# CS 6501-012 Fall 2019
# CPS3: Signal Processing, Machine Learning and Control

Credits: 3
Course number: *(Special Topics CS 6501-012)*
Instructor: Jack Stankovic

## Description

This is a core Cyber Physical Systems (CPS) class. It provides fundamental core material in signal processing, machine learning, and feedback control. Knowledge in these areas is central to understanding and building CPS. However, the material is not presented in a traditional manner and does not replace deep domain expertise in these topics. Rather, the principles and skills taught in this class highlight the intersection of the cyber and the physical and how they impact each other. This knowledge is missing in traditional classes in these individual areas. The class contains two modules: (i) signal processing and machine learning, and (ii) feedback control.

## Course Topics

### *Module 1: Signal Processing and Machine Learning*

**Goals of Module 1:**

a. Learn the basics of time and frequency domains signal processing
b. Learn the basics of ML/DNN/CNN/LSTM
c. Understand the application of the algorithms and concepts to realistic CPS systems, in particular, the implementation on cyber-based platforms and the realities of those implementations
    i. Driving Applications
        1. Smart Buildings – the testbed discussed in CPS1
        2. Smart Cities
        3. Smart Health
        4. Autonomous Systems
d. Intro to Ethics and Policies
e. Exposure to WEKA, PyTorch (tools to create ML classifiers) and a special Matlab toolkit for feedback control with implementation issues

**Topics in Module 1:**

1. Motivation – SP, ML and CPS
2. Sensors, Sensor Properties, and Sensor Platforms
3. Simple SP processing
    a. Threshold-base, moving average, etc.
    b. Affect of noise and real world signals
    c. Features of Signals
4. Time Domain Concepts and CPS
    a. Convolution
    b. LTI systems
    c. Decomposition
    d. System Impulse Response

    e. Filters
    f. Implementation Issues
    g. Problem associated with CPS Systems
5. Frequency Domain
    a. DFT
    b. Implementation Issues
    c. Problems associated CPS systems
6. ML
    a. Supervised Learning - Decision Trees & Random Forest
    b. Learn WEKA
    c. Implementation Issues on small devices
    d. Problem associated with the testbed
        i. ML Hands-on Project
        ii. Activity recognition from wearables
        iii. Gesture recognition from IMU data
    e. NN and DNN
    f. CNN
    g. LSTM (with Smart City example)
    h. PyTorch (with 2 examples)
7. Ethics and Policy

## *Module 2: Feedback Control*

**Goals of Module 2:**

a. Learn the practical basics of (discrete time) Feedback Control (FC)
b. Understand the application of the concepts of FC to CPS, including the cyber
    i. Driving Applications
        1. Smart Buildings
        2. Smart Cities
        3. Smart Health
        4. Autonomous Systems
c. Be able to read CPS performance control papers that use FC – *more and more are appearing!*
d. Understand how to design performance controllers to meet objectives
e. Have a basis in knowledge for more advanced topics
f. Understand the effect of implementation issues on control loops

**Topics in Module 2:**

1. Motivation – including videos; FC and CPS
2. Modeling and System ID – a powerful methodology
3. Z-transforms and transfer functions
    a. CPS example
4. (Briefly) First and Second Order Systems
    a. CPS example
5. P control – shows how it all works
    a. Pole placement design (the methodology, stability, etc.)
    b. Implementation issues

    c. Driving application
6. (Briefly) I, PI, D, PD and PID control
    a. Use of PID control in CPS
7. FC and CPS Implementation Issues
8. CPS Issues
    a. Address issues such as implementation of control loop in software
    b. Effect of OS (scheduling, non-determinism) on control loop
    c. Effect of distributed systems (networking) on control loop
    d. Effects of humans in the loop
    e. Exposure to Matlab toolkit for these CPS issues
9. Integrating Application Example
10. Overview of the Industrial Internet of Things
11. Student Final Project Presentations and Demos

## Texts: (see also a separate reading and video assignment list)

**SP Text (on-line)**: S. W. Smith, The Scientist and Engineer's Guide to Digital Signal Processing, California Technical Publishing, 1997.
**FC Text (on-line)**: J. Hellerstein, Y. Diao, S. Parekh and D. Tillbury, Feedback Control of Computing Systems, Wiley Interscience, 2004.

## Prerequisites

Graduate standing, basic programming skills.

## Grading

Signal Processing Homework (2): 20%

Machine Learning Homework: 10%

Machine Learning Programming Assignments (2): 20%

Feedback Control Homework (2): 25%

Final (Hands-On Project/Show/Present Demo): 25%

### 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 to discuss a range of options to removing barriers in this course, including official accommodations. Please visit their website for information on this process and to apply for

services online: sdac.studenthealth.virginia.edu. 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.

**Discrimination and power-based violence**

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 I 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.

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 - www.virginia.edu/sexualviolence.

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 federal law to report what you tell 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 reviewing the information presented to determine whether further action is necessary to ensure survivor safety and the safety of the University community. If you wish to report something that you have seen, you can do so at the **Just Report It** portal (http://justreportit.virginia.edu/). **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.**

**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.

Students who wish to request academic accommodation for a religious observance should submit their request in writing directly to me 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.

**Honor**

I trust every student in this course to fully comply with all of the provisions of the University's Honor Code. By enrolling in this course, you have agreed to abide by and uphold the Honor System of the University of Virginia, as well as the following policies specific to this course.

- All graded homework assignments must be done alone.
- For team assignments it is necessary to indicate what each team member did.
- Proper citations to papers and Internet information must be identified when appropriate.

- All suspected violations will be forwarded to the Honor Committee, and you may, at my discretion, receive an immediate zero on that assignment regardless of any action taken by the Honor Committee.

Please let me know if you have any questions regarding the course Honor policy. If you believe you may have committed an Honor Offense, you may wish to file a Conscientious Retraction by calling the Honor Offices at (434) 924-7602. For your retraction to be considered valid, it must, among other things, be filed with the Honor Committee before you are aware that the act in question has come under suspicion by anyone. More information can be found at http://honor.virginia.edu. Your Honor representatives can be found at: http://honor.virginia.edu/representatives.