

Real-time Embedded Systems

ECE 4501/6501, CS 6501

Spring 2025

Instructor: Homa Alemzadeh
Associate Professor, ECE
alemzadeh@virginia.edu

Teaching Assistants: Seyed Hamid Reza Roodabeh ydq9ag@virginia.edu
Keshara Weerasinghe cjh9fw@virginia.edu
Paul Karhnak zxz2hm@virginia.edu

Class Time: Mondays and Wednesdays, 2:00 PM - 3:15 PM
Location: Rice Hall 340

Office Hours: Mondays and Wednesdays, 3:30-4:00 PM and other times by appointment
TA Office Hours: Check the course website and UVA Canvas

Course Website: https://homa-alem.github.io/teaching/ece_6501/index.html

Primary Textbook:

- Jonathan W. Valvano, *Embedded Systems: Real-Time Operating Systems for ARM® Cortex™-M Microcontrollers*, Volume 3, Fourth edition, January 2017, ISBN: 978-1466468863.
Outline: <https://users.ece.utexas.edu/~valvano/arm/outline3.htm>

Additional References:

- Edward Lee and Sanjit Seshia, *Introduction to embedded systems: A cyber-physical systems approach*, MIT Press, 2016. (Free PDF: <http://leeseshia.org/download.html>)
- Philip Koopman, *Better embedded system software*, Drumnadrochit Education, 2010.
Companion blog: <https://betterembsw.blogspot.com/>
- J. Knight, *Fundamentals of Dependable Computing for Software Engineers*, CRC Press, 2012.

Course Description

Embedded systems are special-purpose computers (e.g., micro-controllers, DSP processors) at the core of Cyber-Physical Systems (CPS) that monitor and control the physical processes through real-time interactions with sensors and actuators. They are tightly integrated with the electronic and physical components and must operate within real-time performance, battery, and size constraints. More than 90% of manufactured micro-processors go inside airplanes, automobiles, medical devices, digital cameras, toys, home appliances, and smart buildings. What are the building blocks of an embedded system? How can we design an embedded system and make sure it satisfies specific functionality, reliability, and timing requirements? How can we bridge the gap between the inherently sequential embedded software with the intrinsic concurrency in the physical world? How can we execute multiple data acquisition, processing, and control tasks on resource-constrained microcontrollers while satisfying real-time constraints?

This course will help you answer these questions by providing the foundational knowledge and hands-on experience in design and validation of embedded computing systems, with a focus on embedded C programming and real-time operating systems for ARM® Cortex™-M Microcontrollers. In the second half of the class, we will explore related topics and applications in safety and security, cyber-physical systems (CPS), internet of Things (IoT), and robotics through paper presentations and discussions.

Learning Goals and Objectives

This course is intended for the first-year graduate (GRAD) and the third/fourth-year undergraduate (UG) students in Electrical and Computer Engineering and Computer Science as well as the first-year graduate students in the NRT CPS program. It will help you develop the foundational knowledge and technical skills to design, implement, and validate real-time embedded systems. By the end of the course, you will be able to:

1. Describe the design principles for real-time systems and the key building blocks of embedded system architectures and real-time operating systems.
2. Explain how memory management, software/hardware interfacing, interrupt handling, multitasking, thread management and communication, and task scheduling are done in real-time operating systems.
3. Develop C/C++ programs within the ARM embedded programming environments.
4. Design and evaluate an embedded system based on a given specification and validate if the functional and timing requirements are satisfied.
5. Apply acquired knowledge and skills in the class to design and implementation of embedded systems in collaboration with your team members.
6. Relate to the real-world applications of RTOS and associate with related and emerging research areas, such as safety and security of embedded systems, Cyber-Physical Systems (CPS), Internet-of-Things (IoT), and robotics.
7. Construct new knowledge, critique ideas, and effectively present advanced topics.

Assessment and Evaluation

	Undergraduate (ECE 4501)	Graduate (ECE 6501/CPS 2)
Class Participation/Activity	10%	10%
Homework	20%	10%
Mini Projects	30%	30%
Midterm Exam	20%	20%
Final Project	20%	20%
Grad Student Presentations	0%	10%

Class Participation (10%): Active class participation is key in enhancing your team-work and critical thinking skills and improving the learning environment. Every week we will have an *in-class* activity in which you work in groups of two/three on solving problems related to the concepts taught in lectures or discuss topics presented in class (Objectives 1, 2, and 5). **In-person participation for in-class group activities is required.** These class activities are only graded for participation (binary 0 or 100) and not accuracy/correctness and often will be followed by problems that you will complete individually in the

homework. These activities will prepare you for mini-projects and final project, in which you apply the concepts learned in class to design of real embedded systems. Other important components of class participation are course evaluations via online anonymous surveys and peer evaluations by providing comments/feedback to your classmates (Objective 7). Students who cannot attend a class in person due to medical, family, or personal emergencies can, **with the instructor's permission**, attend the Zoom session, complete the in-class activity individually, and submit it **on the same day as the class**.

Homework (UG: 20%, GRAD: 10%): Homework is to reinforce the concepts taught in the lectures and practiced in class activity through individual work. The main purpose of homework is to enhance your understanding of core concepts, encourage critical thinking, and prepare you for the mini projects through small programming or written exercises (Objectives 1 and 2). Homework will be given roughly every week and will constitute a lower percentage of the final grade for the graduate students.

Mini Projects (30%): Mini-projects are hands-on experience programming exercises that enhance your technical skills and help you learn how to apply the concepts learned in the lectures, class activities, and homework into practice (Objectives 3, 4, and 5). There will be roughly four mini projects and they will be done by groups of 2-3 students. Every other week, after you submitted your mini-projects, we will discuss them in the class and you will evaluate your submissions based on the given rubric (Objective 7). You will then have a chance to review and revise your submission in the next mini project.

Midterm Exam (20%): Midterm exam will be based on the lectures, class activities, homework, and mini-projects to test the material covered in the class (Objectives 1-4). Note that the exam will be **closed book and in person** during class time, and **using any electronic tools and devices is prohibited** during the exam. But, you may bring a single 8.5" x 11" sheet of notes and will have access to the relevant datasheets and functional descriptions to answer the exam problems.

Final Project (20%): Building up on the knowledge and skills learned through lectures, class activities, and mini projects, you will work in teams of 3-4 students on a project related to design and evaluation of an embedded system with a real-world application. Around the middle of the semester, each team will select a project and set the milestones, timeline, and division of tasks for completing their project. During an **end-of-semester design competition**, each team will present their progress towards the completion of the project and their results through presentations and demos to the whole class (and an optional final written report). The projects will be evaluated based on the proposed ideas, the techniques used for design and validation, applying concepts learned in the class, demonstrating working prototypes and measurable outcomes, as well as the quality of the final presentation. **All the students are expected to participate in the final presentation in person** and contribute to the evaluation of all the projects by giving feedback on the presentations to each team and grading it based on a given rubric. Each student will also be evaluated by me and the teaching assistants based on the quality and creativity of their ideas, questions, and evaluation. (Objectives 1-7)

Graduate Student Presentations (UG: 0%, GRAD: 10%): Graduate Student presentations will be done in the second half of the semester and are planned to expose you to the advanced topics and emerging research areas in embedded systems and enhance your critical thinking skills. To differentiate the requirements for the graduate class from those for the undergraduate class, the students enrolled in the graduate section will work with me on selecting a relevant topic of interest and will present it to the

class. Each presentation will follow with a class activity or discussion on the topic. All the students are expected to show active participation in evaluating the presentations in terms of quality, content, and arguments using a given rubric. (Objectives 6 and 7)

Pre-requisites

A basic knowledge of computer architecture and embedded systems is required. A working knowledge of computer assembly and C/C++ programming is required for mini projects.

Online Tools and Resources

Class meetings (including lectures and in-class activities) and office hours will be in-person. All students are expected to attend class **in person**. To support asynchronous learning, the lectures will also be broadcasted synchronously via **Zoom**, and their video recordings, along with the lecture notes and reading material, will be posted on the **UVA Canvas website**. You can register and attend the Zoom meetings or watch their recordings under "Online Meetings" on Canvas. We will use **Piazza** for posting announcements, running polls, and Q&A. **GitHub Classroom** will be used for posting and submitting mini projects and the final project. Each student must actively follow the announcements and posts on the Canvas and Piazza and show active participation by posting questions, answering questions posted by their classmates, and taking part in polls and online surveys in a timely manner.

Course Schedule

The following schedule presents the tentative activities for each week and throughout the semester. This schedule is subject to change depending on our progress and interests. I will inform you of any updates or changes on the Canvas or Piazza and at the beginning of each class. https://homa-alem.github.io/teaching/ece_6501/schedule.html. I expect everyone to regularly check this "Schedule of Activities" before each class.

Course Policies

Academic Integrity: By enrolling in this course, you have agreed to abide by and uphold the Honor System of the University of Virginia (<https://honor.virginia.edu>). I expect every student in this course to fully comply with all the provisions of the University's Honor Code. Any attempt to take credit for work done by another person is considered as plagiarism and a violation of the honor code. You are encouraged to study in groups and work together on in-class activities, some of the mini-projects, and the final project. You may also refer to online material, code, and research articles for your projects and presentations. However, you **must properly credit** the team members whom you collaborated with and **cite any resources or individuals you consult or any code or tools that you use**. You should understand the material/code that you use and be able to explain them. All suspected violations will be forwarded to the Honor Committee, and you may, at my discretion, receive an immediate zero on that assignment.

Late Policy: There will be a **10% penalty** for late assignments (**per school day**). You will also have a **grace period of three days** for the whole course to address any unexpected events such as sickness, traveling, other deadlines, interviews, etc. This means that you can always submit late assignments (**except the class activities, presentation slides, and the final project**), but if you don't use more than three late days, you will not be penalized in any way. The late penalties and the grace period will be accounted for at the end of the semester. Also, your lowest grades for homework and class activity will be dropped.

Policy on the Use of Generative AI Tools: Generative artificial intelligence tools—software that creates new text, images, computer code, audio, video, and other content—have become widely available (e.g., ChatGPT, Gemini, DALL-E, Microsoft Copilot). This policy governs the use of all such tools, including new ones released this semester. **You may NOT use generative AI tools on any of the assignments in this course unless otherwise specified.** Specifically:

You **may NOT use** generative AI tools to:

- Complete your class activity and homework problems.
- Write code for your homework, mini-projects, or final project.
- Generate the text and slides for your presentations.

You **may use** generative AI tools to:

- Check grammar and readability of text
- Format plots, figures, or print statements.
- Look up technical concepts or ask for explanations and examples (e.g., how to use a function)
- Write practice exam problems.

If you use generative AI tools for an allowable use listed above (such as plotting a figure), you must **properly document and credit the tools**. Please cite the tool you used and include a brief description of how you used it. Also, you should understand the material and code that you use and **be able to explain them**. The inappropriate use of AI tools will prevent you from achieving the learning goals we have set in this course and result in you doing poorly on the exam and final project. **Remember** that generative AI tools are usually trained on limited or pre-existing datasets and online material that may be outdated, copyrighted, buggy, or incorrect. So, the irresponsible use of their output may result in plagiarism or copyright violations. It is ultimately your responsibility to ensure the quality, integrity, and accuracy of the work you submit in any course.

Recording of Classroom Activities: I will be recording every lecture to accommodate students who will be learning remotely. Recordings will be available in Canvas Online Meetings under “Cloud Recordings.” The default settings in Zoom only record the face of the active speaker. Because these recordings may visually or audibly identify you and your fellow students in the class or contain sufficient context that may result in the identification of a student, they **may only be used** for the purpose of individual or group study with the other **students enrolled in this class during this semester**. They may only be stored on University-owned password-protected sites such as UVA Canvas. You may **not distribute them** in whole or in part through any other platform or to any persons outside of this class, nor may you make your own recordings of this class unless written permission has been obtained from me and all participants in the class have been informed that recording will occur. If you want additional details on this, please see Provost Policy 005 (<https://uvapolicy.virginia.edu/policy/PROV-005>). If you notice that I have failed to activate the recording feature on Zoom, please remind me!

Students with Disabilities or Learning Needs: It is my goal to create a learning experience that is as accessible as possible. If you anticipate any issues related to the format, materials, or requirements of this course, please meet with me outside of class so we can explore potential options. Students with disabilities may also wish to work with the Student Disability Access Center (SDAC) to discuss a range of options to removing barriers in this course, including official accommodations. We are fortunate to have

an SDAC advisor, Courtney MacMasters, physically located in Engineering. You may email her at cmacmasters@virginia.edu to schedule an appointment. For general questions, please visit the [SDAC website: sdac.studenthealth.virginia.edu](http://sdac.studenthealth.virginia.edu). If you need any special assistance, please get in touch with me **as soon as possible** by Email or during office hours. If you have already been approved for accommodations through SDAC, please **send me your accommodation letter** and meet with me so we can develop an implementation plan together.

Harassment, Discrimination, and Interpersonal Violence: The University of Virginia is dedicated to providing a safe and equitable learning environment for all students. If you or someone you know has been affected by power-based personal violence, more information can be found on the UVA Sexual Violence website that describes reporting options and resources available at www.virginia.edu/sexualviolence.

The same resources and options for individuals who experience sexual misconduct are available for discrimination, harassment, and retaliation. [UVA prohibits discrimination and harassment](#) based on age, color, disability, family medical or genetic information, gender identity or expression, marital status, military status, national or ethnic origin, political affiliation, pregnancy (including childbirth and related conditions), race, religion, sex, sexual orientation, or veteran status. [UVA policy](#) also prohibits retaliation for reporting such behavior.

If you witness or are aware of someone who has experienced prohibited conduct, you are encouraged to submit a report to [Just Report It](http://justreportit.virginia.edu) (justreportit.virginia.edu) or [contact EOOCR](#), the office of Equal Opportunity and Civil Rights. If you would prefer to disclose such conduct to a confidential resource where what you share is not reported to the University, you can turn to [Counseling & Psychological Services \("CAPS"\)](#) and [Women's Center Counseling Staff and Confidential Advocates](#) (for students of all genders).

As your professor and as a person, know that I care about you and your well-being and stand ready to provide support and resources as I can. As a faculty member, I am a responsible employee, which means that I am required by University policy and by federal law to report certain kinds of conduct that you report to me to the University's Title IX Coordinator. The Title IX Coordinator's job is to ensure that the reporting student receives the resources and support that they need, while also determining whether further action is necessary to ensure survivor safety and the safety of the University community.

Religious Accommodations: It is the University's long-standing policy and practice to reasonably accommodate students so that they do not experience an adverse academic consequence when sincerely held religious beliefs or observances conflict with academic requirements. If you wish to request academic accommodation for a religious observance, please submit your request directly to me by Email **as far in advance as possible**. Students who have questions or concerns about academic accommodations for religious observance or religious beliefs may contact the University's Office for Equal Opportunity and Civil Rights (EOCR) at UVAEOCR@virginia.edu or 434-924-3200.

Student Support Team: You have many resources available to you when you experience academic or personal stresses. In addition to your professor, the School of Engineering and Applied Science has staff members located in Thornton Hall who you can contact to help manage academic or personal challenges. **Please do not wait until the end of the semester to ask for help!**

Learning

[Lisa Lampe](#), Assistant Dean for Undergraduate Affairs

[Georgina Nembhard](#), Director of Undergraduate Success

[Courtney MacMasters](#), Accessibility Specialist

[Free tutoring](#) is available for most classes.

Health and Wellbeing

[Kelly Garrett](#), Assistant Dean of Students, Student Safety and Support

Elizabeth Ramirez-Weaver, CAPS counselor*

Katie Fowler, CAPS counselor*

*You may schedule time with the CAPS counselors through [Student Health](#) (<https://www.studenthealth.virginia.edu/getting-started-caps>). When scheduling, be sure to specify that you are an Engineering student. You are also urged to use [TimelyCare](#) for either scheduled or on-demand 24/7 mental health care.

Community and Identity: The [Center for Diversity in Engineering](#) (CDE) is a student space dedicated to advocating for underrepresented groups in STEM. It exists to connect students with the academic, financial, health, and community resources they need to thrive both at UVA and in the world. The CDE includes an open study area, event space, and staff members on site. Through this space, we affirm and empower equitable participation toward intercultural fluency and provide the resources necessary for students to be successful during their academic journey and future careers.