CS326: Embedded Systems and the Internet of Things

Calvin University

Spring 2025

Course Instructor: Prof. Derek Schuurman

Textbooks:

Edward Lee and Sanjit Seshia, *Introduction to Embedded Systems: A Cyber-Physical Systems Approach, 2nd Edition*, MIT Press, 2017. Available freely online.

Derek C. Schuurman, *An Introductory Guide to Linux and Programming with the Raspberry Pi*, 2023-2025. Creative Commons, 2023-2025. Available freely online.

Additional online weekly readings on Moodle will be assigned throughout the semester.

Other Tools: A customized Raspberry Pi IoT kit will be provided by the CS department at a reasonable cost. The kit includes selected components that will be used for weekly lab assignments.

Course organization: In addition to regular lectures there will be a hands-on session each week. Regular lectures will be held on Mondays and Wednesdays and a hands-on session will be held in the Gold Lab (SB354) on Fridays.

Catalog Description

An introduction to topics in embedded systems and the Internet of Things (IoT) including hardware and software considerations for special-purpose computing applications that interact with the physical world. Hardware topics include embedded processors, I/O interfacing, sensors, and actuators. Software topics include scheduling considerations, IoT network protocols, the Web of things, state machines, and embedded programming. Additional topics include discussions of related social and ethical issues such as security, privacy, reliability, and the impact of automation. Lectures will be combined with hands-on lab exercises and a final project.

Prerequisites: Computer Science 112 (which may be taken concurrently) and Engineering 204 or 220, or permission of the instructor.

Student Learning Objectives: Upon successful completion of this course, a student will be able to:

- describe theoretical concepts in embedded systems and the Internet of Things (IoT)
- analyze a problem in embedded systems and IoT and design an appropriate solution
- implement software that applies concepts from embedded systems and IoT
- discuss social and ethical implications related to embedded systems and IoT from a Reformed Christian perspective

Lab Assignments: There will be weekly lab assignments posted in Moodle, most of which will be completed in pairs using kits that are provided. Weekly lab reports must include the names of the lab partners and must be submitted to Moodle by the following Thursday at midnight. Late lab submissions will receive at most 75% full credit and no assignments more than one week late will be accepted. Students may discuss aspects of the assignments with each other, but every group must hand in their own work.

Before attempting any labs, students must read and understand the safety guidelines posted on Moodle.

Quizzes: There will be regular quizzes scattered throughout the semester covering content from lectures, labs, and weekly readings. Quizzes will be comprised of multiple-choice questions, short answers, true/false questions, and definitions. Quiz dates will be posted on Moodle.

Final Project and Presentation: The final project in CS326 is an opportunity for you to showcase what you have learned in this class to solve a problem of interest to you. Final projects will normally be done in pairs, must implement new software features and functionality that is unique from that done in the labs, and must include some form of M2M (machine-to-machine) data communications. Your final project is due on the same day your presentation is made and should be submitted on Moodle as a single PDF file. A final presentation of your project will be scheduled during the last weeks of the course. Your presentation should be clear, using good visuals aids and providing clear answers to questions raised. Note that each group will be given a strict time limit of 10 minutes. Further information along with grading rubrics can be found on Moodle.

Grading: The grading for the course will be weighted as follows:

Quizzes	10%
Lab assignments	40%
Final Project Presentation	5%
Final Project Report	20%
Final exam	25%

Grading queries must be raised within one week of the grades being posted and no work will be accepted after the last day of classes.

Course Outline: A tentative schedule for the course is shown below. The weekly reading assignments should be read since not all the material can be covered in detail during lectures.

Week	Text and Readings	Topics	Labs
Week 1 Jan. 22,24	Chapter 1 and sections 8.1, 9.1 in *Introduction to Embedded Systems*	Introduction to embedded systems and IoT Introduction to the Raspberry Pi hardware and software Embedded processors (CPUs), microcontrollers, DSPs, ASICs, FPGAs, GPUs, and NPUs.	Lab 1 Introduction and setup of the Raspberry Pi
Week 2 Jan. 27,29,31	Chapter 2: "Introduction to Programming Languages" and Chapter 3 section on "Memory" in *Exploring Computer Science with the Raspberry Pi*	Memory architectures; flash memory considerations BareMetal or OS: software considerations Programming the Raspberry Pi • Bash shell, assembly language, GNU C/C++, Python and Cython overview • "Headless" remote development	Lab 2 Programming the RPi: assembly, C, headless and remote development
Week 3 Feb. 3,5,7	Chapter 7 in *Introduction to Embedded Systems* "A Guide to De-Bouncing"	General Purpose I/O (GPIO) ports Sensors and actuators: models and examples Sensor issues: calibration, non-linearity, noise, and failures Sensor fusion and Marzullo's Algorithm	Lab 3 Using GPIO pins
Week 4 Feb. 10,12,14	Section 7.1, 10.1 in *Introduction to Embedded Systems* How to read a datasheet	A/D conversion: Quantization, noise, sampling, resolution Pulse Width Modulation (PWM) Microservos and actuators Serial data communications: SPI, I^2C, and TIA232	Lab 4 A/D Conversion

Week 5 Feb. 17,19,21	Chapter 3 in *Introduction to Embedded Systems*	State machines, state diagrams Reachability analysis, traces Introduction to Real time operating systems (RTOS)	Lab 5 PWMs and Servos
Week 6 Feb. 24,26,28	Sections 16.3, 16.4 in *Introduction to Embedded Systems*	Real time operating systems (RTOS) Scheduling and timing analysis for periodic tasks Real Time and Linux; the PREEMPT_RT Patch Interrupts and latency, WCET and BCET Rate Monotonic Scheduling (RMS) Control systems and digital signal processing	Lab 6 Scheduling and Latency. Patching the Linux Kernel.
Week 7 Mar. 3,5,7	Sections 12.1, 12.2 in *Introduction to Embedded Systems* "The computer errors from outer space", BBC.com	Priority inversion and the Mars Pathfinder incident Single Event Upsets (SEU), watchdog timers Embedded systems product testing: HALT, EMC Introduction to IoT and M2M communications CADA framework: Collect, Analyze, Decide, Act Exemplars of IoT for Flourishing	Lab 7 M2M Communications using MQTT
Mar. 10-14	Spring break		
Week 8 Mar. 17,19,21	"Introduction to MQTT for IoT" in *Exploring Computer Science with the Raspberry Pi* "SQL Basics"	Wireless M2M communications: Bluetooth, WiFi, 5G, Zigbee, LoRaWAN Introduction to the MQTT protocol IoT data, SQL, and cloud databases	Lab 8 Fog computing: IoT with local web server and local database
Week 9 Mar. 24,28 (Advising day: Mar. 26)	Intro to the Web of Things (video)	The Web of Things (WoT) HTTP and request/response & polling Polling vs. Publish/Subscribe protocols MQTT over websockets Web and database: sensor data visualization	Lab 9 Cloud computing: IoT with cloud database and cloud web server
Week 10 Mar. 31 Apr. 4 No class Apr. 2	Intro to Edge AI (video) "Intro to AprilTags" "Camera Sensors" in *Exploring Computer Science with the Raspberry Pi*	IoT and Blockchain Big data, IoT data analytics, Cloud vs. Fog computing AIoT: AI + IoT and machine learning NPUs and Edge AI Computer Vision at the edge	Lab 10 Camera sensors, AprilTags, and the Web of Things (WoT)
Week 11 Apr. 7,9,11 Guest lecture by Dr. Rocky Chang (April 7)	Section 17.3 in *Introduction to Embedded Systems* "6 Reasons Why IoT Security Is Terrible" *(IEEE Spectrum)* "Are You Sure Your Software Will Not Kill Anyone?" (*CACM*) "The Importance of Humility and Humor: Countermeasures against Techno-Foolishness" (excerpt from *Habits of the High Tech Heart*)	IoT security issues MQTT security: authentication, SSL encryption Embedded certificates Testing considerations Social and ethical issues: reliability, safety, sustainability, and humility Privacy and security Normative design principles: IoT for flourishing Case studies: • Therac-25 incident • VW emissions scandal • Boeing 737 Max 8 incident	Lab 11 Security and M2M communications
Week 12-14		Final Project Presentations Review	Work on final project

Laptop policy: Laptops used in lectures must be used strictly for notetaking. Regular "hands-on" practice will be provided in the weekly lab sessions. Furthermore, the use of cell phones is not permitted during classes or labs except when they can be used as part of a lecture or lab.

Academic Honesty
Students are expected to display honesty and responsibility in completing assignments. Students are responsible for understanding the information on plagiarism contained in the Student Conduct Code. For more information, refer to the Calvin plagiarism policy.

Use of Generative AI Tools: Students must write their own code and reports and not rely on using generative AI tools. Students may write code that implements an AI solution for their final project (for example, performing object recognition using the camera).

Accommodations: Calvin University will make reasonable accommodations for persons with documented disabilities. Students should notify a disability coordinator in the Center for Student Success in order to arrange accommodations. Then, come and talk to me within the first two weeks of class so we can put your accommodations in place.

Communication outside of Class Times: Important announcements will be sent via Moodle to Calvin email, so students should check their Calvin email on a regular basis. Generally, the instructor will be happy to help you during lab times, during office hours or whenever I am in my office. The preferred way of communication outside the classroom is through Teams. Tutors are available by contacting the Center for Student Success.

Commitment to Hospitality: It is our intent that students from all backgrounds and perspectives are well served in this course. Join me in creating a class that creates a space where we can ask honest questions and explore important ideas related to various technology issues. If you or someone else is hurt by anything said or done in class, let me know so we can work toward a remedy.