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Minor Programme

IN

Cyber Physical Systems

Jointly offered by

Department of Computer Science and Engineering

and

Department of Mechanical Engineering

(Applicable from 2023 Admission onwards)

NATIONAL INSTITUTE OF TECHNOLOGY CALICUT
Kozhikode - 673601, KERALA, INDIA

Brief summary of the Minor Programme in Cyber-Physical Systems

The future of enterprises and product based industrial activities will be digital and smart, employing the model-based engineering system design concepts. Every asset will be replicated virtually, and processes will be automated in the enterprise metaverse. Digital threads and digital twins will be the engines that drive these Cyber Physical Systems (CPS) in the era of the 4th Industrial Revolution. The field is growing rapidly, and there is a high demand for skilled professionals who can design, develop, and ensure the security of Cyber-Physical Systems. A minor course on Cyber-Physical Systems can provide students with the knowledge and skills required to work in smart enterprises of the future. Design and development of these systems need an understanding of multiple engineering disciplines like mechanical engineering and computer science and engineering. Computer-aided design, Product modelling, Model-based system engineering, Modelling and simulations of CPS systems, Smart factory systems based on digital thread and digital twin, Networking, M2M communications, IoT, Computer and cyber security etc. are major areas that will be covered as part of this minor programme. It is envisaged that the students completing this programme will have comprehensive knowledge in these fields. Moreover, a multidisciplinary course like this will equip the students with skills to work in collaboration with professionals from different fields. The programme is expected to be attractive to both academia and industry, aiding the career growth of our students.

Name of the Coordinators for the Programme

1. Deepak Lawrence K, MED
2. Hiran V Nath, CSED
3. R. Manu, MED
4. Vinod Pathari, CSED

Number of seats expected for the Programme

40

BASKET OF COURSES

Sl. No.	Course Code	Course Title	L	T	P	O	Credits	Additional Categories*		
								EI	DA	HM
1.	ME2339E	Computer Graphics and Product Modelling	3	0	0	6	3	N	Y	N
2.	CS4201E	Cyber-Physical Systems: Modeling and Simulation	3	0	0	6	3	N	Y	N
3.	ME3340E	Industry 4.0 and Smart Enterprises	3	0	0	6	3	N	Y	N
4.	CS4202E	Foundations of IoT and M2M Communications	3	0	0	6	3	N	Y	N
5.	CS4032E	Computer Security	3	0	0	6	3	N	Y	N
6.	ME4223E	Cyber Physical Thermal and Energy Systems	3	0	0	6	3	N	Y	N

DETAILED SYLLABI OF COURSES

ME2339E COMPUTER GRAPHICS AND PRODUCT MODELLING

L	T	P	O	C
3	0	0	6	3

Total Sessions: Lecture 39

Course Outcomes:
At the end of the course, the student will be able to:

CO1: Explain the applications of computers in product development, product data management and product life-cycle management.
CO2: Create computer programs to implement various algorithms for generating geometric entities like line, circle and ellipse.
CO3: Create computer programs for performing 2D and 3D geometric transformations and projections of geometric entities.
CO4: Apply fundamental knowledge in mathematics to generate curves, surfaces and 3D objects.
CO5: Apply geometric reasoning principles to extract features from CAD data.

Computer applications in product development: Stages in Product development; Automation of functional activities, Product modelling; Geometric and Non-geometric data; Product Data Management (PDM); Product Life-cycle Management (PLM).
Overview of computer graphics: Mathematics for computer graphics; Graphics hardware and software; raster scan graphics; algorithms for generating line, circle and ellipse.
Transformations in computer graphics: 2D and 3D geometrical transformations: scaling; shearing; rotation; reflection; translation; Projections: parallel projections and perspective projections.
Modelling of planar and space curves: Non-parametric and parametric curves: cubic spline; Bezier curves; B-spline curves; NURBS.
Modelling of surfaces: Surface of revolution; sweep surface; linear Coons surface; Bezier surface; B-Spline surface.
Geometric modelling of 3D objects: Boundary Representation (B-Rep); Constructive Solid Geometry (CSG); Data structure for B-Rep and CSG models; Hybrid solid modellers; Feature based part modelling; Feature extraction from CAD models.
Product data exchange: Neutral file formats and exchange of product data; IGES and STEP
Hands on: Development of programs for transformations and modelling of curves and surfaces, use of commercial CAD packages for modelling and assembly of engineering components.

References:

1. Rogers, D. F., and Adams, J. A., *Mathematical Elements of Computer Graphics,* McGraw Hill, 2017.
2. Rogers, D. F., *Procedural Elements for Computer Graphics,* McGraw Hill, 2017.
3. Pande, S. S., *Computer Graphics and Product Modeling for CAD/CAM*, Narosa, 2012.
4. Patel, C. D., Chen, C. H., *Digital Manufacturing*, Elsevier, 2022.
5. Hearn, D. D. and Baker, M.P., *Computer Graphics*, Pearson, 2022.
6. Foley, J. D., Dam, A. V., Feiner, S. K.,Hughes, J. F., *Computer Graphics: Principles and Practice in C*, Pearson, 1996.
7. Mortenson, M. E., *Geometric Modeling*, John Wiley & Sons, 1997.
8. Martin Eigner, *System Lifecycle Management - Engineering Digitalization*, Springer Vieweg, 2021.

CS4201E CYBER-PHYSICAL SYSTEMS: MODELING AND SIMULATION

L	T	P	O	C
3	0	0	6	3

Total Sessions: Lecture 39

Course Outcomes:
At the end of the course, the student will be able to:

CO1: Explain the evolution and current status of cyber physical systems in the real world.

CO2: Design and Model simple cyber physical systems and specify their safety and liveness requirements.

CO3: Develop prototype for a simple cyber physical system using software tools.

Introduction to Cyber-Physical Systems

Emergence of CPS - Key Features, Theoretical Foundations, Real world Application Domains, Security primitives and considerations.

Design and Modeling of Cyber-Physical Systems

Synchronous Models - Reactive Components, Finite State Machines - Deterministic and Nondeterministic Models. Asynchronous Models - Extended State Machines, Asynchronous Design Primitives - Blocking vs Non-blocking synchronizations, Deadlocks, Shared Memory. Safety and Liveness Requirements. Real-Time Scheduling.

Simulation of Cyber-Physical Systems

Prototype development using simulation tools. Discrete and Continuous simulation. Data Exchange and Time-based Coordination. Use of visualization techniques for cyber physical systems.

References:

1. R. Alur, *Principles of Cyber Physical Systems*, MIT Press, 2015.
2. R. Rajkumar, D. de Niz, M. Klein, *Cyber-Physical Systems*, Pearson Education, 2017.
3. W.M. Taha, A.M. Taha, J. Thunberg, *Cyber-Physical Systems: A Model-Based Approach*, Springer-Cham, 2020.

ME3340E INDUSTRY 4.0 AND SMART ENTERPRISES

L	T	P	O	C
3	0	0	6	3

Total Lecture Sessions: 39

Course Outcomes:
At the end of the course, the student will be able to:

CO1: Assess various 3D data files and model data representations and select the suitable 3-D files for engineering applications.
CO2: Explain the structure and use of STEP files for interoperability applications related to product/system development.
CO3: Develop digital models for engineering system elements and propose reference architecture for digital twin modelling.
CO4: Apply the concepts of digital thread and digital twin aiding automation of product/system development activities

3-D model data files: Industry X.0 and business practices, digital technologies for smart enterprises, digital product design, 3D data digital forms, formats and semantics, point clouds, voxels, meshes, surface model - parametric and non-parametric, solid model - boundary representation (B-reps) and constructive solid geometry, properties, and applications of digital formats - form approaches, parametric modeling, procedural modeling, part digitalization, 3-D model data files for 3-D printing applications, generative design.

Digital thread: Native and neutral 3D files, structure and properties of STEP, STL, QIF, 3D PDF, JT, Parasolid, model-based definition (MBD), model-based engineering systems, model based enterprises, ISO 10303 standards for industrial automation systems and integration, semantics and ontology of STEP, information modelling using EXPRESS, part 21 files, XML files, application protocols, STEP AP 209-multidisciplinary analysis and design, AP233-systems engineering STEP AP203 , AP 214, STEP AP242, STEP AP STEP-NC AP238, STEP - NC compliant CNC ISO 14649 - digital semantic manufacturing modelling, STEP AP 239, STEP in the context of PDM and PLM.

Digital twin and Cyber Physical Systems : Digital twin, modelling approaches, service encapsulation of digital twin, ISO 23247, digital representation of engineering system elements, universally unique identifier, reference architecture, digital twin framework for manufacturing systems , automation markup language, OPC unified architecture, MT connect, digital twin for shop floors, Interaction mechanism in digital twin systems, multidimension models fusion, digital twins for prognostics and health management of engineering systems, configuration of cyber physical production systems (CPPS), real-time data from CPPS operation, sensor networks, protocols.

Applications and case studies: Applications and case studies of digital twin and digital thread in design and manufacturing, smart factories, Automation of downstream product development activities , QIF-based smart metrology and inspection, STEP-based simulation and analyses, cyber-physical machine systems, data-driven overall equipment effectiveness (OEE) analyses of smart factories.

Hands-on: Manipulation of STEP files for automation and system development, Virtual modelling and analyses of engineering system elements.

References:

1. Martin Eigner, *System Lifecycle Management*, Springer Vieweg, Germany, 2021.
2. John M.B. and Thomas H.B., *Effective Model-Based Systems Engineering*, Springer Nature, Switzerland, 2019.
3. Patel D.D., Chen C.H., *Digital Manufacturing*, Elsevier, Netherlands, 2022.
4. Zhang M, Tao F, and Nee A.Y.C., *Digital Twin Driven Smart Manufacturing*, Academic Press, USA, 2019.
5. Sondipon A., Ranjan G., Mrittika G., Souvik C., *Digital Twin- A Dynamic System and Computing Perspective*, CRC Press, USA, 2023.
6. Xun X., and Nee A.Y.C., *Advanced Design and Manufacturing Based on STEP*, Springer, Verlag, London, 2009.
7. Wang L., and Wang X.V., *Cloud-Based Cyber-Physical Systems in Manufacturing*, Springer Nature, Switzerland, 2018.

CS4202E FOUNDATIONS OF IoT AND M2M COMMUNICATIONS

L	T	P	O	C
3	0	0	6	3

Total Sessions: Lecture 39

Course Outcomes:

At the end of the course, the student will be able to:

CO1: Describe the functionality and services offered at various layers of TCP/IP protocol stack.
CO2: Analyze, design and implement protocols in each layer of the TCP/IP stack.
CO3: Configure and Implement M2M and IoT Architecture.

Computer Networks and Internet, the network edge, Core and access network, protocol layers and services, Application layer protocols, Transport layer services, UDP, TCP, Network layer services, Routing, IPv6 Protocol, Transition from IPv4 to IPv6, Network Design.

M2M to IoT – The Vision - Use case, M2M value chains, IoT value chains, Industrial structure for IoT.
M2M to IoT – An Architectural Overview, Building an architecture, Main design principles.
Security considerations.

M2M and IoT Technology Fundamentals, Business processes in IoT, Everything as a service (XaaS).
M2M and IoT Analytics, IoT Architecture – State of the Art, Architecture Reference Model, IoT Reference Architecture, IoT Use Cases with emphasis on security - Industrial Automation, Smart Grid, Smart Cities.

References:

1. Kurose J. F. and K. W. Ross, *Computer Networking: A Top-Down Approach Featuring Internet*, Pearson Education, 2017.
2. Höller, J., Vlasios T., Catherine M., Stamatis Karnouskos, Stefan A, David B., *From Machine-to-Machine to the Internet of Things - Introduction to a New Age of Intelligence*, Elsevier Ltd., 2014.
3. Peterson L.L. and Davie B.S., *Computer Networks, A systems approach*, Harcourt Asia, 2021.
4. Adrian Farrel, *The Internet and its Protocols: A Comparative Approach*, Elsevier, 2005.

CS4032E COMPUTER SECURITY

L	T	P	O	C
3	0	0	6	3

Total Sessions: Lecture 39

Course Outcomes:

At the end of the course, the student will be able to:

CO1: Demonstrate the design of modern cryptosystems

CO2: Design cryptographic protocols

CO3: Analyse and evaluate security of computer networks

Review of Cryptography Fundamentals - Symmetric and Asymmetric Cryptosystems, Cryptographic Hash, Digital Signatures.

Cryptographic Protocols for Authentication - Authentication Protocols: One way and Mutual Authentication, Challenge Response protocols, Needham Schroeder protocol. Interactive proof systems, Zero Knowledge Proof systems.

Network Security - Security at different layers – IPSec / SSL-TLS. Cloud security.

Principles of Secure Design - Software vulnerabilities - Buffer and stack overflow, Phishing. Malware - Viruses, Worms and Trojans. Security problems in network domain - Defense Mechanisms.

References:

1. B. Menezes, *Network security and Cryptography*, Cengage Learning India, 2010.
2. B. A. Forouzan and Mukhopadhyay, *Cryptography and Network Security*, 2/e, Tata McGraw Hill, 2011.
3. D. Gollmann, *Computer Security,* 3/e, John Wiley and Sons Ltd., 2014.
4. C. Kaufman, R. Perlman, and M. Speciner, *Network Security: Private Communication in a Public World*, 2/e, Pearson India, 2017.
5. W. Stallings, *Cryptography and Network Security - Principles and Practice,* 8/e, Pearson India, 2023.

ME4223E CYBER PHYSICAL THERMAL AND ENERGY SYSTEMS

L	T	P	O	C
3	0	0	6	3

Total Sessions: Lecture 39

Course Outcomes:

CO1: Develop models for fluid flow and thermal analysis of common mechanical system components

CO2: Perform numerical simulations of thermo-fluid system components

CO3: Apply the concept of digital twin to thermo-fluid systems for analysis and control

CO4: Demonstrate the use of system design and analysis tools such as Simcenter/Simulink

Introduction to thermal and energy systems: Governing equations of mass, momentum and energy, problem definition, classification and analysis of basic hydraulic components, flow measuring devices, steady-state and dynamic behaviour, engine systems: fuel, cooling, lubrication and ignition; power plant cycles and related components.

Numerical simulations of thermal and energy systems: Fundamentals of computational fluid dynamics (CFD): finite volume and finite element approaches, CFD solver fundamentals, salient features; numerical simulations of hydraulic components, automotive components/systems and thermal management systems.

Model-based system engineering: Digital twin for thermo-energy and automotive systems, Model-in-loop and Hardware-in-loop development approaches, static and dynamic analysis, multi-physics modelling of mechanical systems, system life cycle management

Hands on/Case studies: Virtual modelling and simulation analysis of thermal and energy systems, use of MATLAB/similar tools, application to automotive systems (e.g., battery modelling and thermal management), smart buildings, aerodynamics and flow analysis, hydraulic system analysis

References:

1. Fox, R. W., Mitchell, J. W., and McDonald, A. T., *Introduction to Fluid Mechanics*, Wiley, 2020.
2. Yunus A. Çengel and Ghajar, A.J., *Heat and Mass Transfer: Fundamentals and Applications*, McGraw-Hill Education, 2020.
3. Tu, J., Yeoh, G.H., Liu, C. and Tao, Y., *Computational fluid dynamics: a practical approach*, Elsevier, 2023.
4. Martin Eigner, *System Lifecycle Management - Engineering Digitalization*, Springer Vieweg, 2021.
5. Vasiliu, N., Vasiliu, D., Călinoiu, C. and Puhalschi, R., *Simulation of fluid power systems with Simcenter Amesim*, CRC Press, 2018.
6. Anderl, R. and Binde, P., *Simulations with NX/Simcenter 3D: Kinematics, FEA, CFD, EM and Data Management*, Carl Hanser Verlag GmbH Co., 2018.