CPS1: Cyber-Physical Systems Technology and Ethics

CE 6780 / CS 6780 / MAE 6780 / SYS 6780 / ENGR 6780

Course Teaching Team

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Logistics

Tue/Thu 11:00am-12:15pm
Rice Hall 340

Abbreviated Course Description

*This course is designed to develop cross-competency in the technical, analytical and professional capabilities necessary for the emerging field of Cyber-Physical Systems (CPS). It provides convergence learning activities that are based around understanding **distributed sensing systems** in CPS applications and exploring the **ethical**, **social,** and **policy** dimensions of CPS work. The course also emphasizes the importance of **communication** as a necessary skill.*

Overview

CPS as a discipline integrates the cyber, physical and social worlds. The responsibilities of CPS professionals are then to *sense*, *analyze* and *actuate* upon the world with *efficient*, *safe*, *secure* and efficacious engineered systems. To do this effectively, CPS professionals need to develop *cross-competency* in technical, analytical and professional capabilities that are necessary for the efficacious and safe functioning of CPS systems. CPS is an inherently interdisciplinary discipline and practicing engineers must build systems and create knowledge at the *inter*-section of multiple knowledge domains. The best way to learn to do this is by participating in convergence learning activities that integrate an interdisciplinary CPS perspective from the onset.

Bridging the physical and cyber worlds requires CPS engineers to scalably capture data about the physical world, derive understanding from that data, and then actuate in the physical world based on that understanding. This closed-loop operation is a fundamental aspect of CPS, but requires wirelessly connected, low power, and embedded devices to realize at the large scales that CPS applications require. CPS engineers must understand the principles of how real-world data is collected, and be able to prototype their own designs in a controlled environment. Testbeds provide the environment to simulate real-world conditions and enable engineers to carefully observe the impact of their designs, changes and interventions.

CPS engineers also need to understand the role policy plays in shaping the possibilities of CPS systems and how technical standards can be utilized in achieving societally desirable goals of safety and resiliency. They must be able to perform critical analyses of systems with an eye towards, safety, ethics, compliance and

human welfare. As all engineered systems reconfigure social relationships and hierarchies in ways that can have profound and important long-term societal implications. CPS engineers must have the analytical skills to describe and understand the interaction of their design on various human agents including users, regulators, non-users and various publics.

CPS as a discipline is at the fore-front of engineering new cyber-physical capabilities that could have significant effects on entire industries and job categories and engineers need to be prepared to participate in debates about the future that they are shaping from an informed and ethical perspective.

This course is designed to teach these necessary competencies.

F'23 Course Focus

This semester will focus on a particular CPS application space: **outdoor water management**. This will include flood management and municipal hydrological control. This application will provide you with a concrete testbed to consider the technical and ethical topics in this course, as well as practice working with engineers from other disciplines. We will refer to this application throughout the semester as we examine various topics. This will enable us to take a deep dive in this area and really explore both technical and social concepts in this CPS application. We will hear from experts in this area to guide our discussions.

Course Objectives

At the end of this course, you will be able to do the following:

1. Understand the fundamentals of wireless sensor networks and the tradeoffs of different designs concerning power, communication, reliability, update rate, latency, and ease-of-use.
2. Describe and critically comment on social and policy debates surrounding the field of CPS.
3. Be capable of programming a wireless sensor node and applying it to an existing CPS testbed.
4. Understand the principles of user centered design and how users and non-users are implicated in design.
5. Understand the IEEE Ethically Aligned Design Framework and how to utilize it to design cyber-physical systems.

Assignments

Your progress in the course will be assessed on all the dimensions described in the course objectives above. We will release detailed instructions for each assessment on Collab as we progress throughout the semester.

A. Develop an Application using the Living Link Lab Testbed (10 Points): Working in teams, you will use the existing data streams from the Living Link Lab testbed to prototype a smart office space application.

B. Build a Wireless Sensor (10 Points): Working in teams, you will develop a wireless sensor to monitor a new data stream of interest to your group. The sensor will collect information from sensors, process that information locally, and transmit the results wirelessly.

C. Integrate a New Wireless Sensor into the Living Link Lab (10 Points): Working in teams, you will apply your experience developing embedded devices and leveraging data streams to prototype an end-to-end application leveraging the existing Living Link Lab infrastructure.

D. Case study on Living Link lab using EAD framework (10 Points): In this project, you will work in teams to develop a case study of the Living Link Lab utilizing the IEEE Ethically Aligned Design Framework.

E. Analysis on New Wireless Sensor: In this project you will do a user, ethical, and privacy analysis of the sensor you developed in Assignment B.

F. Discussion (10 Points): This course can be truly transformational in your course of study here at SEAS. However, the level of benefit you will receive is directly proportional to your level of engagement and effort. Active participation is therefore essential to getting the most out of the course. As CPS engineers work in groups, you will need to apply all that we will teach you about group work to ensure that your groups are high-functioning groups.

G. Final Exam (20 Points): Your team will present the motivation, technical details, social, ethical, and policy implications, and results of your integrated Living Link Lab project. The final will provide an opportunity to highlight you new integrated understanding of CPS projects and the different kinds of expertise required of a CPS engineer.

Here is a breakdown of grading weights for each assessment in the class.

● Assessment A	10%
● Assessment B	10%
● Assessment C	10%
● Assessment D	10%
● Assessment E	10%
● Assessment F	10%
● Assessment G	30%
● Attendance	10%
Total	**100%**

Final grades are determined by the schedule below:

A+	97-100	A	93-96	A-	90-92
B+	87-89	B	83-86	B-	80-82
C+	77-79	C	73-76	C-	70-72
D+	67-69	D	63-66	D-	60-62
F	below 60				

Class Schedule

How should we meet?
Prepared, excited, and ready to learn and contribute each and every day.

Dates	Description	Instructor
8/23	Course Introduction – what is CPS; overview of the Link Lab testbed; goals; teams; hands-on	Taught Jointly
8/25	The **Living Link Lab Testbed**: A Technical Overview	Campbell
8/30	**Issues in CPS Ethics 1** - An Introduction Issues in CPS Ethics 1 This is our first class on this topic and will provide an overview of our discussions this semester. Please read the European Parliaments Scientific Foresight Study on Ethical Aspects of CPS.	Heydarian
9/1	**Applications:** why CPS? Special problems at the intersection of cyber and physical. Please read the abstract/introduction of these five papers (found in resources in collab): • Battery-less Zero-maintenance Embedded Sensing at the Mithræum of Circus Maximus • Smart homes that detect sneeze, cough, and face touching • CAN Coach: Vehicular Control through Human Cyber-Physical Systems • I Always Feel Like Somebody's Sensing Me! A Framework to Detect, Identify, and Localize Clandestine Wireless Sensors • Using machine learning classification to detect simulated increases of de facto reuse and urban stormwater surges in surface water Then choose one paper and read it fully. After reading, write one sentence that starts "The key insight of this paper is..." and try to articulate the main insight/contribution underlying the research.	Campbell
9/6	**Issues in CPS Ethics 2:** Why do we need public policy in CPS? Please read: • The Brookings Report on Algorithmic Bias detection and Mitigation. • Also, read the Booz Allen take on preventing bias.	Heydarian
9/8	**The Cloud**: Processing at scale. Why use the cloud for CPS? What are the strengths and weaknesses of cloud computing? We will discuss the key design considerations you should consider when designing CPSes. If time permits we will have an Assignment 1 workshop as well.	Campbell

9/13	Please read: • Algorithm appreciation: People prefer algorithmic to human judgment https://doi.org/10.1016/j.obhdp.2018.12.005 • Overcoming Algorithm Aversion: People Will Use Imperfect Algorithms If They Can (Even Slightly) Modify Them https://doi.org/10.1287/mnsc.2016.2643 • Algorithm Aversion: People Erroneously Avoid Algorithms After Seeing Them Err https://doi.org/10.1037/xge0000033	Heydarian
9/15	**The Edge/Fog**: Processing near the sensors. We will discuss the "gateway tier", how it relates to the cloud, and how gateways and edge computing can aid cyber-physical systems.	Campbell
9/20	**User Centered Design: Some Theories** This is an important and fascinating topic in STS. The notion of "users" and its corollary "non-users" are very useful STS concepts for engineers. Users (and non-users) are involved in various aspects of the engineering, but most notably at the design stage. There are two readings for today. The first is a fascinating piece by Madeleine Akrich about reading technologies as scripts. Akrich is a scholar who works in the ANT tradition. We will also read the first part of the introduction to the book - How Users and Non- Users Matter: The Co-construction of users and Technology by Nelly Oudshoorn and Trevor Pinch. This reading is an overview of the various different ways the idea of users has been utilized in STS and other social science fields. Please pay attention to the evolution of the concept of users as you read this article. • The de-scription of technical objects in Shaping technology/ building society In Shaping technology/ building society by M. Akrich • How Users and Non-Users Matter: The Co-construction of users and Technology by Nelly Oudshoorn and Trevor Pinch	Heydarian
9/22	**The Embedded Tier**: In-situ sensing and computation. Rounding out the third tier, we will discuss devices which are embedded in the physical world to bridge the physical/digital gap. This will cover the strengths and weaknesses of these devices and discuss their limitations.	Campbell
9/27	**User-Centered Design 2** • Chapter 1 (The Psychopathology of Everyday Things) of "The Design of Everyday Things" book by Donald A. Norman.	Heydarian

9/29	**Communicating technical CPS concepts**. How to distill the essential aspects of complex CPSes to effectively communicate your work. **Activity**: System design with specific sensors, constraints, applications, and optimizations.	Campbell
10/4	No Class - Reading Day.	
10/6	**CPS Communication 1**: Wireless communication. What are the wireless protocols used for CPSes, and why are so many in use? What are their tradeoffs? We will explore the basics of the physical layer and a suite of wireless protocols often used with IoT devices. Protocols include: • WiFi • BLE • LoRa • 4G/5G • NBIoT • Enocean	Campbell
10/11	**Smart farming and agriculture 4.0** In this session we will read two papers focusing on the different users in smart farming and how the agriculture industry is coping with new technologies and CPS. • Paper 1: A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda • Paper 2: Making sense in the cloud: farm advisory services in a smart farming future	Heydarian
10/13	**CPS Communication 2**: Networking. What networking protocols do CPS devices use, how do they work, and which should you choose in your own designs? Topics include: • Mesh networks • BLE GATT model • LoRa networks • Data formats and schemas	Campbell
10/18	**Future of Construction Industry** The next normal in construction - McKinsey & Company's 2020 report on the future of the construction industry and how different stakeholders would be	Heydarian

	impacted by the technological transformation taking place. In this article, they also discuss how COVID has expedited some of these changes. • Read chapters 1 – 5 of 2020 McKinsey report	
10/20	**Sensors**. How do sensors actually measure the physical world, from code to physics? This will highlight how layers of abstractions and imperfect hardware have impacts on the limitations and usability of cyber-physical systems.	Campbell
10/25	**How should CPS engineers respond? - Introduction to the EAD** As an introduction to our conversations on the IEEE EAD, please read the following: EAD Document Come to class ready to present your own section of the EAD. Your group should summarize your section and then consider how it relates to the other readings we have done this semester and finally, discuss ways of implementing your section as a CPS engineer. Group 1 – Introduction & Executive Summary + pages 9-35 Group 2 – Introduction & Executive Summary + pages 36-67 Group 3 – Introduction & Executive Summary + pages 68-89 Group 4 – Introduction & Executive Summary + pages 90-123 Group 5 – Introduction & Executive Summary + pages 124-168 Group 6 – Introduction & Executive Summary + pages 169-197 Group 7 & 8 – Introduction & Executive Summary + pages 198-252	Heydarian
10/27	**Security and Privacy**. What do security and privacy mean in the CPS context, and what are the fundamental security and privacy issues for CPS? We will cover encryption and differential privacy, threat models, and techniques which do not provide security.	Campbell
11/1	**Diving into the EAD**: Applicability. Continue discussion from the previous week.	Heydarian
11/3	**End-to-End Applications**. We will revisit smart farming and design a CPS to address a specific smart agriculture application. The class will be split into groups and each group will design a portion of the system (edge, sensors, system, security/attacks). We will discuss the complexities of system integration.	Campbell
11/8	Guest Lecture - Michele Claibourn	
11/10	No class, but please attend the Ethics in Engineering and Cyber-Physical Systems panel on Friday, November 11, 2022, from 12:30 to 1:30 PM in the Link Lab.	
11/15	Guest Lecture - Jess Reia	
11/17	**Ethics Presentations**. Please prepare one slide and a two minute presentation on an ethical or policy question of your choice. Be prepared to concisely communicate the topic in 120 seconds or fewer. There will be time for questions as well.	Joint
11/22	Guest Speaker: Dexcom.	Heydarian
11/24	Thanksgiving Recess	

11/29	Workshop: final projects.	Joint
12/1	**Future of Sensing**. What are some of the emerging research ideas on new sensors, communication protocols, energy techniques, applications, and sustainability that might be in this class in 5-10 years?	Campbell
12/6	**Final Project Paper EAD Critiques**. Groups will swap design papers, and each group will do a peer critique following the EAD guidelines of the other group's design document.	
12/9	**Final Exam Presentations**. Each group will present their final design project for 15 minutes and there will be 5 minutes for questions.	During exam period.

General Course FAQs

How will we communicate in this course?
We will make extensive use of the course website, Collab, and e-mail. You are expected to be courteous, respectful, and professional in your e-mail. To distinguish between course matters and everyday business, please begin each e-mail you write with "CPS 1" in the subject line. As a professional, we expect that you will pay close attention to all e-mail from all instructors.

What texts and supplies do I need for the course?
You do not need to purchase any books for this course. We will read a number of book chapters and articles, all of which will be available under the Resources tab on Collab.

How should I submit my written work?
To facilitate accurate and speedy responses, please submit assignments electronically as **PDF** files to the appropriate folder in Collab. We are unable to process any other file type (e.g. doc or .docx). Late or missing work will lose points. To protect yourself from computer crashes, always make and keep a hard copy of each assignment. Remember that we grade the document as it appears on Collab. Please make sure to turn in your work correctly (i.e. not a Word doc. or a rough draft) and on time by the deadline and to check Collab to verify that it was submitted. Any late or missing work will lose significant points regardless of the reason (and even if you can produce an electronic time-stamped document that shows you haven't made any changes since before the deadline). It is your responsibility to make sure your work is turned in correctly and on time.

What practices can hinder my performance in the course?
While we anticipate that all students will pass this course, previous unpleasant experiences require that we explain in advance the ways in which it is possible to fail the course. First, you can fail the course if you do not turn in all of the assignments and/or the quality of your work is below what we deem as the acceptable minimum. Second, we have the option to fail you if you do not submit any or all of the assignments on the due dates. And third, you can fail if you have an inordinate number of class absences, excused or unexcused.

What accommodations are there for students with learning needs?
Should you have learning needs that require accommodation, please provide the appropriate documentation from the SDAC to your Lab Heads at least two weeks before the mid-term exam. We are not necessarily able to provide accommodation once an assignment or exam is underway.

What is the Attendance Policy?
Attendance is required for all classes and is considered part of your practice of professionalism.

To whom do I go if I have a question that has not been addressed by this FAQ?
It depends. If it is a question about the material discussed in the lecture, please email the faculty member who gave the lecture. If it is any other question about policies or assignments or other kinds of material needs, please email Prof. Odumosu or Prof. Campbell.

Statement on Safety and Wellbeing

The University of Virginia is dedicated to providing a safe and equitable learning environment for all students. To that end, it is vital that you know two values that we and the University hold as critically important:

1. Power-based personal violence will not be tolerated.
2. Everyone has a responsibility to do their part to maintain a safe community on Grounds.

As a result, the School of Engineering and Applied Science proudly serves as a safe space for its students and aims to promote their safety and wellbeing. If you are feeling overwhelmed, stressed, or isolated, there are many individuals here who are ready and wanting to help. If you wish, you can make an appointment with any of your SEAS faculty, and go to their office to talk in private.

As your professors, know that we care about you and your well-being and stand ready to provide support and resources as we can. You should also be aware that as faculty members, we are responsible employees, which means that we are required by University policy and federal law to report what you tell us to the University's Title IX Coordinator.

The Title IX Coordinator's job is to ensure that reporting students receive the resources and support that they need, while also reviewing the information presented to determine whether further action is necessary to ensure survivor safety and the safety of the University community. If you would rather keep this information confidential, there are Confidential Employees you can talk to on Grounds (http://www.virginia.edu/justreportit/confidential_resources.pdf). The worst possible situation would be for you or your friend to remain silent when there are so many here willing and able to help.
If you or someone you know is struggling with gender, sexual, or domestic violence, there are many community and University of Virginia resources available. The Office of the Dean of Students, Sexual Assault Resource Agency (SARA), Shelter for Help in Emergency (SHE), and UVA Women's Center are ready and eager to help. Contact the Director of Sexual and Domestic Violence Services at 434-982-2774 as necessary.

Alternatively, there are also other University of Virginia resources available. The Student Health Center offers Counseling and Psychological Services (CAPS) for its students. Call 434-243-5150 (or 434-972-7004 for after hours and weekend crisis assistance) to get started and schedule an appointment. If you prefer to speak anonymously and confidentially over the phone, call Madison House's HELP Line at any hour of any day: 434-295-8255.