Telecommunications Systems Management

TELE 6550: IoT Smart/Embedded Device Development

Fall 2024 Saturdays, 9:00 AM - 12:00 PM
Ryder Hall 435

Instructor: Rolando Herrero, PhD (e-mail: r.herrero@northeastern.edu)

Course Description: This class explores the technologies and techniques behind the ever-growing field of design and development of embedded/smart devices in Cyber-Physical Systems. Specifically, it focuses on a hands-on approach based on the ESP32 embedded software development. It first introduces different instruction set architectures to transition to C C++ and C++11 development and debugging. It applies theoretical concepts to practical issues affecting embedded systems including processor pipelining, parallelism and concurrency, memory architectures as well as input and output interfaces (GPIO, I2C, UART, SPI). Discusses applications ranging from signal processing to physical system interaction with IoT assets. Presents bare-metal and FreeRTOS based development with focus on multitasking, scheduling, interrupts, threads, processes, tasks, inter process communication, contention, drivers, semaphores, mutexes and shared memory. Serves as the foundation for the Advanced class on Embedded Development.

Prerequisite(s): None

Credit Hours: 4

Text(s): *No Required Text*

Recommended Text(s):

1. *"FreeRTOS Documentation"*, `https://github.com/FreeRTOS/FreeRTOS-Kernel-Book/releases/download/V1.1.0/Mastering-the-FreeRTOS-Real-Time-Kernel.v1.1.0.pdf`; 2024
2. *"ESP-IDF Programming"*, `https://docs.espressif.com/projects/esp-idf/en/stable/esp32/index.html`; 2024
3. *"Introduction to Embedded Systems - A Cyber-Physical Systems Approach"*, E. A. Lee and S. A. Seshia, 2nd Edition, MIT Press; 2017
4. *"Cyber-Physical Systems"*, R. Rajkumar, D. de Niz and M. Klein, 1st Edition, Addison-Wesley; 2017
5. *"Real-time Operating Systems: Book 1"*, J. Cooling, 2nd Edition, Lindentree Assoc; 2019
6. *"Embedded Software for the IoT: The Basics, Best Practices and Technologies"*, K. Elk, 2nd Edition, CreateSpace Independent Publishing Platform; 2017
7. *"Embedded System Design: Embedded Systems Foundations of Cyber-Physical Systems, and the Internet of Things"*, P.Marwedel, 3rd Edition,Springer; 2018
8. *"Fundamentals of IoT Communication Technologies"*, R. Herrero, 1th Edition, Springer-Nature; 2021
9. *"C Programming Absolute Beginner's Guide: C Progr Absol Begin Guide"*, G. Perry, D. Miller, 3rd Edition, Que; 2013

10. *"Effective Modern C++"*, S. Meyers, 1st Edition, Que; 2014

Course Objectives:

At the completion of this course, students will be able to:

1. Identify components of IoT embedded systems
2. Know basic concepts of IoT embedded device design
3. Understand hardware/software mechanisms for sensing and actuation on IoT embedded devices

Grade Distribution:

Labs/Assignments	40%
Project	20%
Quizzes	10%
Midterm Exam	15%
Final Exam	15%

Course Policies:

- **General**
  - Laptops/smartphones are not to be used unless instructed to do so.
  - Exams are closed book, closed notes.
  - **No makeup exams will be given.**
- **Assignments**
  - Students are expected to work independently. **Offering** and **accepting** solutions from others is an act of **plagiarism**, which is a serious offense and **all involved parties will be penalized according to the Academic Integrity and Plagiarism Policies**. A student who is found cheating in any exam or test **will receive an automatic F for this course**. Discussion among students is encouraged, but when in doubt, direct your questions to the professor.
  - **No late assignments will be accepted under any circumstances**.

Academic Integrity:

A commitment to the principles of academic integrity is essential to the mission of Northeastern University. The promotion of independent and original scholarship ensures that students derive the most from their educational experience and their pursuit of knowledge. Academic dishonesty violates the most fundamental values of an intellectual community and undermines the achievements of the entire University.

As members of the academic community, students must become familiar with their rights and responsibilities. In each course, they are responsible for knowing the requirements and restrictions

regarding research and writing, examinations of whatever kind, collaborative work, the use of study aids, the appropriateness of assistance, and other issues. Students are responsible for learning the conventions of documentation and acknowledgment of sources in their fields. Northeastern University expects students to complete all examinations, tests, papers, creative projects, and assignments of any kind according to the highest ethical standards, as set forth either explicitly or implicitly in this Code or by the direction of instructors. Go to `http://www.northeastern.edu/osccr/academic-integrity-policy` to access the full academic integrity policy.

Student Accommodations:

Northeastern University and the *Disability Resource Center* (DRC) are committed to providing disability services that enable students who qualify under Section 504 of the Rehabilitation Act and the *Americans with Disabilities Act Amendments Act* (ADAAA) to participate fully in the activities of the university. To receive accommodations through the DRC, students must provide appropriate documentation that demonstrates a current substantially limiting disability. For more information, visit `http://www.northeastern.edu/drc/getting-started-with-the-drc`.

Diversity and Inclusion:

Northeastern University is committed to equal opportunity, affirmative action, diversity and social justice while building a climate of inclusion on and beyond campus. In the classroom, members of the University community work to cultivate an inclusive environment that denounces discrimination through innovation, collaboration and an awareness of global perspectives on social justice. It is my intention that students from all backgrounds and perspectives will be well served by this course, and that the diversity that students bring to this class will be viewed as an asset. I welcome individuals of all ages, backgrounds, beliefs, ethnicities, genders, gender identities, gender expressions, national origins, religious affiliations, sexual orientations, socioeconomic background, family education level, ability – and other visible and nonvisible differences. All members of this class are expected to contribute to a respectful, welcoming and inclusive environment for every other member of the class. Your suggestions are encouraged and appreciated.

Please visit `http://www.northeastern.edu/oidi` for complete information on Diversity and Inclusion.

TITLE IX:

Title IX of the Education Amendments of 1972 protects individuals from sex or gender-based discrimination, including discrimination based on gender-identity, in educational programs and activities that receive federal financial assistance. Northeaster's Title IX Policy prohibits Prohibited Offenses, which are defined as sexual harassment, sexual assault, relationship or domestic violence, and stalking. The Title IX Policy applies to the entire community, including male, female, transgender students, faculty and staff. In case of an emergency, please call 911. Please visit `www.northeastern.edu/titleix` for a complete list of reporting options and resources both on- and off-campus

Tentative Course Outline: The weekly coverage might change as it depends on the progress of the class.

Week	Content
Week 1 (9/7)	• Embedded Systems Concepts [2][6] – IoT and CPS components – Embedded Device Design Challenges (Power and Computational Constrains) • C Programming on ESP32 – ESP32 Device – Logical operators, binary, hex and decimal arithmetic – Data Types, Variables, Constants and Literals, Storage, Decision Making
Week 2 (9/14)	• REVIEW Embedded Devices Signal Concepts [1][5] – Range, Dynamic Range, Quantization – Noise, Sampling, Harmonic Distortion, Signal Conditioning – Use cases: Temperature Sensor, Engine Speed Control Actuator • C Programming on ESP32 – Loops, Functions, Scopes, Arrays, Pointers, Strings
Week 3 (9/21)	• REVIEW Embedded Devices Machine Learning [1][5] – ML and TinyML • C Programming on ESP32 – Structures, Unions, Bit fields, Typedef, I/O
Week 4 (9/28)	• Theoretical Background (State Machines) [1] – Finite and Extended State Machines • Classic C++ Programming – Streams, inheritance, polymorphism, rule of three, operators, templates.

Week	Content
Week 6 (10/5)	• Theoretical Background (State Machines) [1] – Theoretical Background (Concurrent Computation): – Models, Synchronous Reactive Computation • ARMv7 Assembler Programming
Week 6 (10/12)	• Hardware: Embedded Processors [1][2][3] – General Purpose vs Embedded Processors; Microcontrollers, DSPs, GPUs – Parallelism vs Concurrency, Pipelining – Instruction Level Parallelism – Multiprocessor/Multicore Systems • Modern C++ Programming – Smart pointers, lambda functions, right side references.
Week 7 (10/19)	• Hardware: Memory Architectures [1][3] – Memory Technologies; RAM vs non-volatile – Memory Maps; Register Files; Scratchpads and Caches – Addresses; Stacks; Memory Protection Units – Dynamic Memory Allocation – Usage and Management • ESP32 Memory Management
Week 8 (10/26)	• Hardware: Input and Output [1] – IoT/CPS I/O Technologies – I/O Hardware; PWM, GPIO, Serial (UART, SPI, I2C, SDIO), Parallel, JTAG/SWD – Sequential Software in Concurrent Schemes – Interrupts and Exception, Atomicity, Interrupt Controllers • ESP32 I/Os
Week 9 (11/2)	• Midterm Exam (classes 1 to 7)
Week 10 (11/9)	• OS Basic Concepts [1][3][4] – Multitasking; Imperative Programs – Threads; Creating/Implementing Threads, Mutexes, Semaphores, Deadlocks – Memory Consistency Models – Tasks; Task Priorities; Intertask Communication – Messages, Queues, Mailboxes • FreeRTOS ESP32 Basics
Week 11 (11/16)	• OS Scheduling [1][3][4] – Scheduling Policy; Scheduler Implementation – Rate Monotonic Scheduling, EDF – Scheduling and Mutual Exclusion – Priority Inversion, Priority Inheritance Protocol; Priority Ceiling Protocol – Multiprocessor Scheduling • FreeRTOS ESP32 Multitasking

Week	Content
Week 12 (11/23)	• OS Advanced [3][4] – Strictly polling, RTOS vs GPOS • FreeRTOS ESP32 I/Os
Week 13 (11/30)	NO CLASS (Thanksgiving Recess)
Week 14 (12/7)	• OS Advanced [3][4] • FreeRTOS ESP32 Communications • Class Project Due