# DEPARTMENT OF ELECTRICAL ENGINEERING

National University of Sciences and Technology (NUST)

## 1. Course Information

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| Course Number and Title: | EC-415 Embedded System Design |
| Credits: | 3 (3+0) |
| Instructor(s)-in-charge: | |
| Course type: | Lecture |
| Required or Elective: | Required |
| Course pre-requisites | EE-221 Digital Logic Design |
| Degree and Semester | |
| Month and Year | Spring 2026 |

## 2. Course Assessment

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| Exam: | Mid Term, Report writing/Presentation, Assignments, Project Report, Quizzes, Final Term | |
| Homework: | 3-6 Assignments minimum | |
| Design project: | Complex Engineering Problem | |
| Quizzes: | 3-6 Quizzes | |
| Grading: | Quizzes (3): | 15% Theory |
| | Assignments (3) + Complex Engineering Problem: | 15% Theory |
| | Mid Term/ One Hour Tests (OHTs): | 30% Theory |
| | Final Exam: | 40% Theory |

## 3. Course book and Related Course Material

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| Textbooks: | • [1] Frank Vahid and Tony Givargis, *Embedded System Design: A Unified Hardware/Software Introduction*, John Wiley & Sons, Inc., 2001.<br>• J. W. Valvano, *Embedded Microcomputer Systems: Real Time Interfacing*, 3rd ed., Cengage Learning, 2011.<br>• [2] Michael D. Ciletti, *Advanced Digital Design with the Verilog HDL.* 2nd ed, Pearson Education, Inc., 2017. |
| Reference Books: | • M. Morris R. Mano and Michael D. Ciletti, *Digital Design: With an Introduction to the Verilog HDL, VHDL, and System Verilog.* 6th Edition, Pearson Education, Inc., 2018.<br>• Shoab A. Khan, *Digital Design of Signal Processing Systems.* John Wiley & Sons, Ltd., 2011.<br>• Mark Zwolinski, *Digital System Design with VHDL.* 2nd ed, Pearson Education, Inc., 2004. |
| Additional References: | • [3] Lecture Slides |

## 4. Catalog Descriptions

This course will discuss the basic concepts of embedded system design, with particularemphasis on hands-on and demonstration sessions on system design using Arduino and ARMmicrocontrollers. Keeping in view of the recent developments, this course will be based on state-of-the-art microcontroller boards and programming environments. This course will also help theparticipants to understand the developmental aspects of Internet of Things (IoT) based designs.Starting from the basics, the participants will be introduced to various interfacing issues with sensorsand actuators. It is highly recommended that the participants procure some of the low-costmicrocontroller development boards and carry out the experiments that would bedemonstrated.

## 5. Course Objectives

By the end of the course, students will be able to:
- Analysis of the design and development process for a new embedded product.
- Introduction to software development and debug tool flows.
- Detailed comprehension of hardware details of microcontroller, peripherals, software programming and debugging of some common embedded system boards such as Arduino and ARM.
- Introduction to the common bus standards (i.e., ISA, PCI, AMBA, PCI Express) and common I/O interface standards (i.e., Parallel, RS-232, SPI, I2C, and USB).
- Basic concepts of programmed I/O, Interrupt driven I/O.
- Introduction of software for embedded systems design, role of an embedded operating system, hard and soft real-time systems, multitasking, threads, and synchronization.

## 6. Topics covered in the Course and Level of Coverage

| Topics | Chapter/ Sections | CLOs | Week No. |
|---|---|---|---|
| Introduction to Embedded Systems<br>• Embedded Systems Overview<br>• Design Challenge – Optimizing Design Metrics<br>• The Time-to-Market Design Metric<br>• The NRE and Unit Cost Design Metrics<br>• The Performance Design Metric | Lecture slides, Chapter 1 [1] | 1, 3 | 1 |
| Embedded Systems<br>• Processor Technology<br>• General-Purpose Processors — Software<br>• Single-Purpose Processors — Hardware<br>• Application-Specific Processors<br>• IC Technology<br>• Design Technology<br>• Libraries/IP<br>• Trade-offs, Design Productivity Gap | Chapter 1 [1] | 1 | 2 |
| Custom Single-Purpose Processors: Hardware<br>• Custom Single-Purpose Processor Design<br>• RT-Level Custom Single-Purpose Processor Design<br>• Optimizing Custom Single-Purpose Processors | Chapter 2 [1] | 1, 2 | 3 |
| General-Purpose Processors: Software | Chapter 3 [1] | 2 | 4 |

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|---|---|---|---|
| • Basic Architecture, Datapath, Control Unit, Memory<br>• Operation, Instruction Execution, Pipelining | | | |
| General-Purpose Processors: Software (cont.)<br>• Instruction Set<br>• Program and Data Memory Space<br>• General Purpose Registers<br>• I/O Ports<br>• Interrupts | Chapter 3 [1] | 2 | 5 |
| Development Environment<br>• Design Flow and Tools<br>• Example: Instruction-Set Simulator for a Simple Processor<br>• Testing and Debugging | Chapter 3 [1] | 2 | 6 |
| Application-Specific Instruction-Set Processors (ASIPs)<br>• Microcontrollers<br>• Digital Signal Processors (DSP)<br>• Less-General ASIP Environments | Chapter 3 [1] | 2, 3 | 7 |
| Standard Single-Purpose Processors: Peripherals<br>• Timers and Counters<br>• Reaction Timer<br>• Watchdog Timers | Chapter 4 [1] | 1, 2 | 8 |
| Mid Term Exam | | | 9 |
| Standard Single-Purpose Processors: Peripherals<br>• UART<br>• Pulse Width Modulators | Chapter 4 [1] | 1, 2 | 10 |
| Analog-to-Digital Converters<br>• Example: Successive Approximation | Chapter 4 [1] | 2 | 11 |
| Memory Write Ability and Storage Permanence<br>• Write Ability<br>• Storage Permanence<br>• Trade-offs | Chapter 5 [1] | 2, 3 | 12 |
| Common Memory Types<br>• Mask-Programmed ROM<br>• OTP ROM — One-Time Programmable ROM<br>• EPROM — Erasable Programmable ROM<br>• EEPROM — Electrically Erasable Programmable ROM<br>• Flash Memory<br>• Introduction to Read-Write Memory<br>• SRAM — Static RAM<br>• DRAM — Dynamic RAM<br>• PSRAM — Pseudo-Static RAM<br>• NVRAM — Nonvolatile RAM | Chapter 5 [1] | 2, 3 | 13 |
| Interfacing<br>• Communication Basics, Data Serializing, | Chapter 6 [1] | 3 | 14 |

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|---|---|---|---|
| Address/Data Muxing<br>• Basic Protocol Concepts& Methods, Strobe and Handshake | | | |
| Serial Protocols<br>• I2C<br>• CAN<br>• FireWire<br>• USB | Chapter 6 [1] | 2 | 15 |
| Parallel Protocols<br>• PCI Bus<br>• ARM Bus<br>Wireless Protocols<br>• IrDA<br>• Bluetooth<br>• IEEE 802.11 | Chapter 6 [1] | 2 | 16 |
| • Real-time Operating Systems<br>• Embedded AI | Lecture Slides | 1, 2 | 17 |
| Final Exam | | | |

## 7. Course Outcomes and their Relation to Program Outcomes (Mapping CLO to PLO)

| | Course Learning Outcome (CLOs) | PLOs | Learning Level |
|---|---|---|---|
| **CLO 1** | Analyze different embedded system design technologies, explain thevarious metrics or challenges in designing an embedded system. | 1 | C2 |
| **CLO 2** | Design an embedded system by integrating an embedded processor,memory, buses, peripheral components, and establishing theirinterconnections. | 2 | C2 |
| **CLO 3** | Evaluate how architectural and implementation design decisionsinfluence performance and power dissipation in embedded systems. | 3 | C3 |

## 8. Mapping of CLOs to Program Learning Outcomes

| PLOs / CLOs | CLO 1 | CLO 2 | CLO 3 | CLO 4 | CLO 5 |
|---|---|---|---|---|---|
| **PLO:1** (Engineering Knowledge) | C2 | | | | |
| **PLO:2** (Problem Analysis) | | C2 | | | |
| **PLO:3** (Design/Development of Solutions) | | | C3 | | |
| **PLO:4** (Investigation) | | | | | |
| **PLO:5** (Modern Tool Usage) | | | | | |
| **PLO:6** (The Engineer and Society) | | | | | |
| **PLO:7** (Environment and Sustainability) | | | | | |
| **PLO:8** (ProfessionalEthics) | | | | | |
| **PLO:9** (Individual and Teamwork) | | | | | |
| **PLO:10** (Communication) | | | | | |
| **PLO:11** (Project Management) | | | | | |

| **PLO:12** (Lifelong Learning) | | | | | |
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| **9. Program Learning Outcomes** |
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| PLO 1 | **Engineering Knowledge** |
|---|---|
| | An ability to apply knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution of complex engineering problems. |
| PLO 2 | **Problem Analysis** |
| | An ability to identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences. |
| PLO 3 | **Design/Development of Solutions** |
| | An ability to design solutions for complex engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations. |
| PLO 4 | **Investigation** |
| | An ability to investigate complex engineering problems in a methodical way including literature survey, design and conduct of experiments, analysis and interpretation of experimental data, and synthesis of information to derive valid conclusions. |
| PLO 5 | **Modern Tool Usage** |
| | An ability to create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and modeling, to complex engineering activities, with an understanding of the limitations. |
| PLO 6 | **The Engineer and Society** |
| | An ability to apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice and solution to complex engineering problems. |
| PLO 7 | **Environment and Sustainability** |
| | An ability to understand the impact of professional engineering solutions in societal and environmental contexts and demonstrate knowledge of and need for sustainable development. |
| PLO 8 | **Professional Ethics** |
| | Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice. |
| PLO 9 | **Individual and Teamwork** |
| | An ability to work effectively, as an individual or in a team, on multifaceted and /or multidisciplinary settings. |
| PLO 10 | **Communication** |
| | An ability to communicate effectively, orally as well as in writing, on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions. |
| PLO 11 | **Project Management** |
| | An ability to demonstrate management skills and apply engineering principles to one's own work, as a member and/or leader in a team, to manage projects in a multidisciplinary environment. |

| PLO 12 | **Lifelong Learning** |
|--------|------------------------|
|        | An ability to recognize the importance of, and pursue lifelong learning in the broader context of innovation and technological developments |