocols for Vehicular Networks, Routing in Vehicular Networks, Security and privacy in vehicular networks	Vehicular Ad-hoc Networks (VANETs)
3	Recapitulation of fluid dynamics, Viscid/Inviscid flows, Incompressible airfoil flows, Incompressible finite wing flows, Hydrodynamics	Aerodynamics and Hydrodynamics of unmanned vehicles
4	Batteries for EVs, Ultracapacitors for EVs, Fuel cells for EVs	Storage materials and devices for electric vehicles
5	Introduction, EV Charging standards and connectors, Converter topologies for Plug-In charging, Converter topologies for Wireless charging, XFC station concepts and converter topologies, Battery Management system, V2G technology, Health and safety concerns	Charging Infrastructure for Electric Vehicles
6	Functional safety of Electric Vehicles and risk/hazard assessment, Automotive Safety Integrity Level (ASIL) certifications and ISO 26262 standards	Functional Safety for EVs
7	Vehicle-to-grid communication, grid-to-vehicle communication, and vehicle-to-vehicle communication system, *Intelligent Systems, Security issues,* state-of-health estimation for battery systems, *Monitoring and Modelling*	Intelligent System and Security for EVs
8	EV Integration to Smart Grid, Impact Assessment of EVs on Grid, Energy Market with EVs	Grid Integration of EVs
9	Electrochemical principles, Hydrogen Production, Fuel Cell, Fuel Cell for Automotive Application	Hydrogen Fuel for Transportation

8.3 Common Programme Electives

- Internet of Things, Cyber-Physical Systems and Security, Traffic System and Management
- Wireless Communication, Vehicular Ad-hoc Networks (VANETs), UAV Assisted Wireless Networks, Network Systems and Data Communications,
- Real-time systems,
- Sensors, Measurements, Computer Vision, AR & VR, Haptics
- AI, ML, Deep Learning
- Vehicle Dynamics, Noise and Vibration Control
- Electrochemical principles, Hydrogen Production, Fuel Cell, Fuel Cell for Automotive Application
- Feedback control, observer dynamics, stability results, Event-triggered control, robust and optimal control laws, Multi-agent contro

8.1 Program Elective courses:

Robotics	Mobility systems
Advanced Robotic Manipulation [3] Planning and Decision Making for Robots [3] Robot Operating System [3] Aerial Robots [3] Tele-Robotics [3] Social Robotics [3] Advanced Artificial Intelligence [3]	Energy Storage [3], Traffic System and Management [3] UAV Assisted Wireless Networks [3] Hydrogen Fuel for Transportation [3]# Aerodynamics and Hydrodynamics of unmanned vehicles [3]# Flapping and rotary-wing aerodynamics [3]# Wireless Communication [3] Storage materials and devices for electric vehicles [2]'# Charging Infrastructure for Electric Vehicles [3]# Functional Safety for EVs [1]# Intelligent System and Security for EVs [3]# Grid Integration of EVs [2]# Vehicle Dynamics [3] Noise and Vibration Control []
Machine Learning [3], Deep Learning [3], Advanced Control Systems [3] Networked Dynamical Systems and Control [3], Data Communication and Networking [3], Introduction to AR VR [3], Introduction to Haptics [3] Introduction to Internet of Things [3] Sensors and Measurement [3] Introduction to Cyber-Physical Systems [3]	

Note:

- #Newly Designed Programme Electives
- All Microsecipalization electives will also be available to students as program electives.

MTech Core courses:

Title	**Mobility Systems**	Number	**XXX7XXX**

Department	IDRP: Robotics & Mobility Systems	L-T-P [C]	3-0-0 [3]
Offered for	M. Tech. Robotics & Mobility Systems	Type	Program Core (PC)
Prerequisite	-		

Objectives

1. The course will provide introductory concepts of different kinds of mobility systems
2. The course will provide introduction to different subsystems used in different kinds of mobility.

Learning Outcomes

The students are expected to gain knowledge on:
1. Different subsystems of mobility like Power Sources, control and actuation, Transmission, Communication etc.
2. Traffic flow modelling and vehicle to grid integration.

Content

General Mobility [7 Lectures]
Air Vehicles, Ground Vehicles, Under-Water Vehicles,Transportation System, Space Vehicles, Exploration and Surveillance systems

Power Sources: [7 Lectures]
Wired power sources; Stored/portable power sources such as gasoline/hydrogen/synthetic fuels (chemical), batteries (electrochemical), capacitors/ supercapacitors (electrical); Vehicles with conversion type power devices such as fuel cells, solar cells; Hybrid power sources, Vehicle to Grid Integration

Transmission: [7 Lectures]
Concept of Linkages, Gears, Cams, Hybrid Vehicle transmission / electric vehicle transmission, Transmission for Air Vehicles, Transmission systems in ships

Actuation and Control: [7 Lectures]
Overview of Vehicle Control Unit (VCU), air-fuel ratio control, steering control, speed control, cruise control, transmission control, brake system, Vehicle stability, four-wheel steering, suspension system, Roll Dynamics and Rollover Prevention.

Communication: [7 Lectures]
Introduction to vehicular networking and applications Vehicular network architectures and characteristics Introduction to intra-vehicle and inter-vehicle communication technologies Standardization aspects (IEEE, ETSI and 3GPP

Modelling of Traffic Flow [7 Lectures]
Elements of traffic flow-Road, User, and Vehicle Characteristics, Continuum approach of traffic flow modelling, Car following models, Traffic flow theory in the era of autonomous vehicles.

Reference books

1. Ali Emadi, Mehrdad Ehsani, John M. Miller (2004), Vehicular Electric Power Systems Land, Sea, Air, and Space Vehicles, Taylor & Francis
2. G K Awari et.al. Automotive Systems: Principles and Prectice (2013), CRC Press, Taylor, and Francis
3. Ulsoy, A. Galip, Huei Peng, and Melih Çakmakci. Automotive control systems. Cambridge University Press, 2012.
4. Thomas W Birch (2012), Automatic Transmission and transaxles, Pearson Education
5. H. Moustafa, Y. Zhang, (2009), Vehicular Networks: Techniques, Standards, and Applications, 1st Edition, Auerbach Publications
6. Ni., D. Traffic Flow Theory: Characteristics, Experimental Methods, and Numerical Techniques, Elsevier, 2015 (1st Edition)

Title	**Unmanned Vehicles**	Number	**XXX7XXX**
Department	Mechanical Engineering & Electrical Engineering	L-T-P [C]	3–0-0 [3]
Offered for	M. Tech, RMS	Type	Compulsory
Prerequisite	Fundamentals of Control Theory		

Objectives

The instructor will:

1. Provide knowledge of modelling and control of unmanned ground, aerial, and under water vehicles
2. Discuss various kinds of sensors and actuators used in the control of unmanned vehicles along with advantages and limitations
3. Discuss different communication protocols required for in-vehicle and V2X communications

Learning Outcomes

The students are expected to have the ability to:

1. Understand the design and development of unmanned vehicles for different applications (including aerial, ground, and underwater)
2. Understand the communication and networking aspects of the unmanned vehicles

Contents

Classification, Modelling, and Control Aspects of Unmanned Vehicles: (14 Lectures)

- Discussion on different types of unmanned vehicles: ground (wheeled and legged), aerial (fixed, flapping, and rotary wings), underwater vehicles *(5 Lectures)*
- Modelling of unmanned vehicles considering basic forces, kinematics, and dynamics *(4 Lectures)*
- Discussion on different types of control for aerial, underwater (fins and propulsion control), ground (biped and quadruped motion control for legged robots) *(5 Lectures)*

Sensors and Actuators: (14 Lectures)

- Discussion on different types of sensors used in unmanned vehicles (proximity, IMU, magnetometers, thermal imaging, vision, LiDAR, GPS, RTK, etc.) and their characteristics (4 Lectures)
- Sensor data aggregation, processing, and sensor fusion (5 Lectures)
- Introduction to popular computing platforms for data processing (1 Lecture)
- Different types of actuators: motors, servos, harmonic drive, linear actuators (4 Lectures)

Communication and Networking Protocols: (14 Lectures)

- Introduction to in-vehicle and vehicle to anything (V2X) communications (2 Lectures)
- In-vehicle communication technologies (6 Lectures): Bluetooth, CAIN, LIN
- Vehicle to Anything communication technologies (5 Lectures): Cellular, DSRC, MAVLink
- QoS, QoE Requirements [1 Lecture]

Textbook

1. U. Ozguner, T. Acarman, Keith Redmill, (2011), *Autonomous Ground Vehicles*, 1st Edition, Artech House Publishers
2. Sahiba Wadoo, Pushkin Kachroo, (2011), *Autonomous Underwater Vehicles: Modeling, Control Design and Simulation*, 1st Edition, CRC Press
3. Kenzo Nonami et. al., (2010), *Autonomous Flying Robots: Unmanned Aerial Vehicles and Micro Aerial Vehicles*, 1st Edition, Springer
4. C. Sommer, F. Dressler, (2014), *Vehicular Networking*, 1st Edition, Cambridge University Press
5. H. Sjafrie, (2019), *Introduction to Self-Driving Vehicle Technology*, 1st Edition, Chapman and Hall/CRC

Reference Books

1. C. Venkatesan, (2014), *Fundamentals of Helicopter Dynamics*, 1st Edition, CRC Press
2. John D. Anderson, (2015), *Introduction to Flight*, 8th Edition, McGraw-Hill Education
3. Rajendra Jani, (2009), *Development of an autonomous underwater vehicle - Hydrocopter - A systematic approach to effective low cost design, manufacture and testing of underwater vehicles*, 1st Edition, VDM Verlag

Title	**Mobility Systems and Unmanned Vehicles Lab**	Number	**XXX7XXX**
Department	Mechanical Engineering & Electrical Engineering	L-T-P [C]	0–0-2
Offered for	M. Tech, RMS	Type	Compulsory
Prerequisite	Fundamentals of Control Theory		

Objectives

The instructor will:

1. Provide the knowledge of various mobility systems and unmanned vehicles.
2. Help students to realize different algorithms and sensing, control and navigation techniques which are applicable for mobility systems and unmanned vehicles.

Learning Outcomes

The students are expected to have the ability to:

1. design and implement different algorithms and techniques for mobility systems and unmanned vehicles.

Contents

Mobility Systems Lab Component (06 Sessions)

- Load test on DC series Motor to understand the behavior during the running conditions.
- Field test on DC series Motor to understand the motor characteristics.
- Fabrication and charging discharging of lead acid battery
- Charging discharging cyclability and rate capabilities of li ion batteries

Unmanned Vehicles Lab Component (06 Sessions)

- Data acquisition and analysis with different sensors used for unmanned vehicles
- Experiments related to drift measurement, navigation data analysis, motor control and propeller study, encoders, thrust and torque measurement
- Development of remotely controlled vehicles using demonstration kits (aerial and ground)
- Integration of sensors using embedded systems, integration of communication modules

Title	**Robotics**	Number	MEL7080
Department	Mechanical Engineering	L-T-P [C]	3-0-2 [4]
Offered for	B. Tech, M. Tech and PhD	Type	Program Core
Prerequisite			

Objectives

1. To introduce fundamental aspects of modeling and control of robot manipulators.
2. To provide a brief of results from geometry, kinematics, dynamics, motion planning and control

Learning Outcomes

1. The course will equip students with theoretical and practical knowledge of robot modeling, programming and control.

Contents:

Fractal I: Robot Modeling [1-0-0]

Position Kinematics: Transformations, Rigid Motions, Forward Kinematics: Denavit-Hartenberg Convention, Inverse Kinematics [6 lectures]

Velocity Kinematics – The Jacobian: Angular and Linear Velocity: Singularities, Accelerations [4 lectures]

Robot Dynamics: Equations of Motion, Kinetic and Potential Energy, Euler-Lagrange Equations, Recursive Newton-Euler Formulation [4 lectures]

Fractal II: Robot Motion Planning and Visual Servoing [1-0-0]

Path and Trajectory Planning: Path vs. Trajectory, The Configuration Space, Path Planning in Configuration Space, Probabilistic Roadmap Planner, Potential Fields, RRTs, Trajectory Planning, Point To Point Motion, Paths Specified by Via Points, [7 lectures]

Visual Servoing: The Geometry of Image Formation, Camera Calibration, Camera Motion and Interaction Matrix, Image-Based Control Laws, Relation between End Effector and Camera Motions, Partitioned Approaches [7 lectures]

Fractal III: **Robot Control [1-0-0]**

Linear Control: Feedback and closed-loop control, second-order linear systems, control of second-order systems, Control-law partitioning, trajectory-following control, disturbance rejection, Continuous vs. Discrete time control, modelling and control of a single joint, architecture of an industrial-robot controller [6 lectures]

Nonlinear control: Nonlinear and time-varying systems, multi-input, multi-output control systems, control of manipulators, practical considerations, Lyapunov stability analysis, cartesian-based control systems, adaptive control [5 lectures]

Force Control: Interaction with Environment, Force Control, Hybrid Force/Motion control [3 lectures]

Laboratory Classes (12 exercises)

DH Parameters, Forward and Inverse Kinematics of Robot, Robot Trajectory Planning, Robot Operating System (ROS), Control of Robot through ROS, Path Planning, Vision Based control, Force Control

Reference Books

1. Saha S. K., Introduction to robotics. Tata McGraw-Hill Education
2. Spong M. W., Hutchinson, S., and Vidyasagar, M., Robot modeling and control. New York: Wiley.
3. O'Kane J. M., A Gentle Introduction to ROS, ISBN 978-1492143239
4. Craig J. J, Introduction to robotics: mechanics and control. Pearson/Prentice Hall.

Self Learning Material

1. https://see.stanford.edu/Course/CS223A

Title	**Embedded System Design**	Number	EEL7XX0
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech. Cyber Physical Systems	Type	Core
Prerequisite	Basics of Microprocessors		

Objectives

The Instructor will:

1. introduce concepts of different architectures and programming languages of embedded processors
2. Introduce design of embedded systems.

Learning Outcomes

The students are expected to have the ability to:

1. program and to design embedded system using 32-bit embedded processors based on system specifications.
2. use different IDE and debugging tools.

Contents

Review of Embedded Computing; embedded system design process; CPS and embedded Computing (3 Hours)

Architecture of ARM Cortex M3 and Cortex A series processors; Memory system mechanism; Cache; Memory management units and address translation; Performance assessment of embedded processor; Introduction to Embedded Multicore Architecture (16 Hours)

Programming of Embedded processors using assembly and C; models for program --data flow graphs; Assembly language programming of ARM Cortex M3; Hardware software co-design; (13 Hours)

Processes and real time operating systems; Multi-rate system; real time scheduling algorithms e.g. RMA,EDF and their variants; Energy efficient scheduling algorithms; Examples of design of embedded systems. (8 Hours)

Textbook

1. JoshephYiu, (2013), The definitive Guide to ARM Cortex M3 and M4 Processors, 3 rd Edition, Elsevier.
2. Marilyn Wolf, (2014), High Performance embedded Computing: Applications in Cyber Physical Systems and Mobile Computing, 2 nd Edition, Elsevier.

Self-learning Material

1. Prof. Santanu Chaudhary, Introduction to Embedded Computing, NPTEL Course Material, Department of Electrical Engineering, Indian Institute of Technology Delhi, https://nptel.ac.in/courses/108102045/#

Online Course Material

1. Marilyn Wolf, Computers as Components: Principles of Embedded Computing System Design, Third Edition, Elsevier 2012.

Title	**Embedded System Design Laboratory**	Number	EEL7XX0
Department	Electrical Engineering	L-T-P [C]	0–0–2 [1]
Offered for	M.Tech. Cyber Physical Systems	Type	Core
Prerequisite	Basics of Microprocessors		

Objectives

The Instructor will:

1. design experimentations to ensure students get practical exposure for embedded system design tools.
2. introduce students overall design process of embedded systems using Integrated Development Environment (IDE).

Learning Outcomes

The students are expected to have the ability to:

1. use assembly and high level languages to program 32-bit processors
2. design interfacing circuits for embedded processors

Contents

Programming Cortex M3 processors using assembly and C language; Interfacing the processors with LCD, Seven Segment; DC Motor; Key board etc.; use of serial communication with processors; Interfacing sensors through ADC

Title	**Autonomous Systems**	Number	CSXXX0
Department/ IDRP	Robotics and Mobility Systems and CSE	L-T-P [C]	3-0-0 [3]
Offered for	M.Tech.	Type	Specialization Core
Prerequisite			

Objectives

1. Provide an understanding about autonomous/ semi-autonomous systems like autonomous mobile robots and cars.

Learning Outcomes

1. Understand and use the methodologies to design, model and implementation of autonomous systems for real time applications.

Contents: (This course is superset of Real Time Autonomous System offered for M.Tech. in AI and include two fractals from the course)

Fractal I: Introduction to Agent Systems [14 Lectures]

Introduction to Agents, Agent Architectures [4]
Multi-agent Systems and Society of Agents [4]
Distributed Problem Solving and Planning [5]
Case Study: Collaborative Robotics, Robocup [2]

Fractal II: Architecture of Autonomous Systems [14 Lectures]

Degree of Autonomy, Reactive Systems, Real-time Systems [4]
Architecture of AGV's [2], AUV [2], Drones[4]
Tele-Operation, AR, VR applications [2]

Fractal III: Design of Autonomous CAR [14 Lectures]

Sensors for Navigation: Camera, GPS, IMU, Lidar, Odometry, Place Recognition, Extraction based on Range Data [4 lectures]
Localization: Noise and Aliasing, Belief Representation, Map Representations, Probabilistic Map based localization, Autonomous Map Building, [5 lectures]
Planning and Reacting, Path Planning, Obstacle Avoidance, Navigation Architectures, Data Fusion [5 lectures]

Reference Books

1. Roland Siegwart, Illah Reza Nourbakhsh, Davide Scaramuzza(2018),Introduction to autonomous mobile robots, MIT press.
2. Gerhard Weiss ed. (2013), Multiagent System, Second Edition, MIT Press.
3. Stuart J. Russell and Peter Norwig (2019), Artificial Intelligence: A Modern Approach, 4th edition,Pearson Press
4. Spyros G. Tzafestas (2014), Introduction to Mobile Robot Control, Elsevier
5. Gerald Cook (2011), Mobile Robots: Navigation, Control and Remote Sensing, Wiley.
6. Choset, H. M., Hutchinson, S., Lynch, K. M., Kantor, G., Burgard, W., Kavraki, L. E., &Thrun, S. (2005). Principles of robot motion: theory, algorithms, and implementation. MIT press.

Online Course Material:

1. https://www.edx.org/course/autonomous-mobile-robots

Autonomous Mobile Robots Core Courses
(All Courses are existing senate approved courses)

UAV Microspecializations Core Courses

Title	**Flight Mechanics**	Number	MEL7XX
Department	Mechanical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M. Tech/PhD	Type	Program Elective
Prerequisite	Aerodynamics and Hydrodynamics of unmanned vehicles		

Objectives

1. Basics of flight dynamics
2. Understanding equilibrium and stability
3. Flight control systems

Learning Outcomes

1. Apply the simplified equations of motion for analyzing various motion profile
2. Equilibrium and stability analysis of flight
3. Control

Contents

Fixed Wing Flight Dynamics: Level flight equilibrium and corresponding forces and moments, simplified equation of longitudinal motion including the concept of neutral point and manoeuvres, lateral-directional equations of motion including forces and moments, concepts of short period, phugoid, roll and yaw motions and their stability (14 lectures)

Rotary Wing Flight Dynamics: Forces and moments acting on a rotary-wing vehicle, simplified dynamic models for Heave dynamics, pitch-roll-yaw dynamics (14 lectures)

Flapping wing flight dynamics: Forces and moments on a flapping vehicle and simplified equations of motion, pitch, roll and yaw motion profiles, their stability and control (14 lectures)

Textbook

1. Nelson, R.C., 'Flight Stability and Automatic Control', SIE, 2017
2. Padefiled, D, (2008) Helicopter Flight Dynamics, AIAA series,
3. Venkatesan, C. (2014), Fundamentals of Helicopter Dynamics, CRC Press.
4. Bernard Etkin, 'Dynamics of Flight: Stability and Control', Wiley, 1995

Reference Books

1. NPTEL Lectures, Helicopter dynamics and aerodynamics
2. Orlowski CT, Girard AR. Dynamics, stability, and control analyses of flapping wing micro-air vehicles. Progress in Aerospace Sciences. 2012.

Title	**Unmanned Aerial Vehicle Control**	Number	RML
IDRP	Robotics and Mobility Systems	L-T-P [C]	3-0-0
Offered for	B. Tech (All Branches), M.Tech, PhD	Type	Elective
Prerequisite	Classical Control Systems		

Objectives

The Instructor will:

1. To provide general knowledge of on controlled systems and its application to Unmanned Aerial Vehicles
2. To understand basic issues and challenges related to UAV control and motion planning.

Learning Outcomes

The students are expected to have the ability to

1. Regulate the behavior of UAV systems by designing several control and sensing algorithms.

Contents

Introduction: [5 lectures] *Introduction to UAVs, Classifications, key components, Applications of UAVs, Challenges.*

Modeling:[10 lectures] Frame Rotations and Representations, Quaternions, *Lagrangian methods, UAV Equation of motion, Model of fixed-wing UAV, quadrotor and PVTOL aircraft etc.,* Aerodynamic loads, *State space representation of UAV dynamics*

*Sensing, flight planning and control: [*17 lectures*]:*

[7 lectures*]*

UAV mission planning, Time, Motion, and Trajectories, *Sensors for mission, Path and trajectory planning, localization using inertial sensors and satellite positioning system, Estimator for sensor fusion, guidance and obstacle and collision avoidance*

[10 lectures*]*

Feedback linearization, 2-D and 3-D control of UAV , concept of equilibrium points, *motion control: Linear and nonlinear control laws, Trajectory tracking, Stability results.*

Control of interconnected UAVs [10 lectures]*: Swarm, modeling of interconnected UAVs, Control strategies for interconnected UAVs, Trajectory generation and path planning for a team of UAVs, stability analysis of connected UAVs and swarms.*

Textbook

1.Vachtsevanos,G.J. and Valavanis,K.P.(2015), *Handbook of Unmanned Aerial Vehicles*, 3rd Edition, Springer

2. Fahlstrom,P.G., and Gleason, T.J.,(2012), Introduction to UAV Systems, 4th Edition, Wiley.

Online Course Material

1.Vijay Kumar, Aerial robotics, University of Pennsylvania, Link: https://www.coursera.org/learn/robotics-flight#syllabus.

Title	**Estimation, Navigation and Guidance**	Number	
Department	IDRP RMS	L-T-P [C]	3-0-0
Offered for		Type	
Prerequisite			

Objectives

The Instructor will:

1. Provide knowledge of filtering, navigation and guidance techniques.
2. Help to understand basic issues and challenges related to filtering, navigation and guidance techniques.

Learning Outcomes

The students are expected to have the ability to:

1. Apply the obtained knowledge in various applications.

Contents

Estimation Theory and Applications: (14 Lectures): Linear Dynamic Systems, Probability and Expectancy, Random Processes, Deterministic & Stochastic Least-Squares Problems, Estimation of stationary and non-stationary processes, Linear Optimal Filters, Kalman Filter and its Various Forms, Examples of Kalman Filter Applications

Navigation Principles and Techniques: (14 Lectures): Fundamentals of Navigation, Radio and Radar based Navigation Systems, Inertial Navigation System (INS), Global Positioning System (GPS) based Navigational Aids, INS-GPS based Navigation Strategies, Vision-based Navigation Methods, Typical Examples of Navigation in Unmanned Systems

Fundamentals of Guidance: *(14 Lectures):* Concepts of Intercept Geometry (1), Line of Sight and Collision Triangle (1), Proportional Navigation & Guidance (PNG) and Determination of Miss Distance (4), Augmented PNG and its comparison with PNG (2), Command to LOS & Beam Rider Guidance (3), Pulsed Guidance Technique (2), Examples of UAV Guidance (1)

Textbook

1. Kailath, T., Sayed, A.H. & Hassibi, B., ‘Linear Estimation’, Prentice Hall, 2000.
2. Grewal, M.S. & Andrews, A.P., ’Kalman Filtering: Theory and Practice with MATLAB’, 4th Ed., Wiley-IEEE press, 2014.
3. Farrell, J.L, 'Integrated Aircraft Navigation', Academic Press, 1976.
4. Yanushevsky, R., ‘Guidance of Unmanned Aerial Vehicles’, CRC Press, 2011.

Reference Books

1. Zarchan, P., 'Tactical & Strategic Missile Guidance', AIAA Education Series, 2nd Ed., AIAA Publication, 1992.
2. Parkinson, B.E. & Spilker, J. J., 'Global Positioning System: Theory and Applications', Vol.1, Progress In Aeronautics and Astronautics Series, Vol.163, AIAA Publication, 1996.
3. Biezad, D.J., 'Integrated Navigation and Guidance Systems', AIAA Education Series, 1999.
4. Misra, P. and Enge, P., 'Global Positioning System', 2nd Ed., Ganga-Jamuna Press, 2001.

EV Microspecializations Core Courses

Title	**Automotive Electronics design**	Number	EEL7XX0
Department	IDRP: Robotics & Mobility Systems	L-T-P [C]	3-0-2 [4]
Offered for	M.Tech, B.Tech, Ph.D.	Type	Program Elective (PE)
Prerequisite	Basic of Electrical Engineering		

Objectives
The instructor will:
1. Help students fit together their complete electrical engineering background to tackle practical design of a power electronics converter used in EVs.
2. Class will be taught using combination of slides, design examples and live simulation using electronic circuit simulator such as LTspice; FEA simulation tool such as FEMM; and PCB design software such as KiCad.
3. Emphasis will be given on using open source/free software packages.

Learning Outcomes
The students are expected to have the ability to:
1. Hands-on experience in design of practical aspects of any power converter such as: snubber design, heat sink design, magnetics design, EMI/EMC challenges.
2. Use software packages for circuit simulation, FEA simulation and Schematic capture and PCB layout.
3. Understand the product development process and challenges in designing an automotive standard product.

Contents
Characteristics and limitations of power semiconductors (3 Lectures) (Diode, SCR, BJT, MOSFET, IGBT) as switching devices. **Case study**: Characteristics and loss breakdown in MOSFET and IGBT devices using LTSpice simulation example.
Mathematical modelling of power converter topologies including resonant converters (4 Lectures): input output requirements, sizing of components, Design driving factors. **Case study**: Mathematical model of Flyback converter for a laptop battery charger application and validated using LTspice simulation.
PWM Techniques in power electronics (3 Lectures): PWM techniques of DC-AC converter; PWM techniques of DC-DC converter; PWM techniques of Resonant converter; How to model a PWM in simulation; Circuits for generation of PWM waveforms.
Case study: PWM generating circuit for Flyback converter presented using LTspice simulation example.
Soft switching techniques (3 Lectures): Zero voltage switching, Zero current switching, snubber design: Turn-off snubber, turn-on snubber, overvoltage snubber.
Case study: Passive and active Snubber design for Flyback converter for a laptop power supply presented using LTspice simulation example.
Drive circuits (3 Lectures): Gate drive circuits for MOSFET, IGBT and Thyristors.
Case study: Gate driver design for Flyback converter presented using LTspice simulation.
Input and output filter design for power converters (4 Lectures): Input filter design for differential mode noise and common mode noise; output filter design for DC-DC converter: sizing of output capacitor and inductors.
Case Study: Input filter design for Flyback Converter for laptop power supply.
Feedback loop compensation and stability analysis (4 Lectures): Design and testing of PI type controller; Introduction to Switching PWM model and AC average model such as state space average model (SSA), PWM switch model also known as Vatche Vorperian model; Introduction to simulation and hardware tools for Ac analysis; Measuring negative resistance and input impedance of a power supply.
Case Study: Loop compensation of Flyback power supply using current mode and voltage mode control.
Design of Magnetic components (3 Lectures): Magnetic materials and cores, thermal consideration, inductor design process, eddy current, transformer leakage inductance, transformer design process, Electromagnetic field simulation using FEA tools such as FEMM.
Case Study: Coupled inductor design for Flyback power supply, validation of design using LTspice circuit simulation and FEMM FEA simulation.
Thermal Consideration for Power converter design (3 Lectures): Control of semiconductor device temperature, heat transfer by radiation and convection, understanding heat sink datasheets, heat sink design.
Case Study: Heat sink design for Flyback power supply.
Introduction to Electro-Magnetic Compatibility: EMC Basic knowledge (3 Lectures): Time and frequency domains, measurements in product life cycle (PLC), measurements test methods, measurement uncertainty and result repeatability, standard, directives and accreditations.
PCB layout (3 Lectures): Introduction, PCB Stack-up, Layout techniques, PCB manufacturing methods, Thermal management concerns, Electric safety concerns, EMI/EMC concern, Software for PCB Layout
Case study: Layout of Flyback power supply using KiCad EDA.
Failure analysis Techniques (3 Lectures):
Introduction to Failure mode and effect analysis, Automotive industry safety standard (ISO 26262), Automotive electronics council, Problem solving techniques such as: Fault tree analysis techniques, A3 problem solving techniques, 8 Discipline problem solving techniques, KT analysis.
Case Study: Perform FMEA on Flyback power converter. Perform KT analysis to find root cause of failure in a given case study.

Lab component
1. Design a DC-DC converter using LTspice. See the effect of parasitic on switching nodes.
2. Snubber design for the MOSFET in a Flyback converter using LTspice.
3. Heat sink design for a power converter targeting Automotive application.
4. Create PCB layout for a DC-DC converter
5. Magnetics design using FEMM

Textbook

1. IEEE Papers and industry application notes
2. MOHAN, N. (2012). *Power electronics: a first course*. Hoboken, N.J., Wiley.
3. Basso, C. (2012). Designing Control Loops for Linear and Switching Power Supplies: A tutorial Guide

Title	**Special Drives for Electric Vehicles**	Number	MTL6XX0
Department	IDRP: Robotics & Mobility Systems	L-T-P [C]	3-0-0 [3]
Offered for	-	Type	Program Elective (PE)
Prerequisite	-		

Objectives

The instructor will:

Provide exposure on different types of machines for EV applications, its control technique as well as the architecture of electric vehicles.

Learning Outcomes

The students are expected to gain knowledge on:

1. Different types of motor and their control technique for electric vehicle application.
2. Selection procedure of electric drives, according to the electric vehicle's architecture, application, and energy supply system.

Contents

Introduction [6 lectures]: Introduction to EVs, Classification of EVs, and Working Principle of EVs.

Configurations and components of electric drives [8 lectures]: Basics of Electric Propulsion System, Transmission System, Energy Management System, Energy Source, and Auxiliary Power System.

Architectures of EVs [3 lectures]: Different types of architectures based on electric propulsion and energy sources.

DC Series Motor [4 lectures]: Voltage Equation, Back EMF, Condition for Maximum Mechanical Power, Armature Torque of DC Motor, Relation of Speed with Back Emf and Flux, Characteristic and Speed Control of DC Series Motors, Electric Breakings of DC Series Motors.

Brushless DC Motor (BLDC) [4 Lectures]: Classification, Construction, Electronic Commutation, Principal of Operation, Microprocessor/DSP Based Control Scheme of BLDC Motor, Sensor Less Control, Comparison with DC Series Motor.

Permanent Magnet Synchronous Motor (PMSM) [4 Lectures]:

Principle of Operation, EMF Calculation, Power Input and Torque Expressions, Torque and Speed Relation, Phasor Diagram. Power Controllers, and Torque Speed Characteristics.

Three Phase AC Induction Motor [5 Lectures]:

Introduction and Construction, Rotor EMF & Frequency, Current and Power, Power Stages, Phasor Diagram, Analysis of Equivalent Circuit, Torque-Speed Characteristics in Braking, Motoring and Generating Regions. Effect of Voltage and Frequency Variations on Induction Motor Performance, Losses and Efficiency, No Load and Block Rotor Test, Speed Control Methods Including V/F Method, Starting Methods, Cogging and Crawling.

.*Switched Reluctance Motors (SRM) [4 Lectures]:* Basics of SRM Analysis, Constraints on Pole Arc and Tooth Arc, Torque Equation and Characteristics, Power Converter Circuits, Control of SRM, Rotor Position Sensors, Current Regulators, Sensorless Control of SRM, Relationship in-between Torque, Speed and Input Power.

Synchronous Reluctance Motor (Syrm) [4 Lectures]: Principle and Construction of Synchronous Reluctance Based Drive, Operating Condition and Power Factor of Synchronous Reluctance Motors, Constant Power Operation, Permanent Magnet Reluctance Motors, Torque and Speed Relationship.

Textbook

1. P. S. Bimbhra, (1977), *Electrical Machinery*, KHANNA PUBLISHERS, Seventh edition, (1 January 1977).
2. D. P. Kothari, and I. J. Nagrath, (2017), *Electric Machines*, McGraw Hill Education; Fifth edition, (23 Jun 2017).

Title	**Battery Management System**	Number	
Department	IDRP-Robotics and Mobility Systems	L-T-P [C]	3-0-0 [3]
Offered for	B. Tech. (BT), M. Tech. (MT) and Ph.D. (P) Programs	Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide the basics and function of the battery-management-system
2. The computer methods and their implementation in specialized electronics—that protect the user and the battery pack to get an optimize performance and service life of the battery

Learning Outcomes

The students are expected to have the ability to:

1. Knowledge of lithium-ion cell terminology and function and battery-management-system requirements
2. Knowledge of designing cell model
3. SOC and SOH estimation

Contents

Fundamentals: Battery terminology, lithium-ion battery's different component and working principles, BMS electronics and different requirements. [4]

Cell models: Equivalent circuit model, experimental techniques e.g electrochemical impedance spectroscopy, Microscale cell model, Continuum scale cell model, State-space model, Reduced order model [10]

SOC estimation: Different methods for SOC estimation, Kalman filter, SOC estimation using an extended Kalman filter, SOC estimation using a sigma-point Kalman filter, Methods to detect and discard faulty voltage-sensor measurements [12]

SOH estimation: Negative/positive electrode aging, Different methods for SOH estimation, Estimation of capacity using WLS, WTLS, and AWTLS methods, Methods to estimate cell's equivalent series resistance [12]

Battery pack balancing: Cell balancing, voltage based power limit estimation, physics based optimal control. [4]

Textbook

1. Plett, Gregory L.; (2015), Battery Management Systems: volume I Battery Modelling, Artech House
2. Plett, Gregory L.; (2015), Battery Management Systems: volume II Equivalent-Circuit Methods, Artech House
3. Andrea, Davide; (2010), Battery Management Systems for Large Lithium Ion Battery Packs, Artech House

Reference Books

1. Xiong, Rui; (2020), Battery Management Algorithm for Electric Vehicles, Springer, Singapore.
2. Bergveld, Henk J.; Kruijt, W.S.; and Notten, P.H.L.; (2005), Battery Management Systems: Design by Modelling, Springer, Dordrecht

Online Course Material

1. Algorithms for Battery Management Systems Specialization, University of Colorado Boulder, https://www.coursera.org/specializations/algorithms-for-battery-management-systems

New Programme Electives

Title	**Electrochemical Energy storage devices and materials for electrical vehicles**	Number	MTL7XX0
Department	IDRP: Robotics & Mobility Systems	L-T-P [C]	2-0-0 [2]
Offered for	B. Tech., M. Tech., PhD	Type	Micro-specialization Elective (MSE)
Prerequisite	None		

Objectives

The course outlines in a nutshell:

1. Different energy storage devices put into electric vehicles
2. Development of materials for the energy storage devices to be used in electric vehicles

Learning Outcomes

The students are expected to gain knowledge on:

1. Structure processing property performance relationship of the energy materials developed over time.
2. Different modes of energy storage with respect to scale, cost, energy, and power density to be used in electric vehicles

Content

Introduction [5 lectures]:

Introduction, classification of EVs; components of EVs; Introduction to electrical/ electrochemical energy storage/conversion devices (Capacitors, supercapacitors, batteries, fuel cells) for EVs; concept of voltage, capacity, energy & power density, cycle life, columbic efficiency; comparison among different devices in terms of the parameters mentioned; comparison with fossil fuels.

Batteries for EVs [9 lectures]:

Basics of an Electrochemical cell (Battery), battery materials, primary and secondary batteries, primary batteries for EVs: metal-air, Al-graphite batteries, secondary batteries for EVs: Pb-acid, NiCd, NiMH, and Li-ion batteries; raw materials; testing of batteries; safety aspects; recycling

Ultracapacitors for EVs [5 lectures]:

Basics of capacitors and ultracapacitors; Difference between double-layer and pseudo-capacitors; similarities with batteries; hybrid capacitors; Ultracapacitor specifications for EVs; A combination of ultracapacitors and batteries to drive EVs; ultracapacitors as stand-alone systems to power EVs; carbon materials and metal oxides as electrodes for ultracapacitors.

Fuel cells for EVs [4 lectures]:

Basics of Fuel Cells (FC), proton exchange FC for EVs, direct & indirect methanol fuel cells for EVs. Combination of battery and fuel cell: metal-air system & Ni-hydrogen systems.

Case study: *(lectures with demonstrations) [5 lectures]:*

1. Compare different primary and secondary batteries in terms of voltage, capacity, energy & power density, cycle life, columbic efficiency
2. Compare secondary batteries of different companies to suit the demands of EVs.
3. Effect of hydrogen flow rate on performance of PEM fuel cells for EVs
4. Fabrication of carbon-based and metal-oxide based supercapacitors
5.

Exercise/Mini Project: Design appropriate charging cycle for different batteries for fast charging

Textbook

1. Cheong K.Y., Impellizzeri,G and Fraga,M.A., (2018), *Emerging Materials for Energy Conversion and Storage*, 1st Edition, Elsevier

Reference book

1. Thomas B Reddy, (2011: fourth edition) Linden's Handbook of Batteries, McGRAW HILL

Online Course Materials

1. Prof. Ashok Jhunjhunwala Prof. Prabhjot Kaur Prof. Kaushal Kumar Jha Prof. L Kannan, Fundamentals of Electric vehicles: Technology & Economics, IIT Madras; https://nptel.ac.in/courses/108106170

Title	**Charging Infrastructure for Electric Vehicles**	Number	
Department	IDRP: Robotics & Mobility Systems	L-T-P [C]	3-0-0 [3]
Offered for	-	Type	Program Elective (PE)
Prerequisite	-		

Objectives

The instructor will:

1. Teach students about the operation, standards and design of battery chargers used for Electric Vehicle applications.

Learning Outcomes

Students are expected to gain knowledge on:

1. EV charging standards for connectors (SAE J1772, SAE J2954, CHAdeMo, Tesla Supercharger, CCS); EV charging level standard: AC, DC, XFC
2. Different converter topologies used for charging an EV; EV charging Methods: Plug-In, Wireless.
3. Electrical Characteristics and charging algorithm of Energy storage element

Contents

Introduction (4 Lectures): Architecture, building blocks and basic functionality of different kind of vehicle technology such as Hybrid, Electric and Fuel cell vehicle. EV Charging Methods: Battery Exchange, Plug-In and wireless charging.

EV Charging standards and connectors (5 Lectures): Off-board charger, onboard charger, Different charging connectors used around the globe such as SAEJ1772, SAEJ2954, CHAdeMO, CCS. EV charging Level**:** Level 1, Level 2, Level 3-DC (Fast charging), XFC.

Converter topologies for Plug-In charging (6 Lectures): Components of a plug-in battery charger, AC/DC converter: Unidirectional, Bidirectional; DC/DC converter: Unidirectional isolated converters, Bidirectional isolated converter, non-isolated DC-DC converters.

Converter topologies for Wireless charging (10 Lectures): Components of a wireless battery charger**,** Wireless charging principle: Capacitive, Inductive; Converter for capacitive power transfer, converters for inductive power transfer, Compensation network, Coil design for inductive charging, Capacitor design for capacitive wireless power transfer, Foreign object detection, EMF Shielding, Concept of dynamic charging and opportunity charging.

XFC station concepts and converter topologies (2 Lectures): Configuration of XFC station: AC-connected system and DC connected system, Grid Facing AC-DC converters, SST-BASED MV extreme fast chargers.

Battery Management system(5 Lectures): Battery pack design, CC/CV charging, Pulse charging, Constant temperature-constant voltage charging, Boost charging, battery management system, communication interface.

V2G technology (3 Lectures): state of the art, Methods of V2G realization, Economic and social value of V2G

Health and safety concerns (3 Lectures): functional and constructional requirement, insulation coordination, electromagnetic compatibility, personal protection against shock, safety faults and countermeasures, the human electromagnetic exposure limits (IEEE and ICNIRP guidelines).

Textbook

1. IEEE Papers and industry application notes

Course Title	**Functional Safety for EV**	Number	**EEL7XX0**
Department	IDRP; Robotics & Mobility Systems	L-T-P [C]	1–0–0 [1]
Offered for	BTech., MTech. & PhD	Type	Micro-Specialization Elective (MSE)
Pre-requisite	None		

Objectives

The Instructor will:

1. Make the students analyze different types of hazards associated with the operation of electric vehicles.
2. Make the students appreciate the safety requirements and design guidelines to mitigate functional safety hazards.
3. Explain the different automotive safety standards such as ISO 6469, ISO 26262 and ASIL certification requirements.

Learning Outcomes

The students are expected to have the ability to:

1. Analyze different automotive safety requirements and techniques of safety assessment for EV
2. Understand the automotive safety specifications and standards.

Contents

Brief introduction to electric vehicles and identification of safety requirements and specifications at component-level and integration-level (2 lectures)

Assessment methodologies of functional safety assessment and their analysis: hazard and risk analysis (HARA), functional hazard assessment (FHA), fault tree analysis (FTA), failure mode and effects analysis (FMEA), failure modes, effects, and diagnostic analysis (FMEDA), failure modes, effects, and diagnostic analysis (FMECA) probabilistic reliability analysis and hardware failure metrics (6 lectures)

Functional safety at electronic level (e.g.-software-related hazard analysis), Safety analysis of power and thermal management components in EV (2 lectures)

Introduction to Automotive Safety Integrity Level (ASIL) certifications and ISO 6469, ISO 26262 standards, design guidelines for mitigation of safety hazards (4 lectures)

Text Books

1. P. Enge, N. Enge and S. Zoepf, “Electric Vehicle Engineering”, McGraw Hill (2021)
2. ISO Documents (International Standards) for ISO 6469, ISO 26262 specifications

Title	**Intelligent Systems and Security for EVs**	Number	
Department	IDRP: Robotics & Mobility Systems	L-T-P [C]	3-0-0 [3]
Offered for	-	Type	Program Elective (PE)
Pre-requisite	-		

Objectives

1. Understand the condition monitoring for EVs.
2. Understand the intelligent systems for self-driving and decision prediction for EVs.
3. Understand the Cyber-security threats and solutions for EVs

Learning Outcomes

The students are expected to understand theoretical and practical aspects of:

1. Self-driving vehicles.
2. Vehicle communication protocols.
3. Vehicle cyber security.

Contents

Introduction **[3 lecture]**

Introduction to EVs, vehicle-to-grid, grid-to-vehicle, vehicle-to-vehicle power or data exchange, data exchange protocols, intelligent systems, self-driving control, economics aspects.

Communication Technology **[7 Lectures]**

[4 Lecture] Communication systems for EVs: Vehicle-to-grid communication, grid-to-vehicle communication, and vehicle-to-vehicle communication systems.

[3 Lectures] Data Protocols: data exchange protocols and performance requirements for vehicles, RTUs, charging stations, and /or utilities.

Intelligent Systems **[10 Lectures]**

[3 Lectures] Foundation of self-driving vehicles, sensing and control, vehicle navigation system, localization and mapping, and path planning.

[4 Lectures] Deep learning basics, workflow, computer vision for behavior cloning, mapping, and control.

[3 Lectures] Object Detection: pedestrian detection, traffic light detection, lane detection, vehicle detection, and semantic segmentation.

Cyber-Security **[10 Lectures]**

Data integrity and cyber-physical Attacks: vehicle management system, attack taxonomy and evaluation metrics, simulation and impact assessment, and detection methodologies.

Monitoring and Modelling **[5 Lectures]**

State-of-charge, state-of-health estimation for battery systems, supercapacitors. Fault isolation and prognosis for electric drives.

Case study: **[7 Lectures]**

1) Develop deep learning, CNN models in Keras for object detection. [3 lectures]
2) Driver behaviour modelling and rerouting algorithms for EVs using pyhton libraries. [2 lecture]
3) Data integrity attack modelling and testing a detection strategy. [2 lectures].

Reference Material:

[1] El. Ghanam, E. Hassan, M. Osman, A. Ahmed, I. Review of Communication Technologies for Electric Vehicle Charging Management and Coordination. *World Electr. Veh. J.* **2021**, *12*, 92.

[2] J. Lu and J. Hossain, *Vehicle To Grid Linking Electric Vehicles To The Smart Grid*, The Institution of Engineering and Technology, 2015.

[3] Thor I. Fossen, Kristin Y. Pettersen, and Henk Nijmeijer, *Sensing and Control for Autonomous Vehicles*, Springer, 2017.

[4] L. Venturi, K. Korda , *Hands-On Vision and Behavior for Self-Driving Cars*, Packt Publishing, 2020.

[5] L. Guo *et al*., "Systematic Assessment of Cyber-Physical Security of Energy Management System for Connected and Automated Electric Vehicles," in *IEEE Transactions on Industrial Informatics*, vol. 17, no. 5, pp. 3335-3347, May 2021.

[6] C. Zhang, Y. Zhang and Y. Li, "A Novel Battery State-of-Health Estimation Method for Hybrid Electric Vehicles," in *IEEE/ASME Transactions on Mechatronics*, vol. 20, no. 5, pp. 2604-2612, Oct. 2015.

Online Course Material:

1. Prof. Ashok Jhunjhunwala Prof. Prabhjot Kaur Prof. Kaushal Kumar Jha Prof. L Kannan, Fundamentals of Electric vehicles: Technology & Economics, IIT Madras. https://nptel.ac.in/courses/108106170

Title	**Grid Integration of EVs**	Number	
Department	IDRP: Robotics & Mobility Systems	L-T-P [C]	2-0-0 [2]
Offered for	-	Type	Program Elective (PE)
Pre-requisite	-		

Objectives

Develop an understanding of the grid integration, management, control, and market aspects of electric vehicles.

Learning Outcomes

z The course work aims to provide detailed theoretical and practical aspects related to grid integration of EVs and future energy markets.

Contents

***Introduction* [3 lectures]**

Introduction to the smart grid with PEVs: the smart grid and microgrid, impact of EVs on smart grid energy management, basics of V2G technology, and PEVs charging infrastructure, policy drivers, and impact assessment.

***EV Integration to Smart Grid* [9 lectures]**

[3 lectures] distributed energy resources with PEV in the grid: distributed energy sources, smart and microgrid, energy management with mixed sources.

[3 Lectures] power conversion technology for EV integration: dynamic modeling of EVs with grid, feedback linearization, distributed control design for grid integration of EVs, performance analysis.

[3 lectures] Analysis and regulating power from EVs: driving pattern analysis for EV integration, optimal charging of EVs.

***Impact Assessment of EVs on Grid* [9 Lectures]**

[3 Lecture] The response of EV charging on the grid voltage, the response of EV charging on grid frequency.

[3 Lectures] the asynchronous response of small-scale charging facilities, Impact study of EV integration on distribution networks.

[3 Lectures] Stochastic coordination of EVs with renewables, optimal coordination of V-2-G batteries and renewable generators

***Energy Market with EVs* [9 Lectures]**

[3 Lectures] EVs in current electricity markets: market actors, electricity market, electricity prices, EVs in different markets.

[3 Lectures] EVs in future electricity markets: alternative markets for power and reserves, alternative markets for EV integration, management congestions.

[3 Lectures] investment and operation in integrated power and transport, day-ahead grid tariffs.

Reference Material:

1. C. Li, Y. Cao, Y. Kuang, and B. Zhou, *Influences of Electric Vehicles on Power System and Key Technologies of Vehicle-to-Grid*, Springer-Verlag Berlin Heidelberg 2016.
2. Q. Wu, *Grid integration of electric vehicles in open electricity markets*, John Wiley & Sons, Ltd, 2013.
3. J. Lu and J. Hossain, *Vehicle-to-Grid: Linking Electric Vehicles to the Smart Grid*, The Institution of Engineering and Technology 2015.

Online Course Material:

1. Prof. Ashok Jhunjhunwala Prof. Prabhjot Kaur Prof. Kaushal Kumar Jha Prof. L Kannan, Fundamentals of Electric vehicles: Technology & Economics, IIT Madras. https://nptel.ac.in/courses/108106170

Title	**Hydrogen Fuel for Transportation**	Number	
Department	IDRP-Robotics and Mobility Systems	L-T-P [C]	3-0-0 [3]
Offered for	B. Tech. (BT), M. Tech. (MT) and Ph.D. (P) Programs	Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. Provide student an understanding of hydrogen as an alternative fuel in the transport sector from an economic, technical and environmental point of view
2. Provide student the fundamentals of fuel cell operations

Learning Outcomes

The students are expected to have the ability to:

1. Understand the basics of fuel cell
2. Select right fuel cell for a given application
3. Design a complete system

Contents

Introduction: Hydrogen as future energy carrier [1]

Electrochemical principles: Electrochemical cell, Nernst equation, Tafel equation, Exchange current density, Butler–Volmer Equation, Electrocatalysis, Sabatier Principle for Catalyst Selection. [5]

Hydrogen Production: Different methods for hydrogen production, Electrochemical methods for hydrogen generation in detail, Catalysts for hydrogen production, Hydrogen storage challenges and solution, Infrastructure requirement [5]

Fuel Cell: Introduction, types and detail working of fuel cell (molten carbonate, solid oxide, acid and alkaline, proton exchange membrane cell), fuel cell thermodynamics, fuel cell reaction kinetics, Catalyst-electrode design, charge transport, voltage loss, fuel cell electrolytes, Fuel cell performance characterization. [23]

Fuel Cell for Automotive Application: Fuel cell stack, operating conditions, Hydrogen fuel cell system for road vehicles. [4]

Case study: Any two case study [4]

1) Fuel cell power car
2) Hydrogen infrastructure in Europe
3) Hydrogen infrastructure in USA
4) Hydrogen and electricity co-production
5) Relevant case study as per the choice of instructor

Textbook

1. Ryan O'hayre, Suk-won Cha, Whitney G. Colella, Fritz B. Prinz; (2016), Fuel Cell Fundamentals, Wiley Publications.
2. Pasquale Corbo, Fortunato Migliardini, Ottorino Veneri; (2011), Hydrogen Fuel Cells for Road Vehicles, Springer London.
3. Matthew M. Mench; (2008), Fuel Cell Engines, Wiley Publications.

Reference Books

1. Bent Sørensen; (2005), Hydrogen and Fuel Cells: Emerging Technologies and Applications, Elsevier Academic Press.
2. Michael Ball, Martin Wietschel; (2009), The Hydrogen Economy: Opportunities and Challenges, Cambridge University Press
3.

Online Course Material

Title	**Flapping and rotary wing aerodynamics**	Number	MEL7XX
Department	Mechanical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M. Tech/PhD	Type	Program Elective
Prerequisite	Fluid Mechanics		

Objectives

1. Define basic terminology used in flapping kinematics and aeroelasticity
2. Understanding of various unsteady aerodynamic phenomena responsible for thrust/lift generation in flapping aerial vehicles
3. Impart knowledge to grasp the interplay of inertia, kinematics, aerodynamics and wing flexibility for optimized flapping performance

Learning Outcomes

1. Apply the simplified models of unsteady aerodynamics to estimate lift coefficients in flapping and rotating wings
2. Comprehend the underlying principles of unsteady aerodynamics for designing an unmanned aerial vehicle
3. Selection criteria for a flapping and rotary wing

Contents

Recapitulation of fixed wing aerodynamics: Conservation equations, Kutta-Joukowski theorem, conformal transformation, Kelvin's circulation theorem, thin airfoil theory (4 lectures)

Introduction to flapping: Nature's flight, geometric similarity, mechanics of gliding, forward and hovering flight, power implication of flapping wings (4 lectures)

Rigid flapping wing aerodynamics: Kinematics and governing equations, dynamic stall, thrust generation of pitching/plunging airfoil, lift estimation models, unsteady aerodynamic mechanisms (10 lectures)

Flexible wing aerodynamics: General background, governing equations for wing structures, scaling parameters, coupled elastic structures and aerodynamics, biological flyers and wing elasticity (10 lectures)

Rotary Wing Aerodynamics: Momentum theory and blade element theory. Hovering flight, Inflow model in vertical climb and descent, Forward flight, Flap dynamics: simplified model, Mean hub loads (14 lectures)

Textbook

1. Shyy, W., Aono, H., Kang, C.K. and Liu, H. (2013) *An introduction to flapping wing aerodynamics*, Cambridge University Press.
2. Venkatesan, C. (2014), Fundamentals of Helicopter Dynamics, CRC Press.

Reference Books

1. Shyy, W., Lian, Y., Tang, J., Viieru, D. and Liu, H. (2008), *Aerodynamics of low Reynolds number flyers,* Cambridge university press.
2. NPTEL Lectures, Helicopter dynamics and aerodynamics

Title	**Aerodynamics and Hydrodynamics of unmanned vehicles**	Number	MEL7XX
Department	Mechanical Engineering	L-T-P [C]	3–1–0 [4]
Offered for	M. Tech/PhD	Type	Program Elective
Prerequisite	Fluid Mechanics		

Objectives

1. Define basic terminology used in aerodynamics and hydrodynamics
2. Provide a deep understanding of various complex phenomena that govern the fluid flow past an arbitrary body
3. Impart knowledge to compute lift and drag on airfoils/wings for simplified cases

Learning Outcomes

1. Apply the mathematical tools of aerodynamics to estimate lift coefficients for an airfoil
2. Comprehend the underlying principles of aerodynamics and hydrodynamics behind the design of an aerial and under water unmanned vehicle
3. Interpret the performance of a finite-/infinite-span wing

Contents

Recapitulation of fluid dynamics: Review of vector calculus, Reynold's transport theorem, conservation equations of mass, momentum and energy, circulation, vorticity, stream function and velocity potential function (6 lectures)

Viscid/Inviscid flows: Bernoulli's equation, Laplace's equation of irrotationality, Elementary flows, Kutta-Joukowski theorem, Integral equations of boundary layer, Blasius solution, laminar and turbulent boundary layer, (8 lectures)

Incompressible airfoil flows: Kutta condition, Kelvin's circulation theorem, thin airfoil theory for symmetrical and cambered airfoils, vortex panel method, conformal transformation (12 lectures)

Incompressible finite wing flows: Biot-Savart law, Helmholtz's theorem, Prandtl's lifting line theory, vortex lattice method, delta wings (8 lectures)

Hydrodynamics: Buoyancy, metacentre and stability, pressure and viscous force calculation on immersed bodies, flotation and trim, methods of drag reduction, maneuverability in vertical and horizontal planes (8 lectures)

Textbook

1. J.D. Anderson Jr. (2010), *Fundamental of Aerodynamics*, 5th Edition, Tata McGraw Hill
2. J.J. Bertin and R.M. Cummings (2014), *Aerodynamics for Engineers*, 6th Edition, Pearson Education

Reference Books

1. L.J. Clancy (2006), *Aerodynamics*, 1st Edition, Shroff publishers
2. E.L. Houghton and P.W. Carpenter (2005), *Aerodynamics for Engineering students*, 4th Edition, CBS publishers

Self Learning Material

1. https://ocw.mit.edu/courses/aeronautics-and-astronautics/16-100-aerodynamics-fall-2005/