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
   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
   d. Intro to Ethics and Policies
   e. Exposure to WEKA (a tool to create ML classifiers)

Topics in Module 1:

1. Motivation – SP, ML and CPS
2. Sensors 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. Ethics and Policy
6. Frequency Domain
   a. DFT
   b. Implementation Issues
   c. Problems associated CPS systems
7. 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

Module 2: Feedback Control

Goals of Module 2:
   f. Learn the practical basics of (discrete time) Feedback Control (FC)
   g. 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
   h. Be able to read CPS performance control papers that use FC – more and more are appearing!
   i. Understand how to design performance controllers to meet objectives
   j. Have a basis in knowledge for more advanced topics
   k. Understand implementation issues

Topics in Module 2:
1. Motivation – 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 on control loop
d. Effects of humans in the loop

Texts:


**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): 25%