M. Tech. And Dual Degree (M.Tech. and Ph.D.) in Cyber Physical Systems

Program Structure

M.Tech.&M.Tech.-Ph.D. Dual Degree Programs in

Cyber Physical Systems

Introduction

Beginning in the first decade of 21st century and continuing today, computational and communication resources, tightly integrated with physical systems, shaping the new capabilities for the modern systems. The use of computational resources to achieve different capabilities is in existence for several decades. However, many modern systems have high degree of complexities and also the scale of these systems is large and/or has distributed nature. For example traffic control system in a city requires modelling of traffic flows in different areas and optimizing different performance objectives by appropriately taking routing decisions, and decisions about actuating different signals for smooth traffic flow; this is a large scale distributed system. There are several other domains where CPS examples can be seen e.g. Healthcare, Robotics, Automotive, Power Grid, Avionics and Transportation. Such system necessitates a deeper understanding of system behaviour and also provides feedback to augment system design to achieve overall objectives from the system. Emergence of ubiquitous computing and communication has open enormous opportunities to provide new capabilities to systems e.g. robotics assisted remote surgery. Many (small) systems can work in collaborative/cooperative manner to achieve a larger overall objective. The examples can be seen in robotics and modern warfare where collaboration/cooperation achieves larger objectives. The communication capability also provides a possibility of distributed learning for systems.Hybrid system modelling is one of the possible approaches to model CPS. Hybrid system approach allows inclusion of both continuous time and discrete time states (variables) in the model.

The seamless integration of cyber system with physical system also poses several challenges towards system security against possible system attacks. With modelling of physical system, it is necessary to model different possible attacks and to provide adequate security at hardware and software to ensure overall system security in all scenarios. The cyber component includes hardware and associated software. The design of cyber component also requires software level abstraction to have system level model of cyber component. This also allows designing a very high reliability system as the model allows a predictable behaviour. Conventionally software is developed without formal models and largely depends on programmers' experience and knowledge; however, requirement of safety, reliability in CPS demand higher level of abstractions at software level as well. This allows the system remains correct and secure by design.

Objective of the Programme

The program aims to produce competent engineerswho can design engineered systems that are built from seamless integration of physical system and cyber systems. The program will enable engineers with required competency to design software-hardware architecture. The program also imparts knowledge of several tools for modelling physical systems and tools for designing cyber components. The program will produce professionals who can design predictable and secure Cyber Physical Systems (CPS).

Expected Graduate Attributes (M.Tech)

1. Ability to understand modern approaches to Model CPS.
2. Appreciation of cross disciplinary interaction of cyber and Physical systems.
3. Capability to design cyber components to meet the overall specifications of a unified system.
4. Adequate design knowledge to ensure system remains correct by design.
5. Ability to use knowledge from machine learning, control theory to achieve overall objectives of a given CPSs.
6. High quality technical communication skills.
7. Appreciation and adherence to norms of professional ethics.
8. Ability to plan and manage technical projects.

Learning outcome:

1. Ability to analyse overall specifications of CPS and translate it to the different sub-systems design requirements.
2. Adequate competency to model overall CPS using Hybrid system and other approaches and validate the model.
3. Capability toco-design hardware-software architecture in distributed environment.
4. Knowledge of Machine Learning algorithms and Distributed Control algorithms.
5. Methods to embedded security in overall design of CPS.
6. Ability to understand applications like smart grid, mobile networks and different systems of smart city.
7. Critical thinking and scientific problem solving.
8. Skill to communicate scientific ideas and /or application systems.
9. Acquire basic project management skills

Topics Cloud for the CPS program

- Modelling of CPS system from Hybrid system's perspectives
- Distributed computing; FoG and Cloud computing
- Embedded System design (Using programmable system-on-chip approach)
- Real time operating system
- Communication protocols
- Networked and distributed Control system
- Algorithms of Machine Learning
- Digital Signal Processing

Proposed Program's Structure Overall Structure

Category	Program Core (MC)	Program Elective (ME)	Open Elective (MO)	Project (MP)	Total Graded Credits	Total Graded + Nongraded Credits
Credits	18	18	06	16	58	**62**

Semester wise distribution of credits

I Semester

Cat.	Course Title	L-T-P	Credits
MC	*Introduction to Cyber Physical Systems*	3-0-0	3
MC	*Cyber Physical System Modelling and Simulation Laboratory*	0-0-2	1
MC	*Introduction to Modelling (Fractal offered by Dept. Of Mathematics)*	1-0-0	1
MC	*Simulation of Dynamical Systems*	1-0-0	1
ME	*Program Elective-1*	3-0-0	3
ME	*Program Elective-2*	3-0-0	3
MO	*Open Elective-1*	3-0-0	3
NG	*Professional Ethics*	1-0-0	1
	Total(Graded+Non-graded)		**16**

II Semester

Cat.	Course Title	L-T-P	Credits
MC	*Security in CPS*	2-0-0	2
MC	*Data Communication and Networking*	3-0-0	3
MC	*Advanced Control System*	3-0-0	3
MC	*Embedded System Design*	3-0-0	3
ME	*Program Elective-3*	3-0-0	3
MC	*Embedded System Design Laboratory*	0-0-2	1
NG	*Technical Communication*	1-0-0	1
	Total(Graded+Non-graded)		**16**

III Semester

Cat.	Course Title	L-T-P	Credits
MP	Project-1		6
ME	*Program Elective-4*	3-0-0	3
ME	*Program Elective-5*	3-0-0	3
ME	*Program Elective-6*	3-0-0	3
NG	*Systems Engineering and Project Management*	1-0-0	1
	Total(Graded+Non-graded)		**16**

IV Semester

Cat.	Course Title	L-T-P	Credits
MP	Project-2		10
MO	*Open Elective- 2*	3-0-0	3
NG	*IP Management and Exploitation*	1-0-0	1
	Total(Graded+Non-graded)		**14**

List of Program Electives

Course Title	***L-T-P***	***Credits***	***Department offers the course***
Computer Vision	3-0-0	3	CSE
Advanced Digital Signal Processing	3-0-0	3	EE
Vehicular Ad-Hoc Networks(VANETs)	3-0-0	3	CSE
Edge & Fog Computing	3-0-0	3	CSE
Robotics : Fractal 1 Robot Modelling	1-0-2	2	ME
Robotics : Fractal 2 Control	1-0-0	1	ME
Robotics : Fractal 3 Motion Planning and Programming	1-0-0	1	ME
Machine Learning I	3-0-0	3	CSE
Digital and Systems-on-Chips Design	3-0-0	3	EE
Introduction to Virtual Reality	3-0-0	3	CSE
Smart Grid	3-0-0	3	EE
Adaptive Signal processing	3-0-0	3	EE
Computer Architecture	3-0-0	3	CSE
Digital Twin	3-0-0	3	EE
Machine Leaning II	3-0-0	3	CSE
Artificial Intelligence I	3-0-0	3	CSE

Artificial Intelligence II	3-0-0	3	CSE
Smart Manufacturing	1-0-2	2	ME
Resource Constrained AI	3-0-0	3	CSE
Real Time Communications	3-0-0	3	EE
Industry 4.0 Applications in Manufacturing Systems	1-0-0	1	ME
Optimization	1-0-0	1	Mathematics

The department may add new electives from time to time.

Title	**Introduction to Cyber Physical Systems**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech. Cyber Physical Systems	Type	Core
Prerequisite	Differential Equations, Basics of Microprocessors		

Objectives

The Instructor will:

1. introduce modeling of CPS
2. introduce ability to analyze and simulate CPS systems

Learning Outcomes

The students are expected to have the ability to:

1. apply modeling and associated tools for Hybrid system
2. to analyze CPS by with holistic models of cyber and physical components.

Contents

Motivation and examples of CPS e.g. Energy, Medical and Transportation cyber physical systems; Key design drivers and quality attributes of CPS. Attributes of high confidence CPS; (8 hours)

Continuous systemsmodeling; Discrete time system modeling; Finite state machine; Extended state machines; Hybrid system modeling; Classes of Hybrid Systems. (17 Hours)

Analysis and Verification:
Basic concepts of embedded systems; Embedded Processors; Input-outputs; Invariants and Temporal Logic; Linear Temporal Logic; Equivalence and Refinement; Development of models from specifications; Rechability analysis and Model Checking (17 Hours)

Text Books

1. R. Rajkumar, D. de. Niz and M. Klein, (2017), *Cyber Physical Systems,* Addision-Wesely.
2. E.A.Lee and S A Shesia, (2018), *Embedded system Design: A Cyber-Physical Approach*, Second Edition, MIT Press.
3. A.Platzer, (2017), *Logical Foundations of Cyber Physical Systems*, Springer.

Preparatory Course Material

Basics of Differential equations and basics of Microprocessors from any standard textbook.

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)

Text Books

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

Preparatory Course Material

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

Title	**Advanced Control**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech. Cyber Physical Systems	Type	Core
Prerequisite	Differential equations and Basics of Control system desirable		

Objectives

The Instructor will:

1. introduce Multi-Agent based Modeling control algorithms
2. introduce robust controller for distributed systems

Learning Outcomes

The students are expected to have the ability to:

1. evaluate different controllers for a given distributed system.
2. use different tools to design robust controllers

Contents

Review of state space analysis and feedback control design; Problem of estimation and observer design; Cooperative control motivation and examples. (7 Hours)

Distributed Control: Sources of uncertainty and robust control; Concepts of Sliding Mode control and its applications to Robust control design for distributed systems; Robust observer design. (14 Hours)

Design behaviour of swarms Consensus problem and distributed flocking behaviour; Stability analysis of flocking motion; (8 Hours)

Event Triggered Control: Introduction to event based sampling; stability with event based sampling; event based multi agent systems; consensus with event triggered control (7 Hours)

Control of Cyber physical systems: Control of CPS with logic specifications, symbolic models for nonlinear system and extension to large classes of systems. (6 Hours)

Textbooks

1. Jeff Shamma, *Cooperative Control of Distributed Multi-agent Systems*, Wiley, 2008
2. Edwards, Christopher, and Sarah Spurgeon, *Sliding mode control: theory and applications*, CRC Press, 1998.

Other references:

1. Tabuada, Paulo. "Event-triggered real-time scheduling of stabilizing control tasks." IEEE Transactions on Automatic Control 52.9 (2007): 1680-1685.

PreparatoryCourse Material

Basics of Control System from Norman Nice, 2007.

Title	**Simulation of Dynamical Systems**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	1–0–0 [1]
Offered for	M.Tech. Cyber Physical System	Type	Core
Prerequisite	Basics of ODE		

Objectives

The Instructor will:

1. introduce different techniques to simulate different class of systems.

Learning Outcomes

The students are expected to have the ability to:

1. use different tools for simulating systems using right set of simulation parameters

Contents

Simulation as problem solving tool; Basic principles of numeric integration; Euler integration; difference equation simulation (3 hours)

Runge–Kutta Algorithms; stability domains of Runge–Kutta Algorithms; extrapolation technique; solver for Differential Algebraic Equations; (4 hours)

Random variables; probability distribution; poison process; Markov process; Markov chain, Bayesian statistics; simulated annealing; Monte-Carlo simulation (7 hours)

Textbooks

1. François E. Cellier and Ernesto Kofman (2006), *Continuous Systems Simulation*, Springer 2006
2. Sheldon M. Ross (2013), *Simulation*, Academic Press, 5th Edition.

Title	**Cyber Physical System Modelling Laboratory**	Number	**EEP7XX0**
Department	Electrical Engineering	L-T-P [C]	0–0–2 [1]
Offered for	M.TechCyber Physical System	Type	Core
Prerequisite	ODE		

Objectives

The Instructor will:

1. introduce techniques to model/simulate different Cyber Physical Systems
2. introduce techniques to verify different CPS models

Learning Outcomes

The students are expected to have the ability to use different tools for Modelling/Simulation and verifications.

Contents

Modelling experiments in continuous, discrete and hybrid system; Verification of model using different techniques; Sensitivity analysis of Models; Sensitivity analysis of Hybrid Models; Scheduling in embedded system

Title	**Embedded System Design Laboratory**	Number	**EEP7XX0**
Department	Electrical Engineering	L-T-P [C]	0–0–2 [1]
Offered for	M.Tech.Cyber Physical System	Type	Core
Prerequisite	Basics of Processors		

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	**Smart Grid**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M.Tech. Cyber Physical System	Type	Elective
Prerequisite			

Objectives

The Instructor will:

1. concepts and topics that are relevant to smart grid technologies to facilitate exploring research opportunities.

Learning Outcomes

The students are expected to have the ability to:

1. understand main concepts of smart grid development and the critical technologies that underpin such development, their basic principles, physical constraints, and technological potentials

Contents

Smart Grid Basics: Evolution of Electric Power Grid and Smart Grid, Objectives, main features and challenges of smart grid (5 Hours)

Energy resources : centralized vs. distributed generation; renewable energy: solar, wind, hydropower, biomass, geothermal, ocean wave; benefit, costs, and policies of renewable energy; renewable sources integration – overcoming intermittence; storage systems technology (10 Hours)

Plug-in Electric Vehicle(PEV): history of EV; PEV challenges and potential solutions; EV and electric power grid; PEV charging infrastructure, challenges and solutions; PEV as an energy storage device and an energy source (V2G). (9 Hours)

Demand-side management: load profile of the power grid; market pricing; peak shaving and valley filling; load forecasting; regulations and policies. (9 Hours)

Monitoring and Protection: wide-area monitoring system (WAMS), SCADA and PMU; advanced metering infrastructure (AMI); smart metering; communication infrastructure and technologies (9 Hours)

Textbooks

1. J. Duncan Glover, Mulukutla S. Sarma, and Thomas J. Overbye, (2008), *Power System Analysis and Design*, 4th Ed.,Stamford, CT: Cengage Learning,.
2. Jan Machowski, JanuszBialek, and James R. Bumby, (2008), *Power Systems Dynamics, Stability and Control*, 2nd Ed.New York, New York: John Wiley.
3. B. Droste-Franke, et al.,(2012), *Balancing Renewable Electricity – energy storage, demand side management, and network extension from an interdisciplinary perspective*. Heidelberg, Germany: Springer.
4. T. Ackermann, Ed.,(2005), *Wind Power in Power Systems*. *New York*, New York: Wiley.

Title	**Security in Cyber Physical Systems**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	2–0–0 [2]
Offered for	M.Tech. Cyber Physical System	Type	Core
Prerequisite	Basics of Control system is desirable		

Objectives

The Instructor will:

1. introduce mathematical framework for Cyber Physical System attacks
2. introduce centralized and decentralized techniques of attack detection

Learning Outcomes

The students are expected to have the ability to:

1. analyze the system for possible security vulnerability.
2. design attack resilient system.

Contents

Review of graph theory based models; some examples from infrastructure system modelling; Descriptor system; Unified modelling of CPS attack; case of undetectable attacks; (7 Hours)

Graph theoretic characterization of attacks and its limitations; Centralized and distributed monitors; examples from power system, water distribution networks etc. (7 Hours)

Security issues of Industrial Control Systems; Integrity attacks on SCADA systems; Model based technique to detect integrity attacks on sensors; threat model and its effect on control scheme; countermeasure for detecting such attacks; watermarking scheme; (7 Hours)

Design of observers under sensor and actuator attacks; design of observer for distributed environment under different attacks; applications of swarms of UAVs; Control design with denial service attack; case studies (6 Hours)

References

1. F. Pasqualetti, F. Dörfler and F. Bullo, "Attack Detection and Identification in Cyber-Physical Systems," in *IEEE Transactions on Automatic Control*, vol. 58, no. 11, pp. 2715-2729, Nov. 2013.
2. H. Fawzi, P. Tabuada and S. Diggavi, "Secure Estimation and Control for Cyber-Physical Systems Under Adversarial Attacks," in *IEEE Transactions on Automatic Control*, vol. 59, no. 6, pp. 1454-1467, June 2014.
3. Yilin Mo, Rohan Chabukswar and Bruno Sinopoli "Detecting Integrity Attacks on SCADA Systems" in *IEEE Transactions on Control System Technology, Vol. 22, No. 4, 2014*
4. F. Pasqualetti, F. Dörfler and F. Bullo *"Control Theoretic methods for Cyber Physical Security", in IEEE Control System Magazine, pp. 110-127, Feb. 2015*

Preparatory Course Material

Basics of Control System from Norman Nice, 2007.

Title	**Data Communication and Networking**	Number	**EEL7XX0**
Department	Electrical Engineering	L-T-P [C]	3–0–0 [3]
Offered for	M. Tech. 1st year	Type	Compulsory
Prerequisite	Fundamentals of Wireless Communications		

Objectives

The Instructor will:

1. Expose the students to distinguishing features of wireless networks

Learning Outcomes

The students are expected to have the ability to:

1. Design and optimize wireless network architectures.
2. Implement security techniques for wireless networks.

Contents

Fundamentals: Layered architecture overview, data communication techniques, motivations for cross-layer protocol design, motivations for performance analysis, forward error correction and re-transmission performances (7 Lectures)

Network layer and topology design: Markov and semi-Markov processes, Little's theorem, M/M/m/k, M/G/1 systems, priority queueing, network of queues, network traffic behavior, routing algorithms and analysis, distributed networks, design constraints, bounded latency networks, optimization, cognitive networks (10 Lectures)

Network Management: Power management, time synchronization, localization, energy-efficient protocols for sensor networks (7 Lectures)

Mechanisms to improve performance: Self-Organizing Network, Software-Defined Networking (7 Lectures)

Transport and Application Layers: congestion control and quality of service, scheduling, multimedia, key aspects and design issues (7 Lectures)

Reliability and security: Security requirement and attacks, Encryption techniques, reliable and secure communication protocols (4 Lectures)

Textbook

1. Dargie, W., and Poellabauer, C., (2010), *Fundamentals of Wireless Sensor Networks: Theory and Practice*, Wiley
2. Stallings, W., (2007), *Data and Computer Communications*, 8th Edition, Pearson
3. Bertsekas, D. P. and Gallager, R. G., (1992), *Data Networks,* 2nd Edition, Prentice Hall

Self-Learning Material

1. Mishra, S., *Wireless Adhoc and Sensors Networks*, NPTEL Course Material, Department of Electrical and Electronics Communication Engineering, Indian Institute of Technology Kharagpur, https://nptel.ac.in/courses/106105160/
2. Zou, Y., Zhu, J., Wang, X., and Hanzo, L., "A Survey on Wireless Security: Technical Challenges, Recent Advances, and Future Trends," in *Proceedings of the IEEE*, vol. 104, no. 9, pp. 1727-1765, Sept. 2016.
3. W. Xia, Y. Wen, C. H. Foh, D. Niyato and H. Xie, "A Survey on Software-Defined Networking," in *IEEE Communications Surveys & Tutorials*, vol. 17, no. 1, pp. 27-51, First quarter 2015.

Preparatory Course Material

1. Zheng, L., Principles of Wireless Communications, MIT OpenCourseWare, Electrical Engineering & Computer Science, Massachusetts Institute of Technology, https://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-452-principles-of-wireless-communications-spring-2006/index.htm