Course Goals

The goal of this course is to give senior and graduate students in Electrical and Computer Engineering a hands-on introduction to the fundamental technology and practical application of sensors. Capacitive, inductive, optical, ultrasonic, and other sensing methods are examined. Instrumentation techniques incorporating computer control, sampling, and data collection and analysis are reviewed in the context of real-world scenarios. Open-ended laboratory activities and required written documentation help to develop students’ analytical and communication skills.

Weekly lecture topics and labs:

1. **Introduction to FPGA programming** and OpalKelly USB 2.0 data acquisition board. Debugging approaches for FPGA (Verilog or VHDL code) will be reviewed. An overview of the different sensors and sensory boards that will be used together with the OpalKelly board will be covered.

   **Lab:** Students will get familiar with the working environment for the FPGA board. They will write an example code to send data to and from the FPGA board and a PC using USB 2.0 data interface. The software code on the PC will be written in Python. The FPGA code will be written in Verilog or VHDL. The data acquisition card from OpalKelly will be XEM 6002. More information about the FPGA board can be found here.

2. **Introduction to ultrasonic sensors.** Variety of ultrasound sensor will be covered such as passive and active sensors, different beam shaping methods, etc.

   **Lab:** A pmod ultrasonic sensor will be used for the lab. More information about the sensor can be found here. The students will write UART protocol on the FPGA to send data from the pmod sensor to the PC via USB 2.0 interface. Once the data is received, a gesture recognition controlled game will be implemented in Python.

3. **Introduction to CMOS imaging sensors.** The basic building blocks of a CMOS imaging sensor will be covered: 4 transistors per pixel with pinned photodiode (4T active pixel sensor), digital scanning registers, control block, ADCs and DACs.

   **Lab:** Students will start putting together the building blocks to obtain an image from a custom analog CMOS sensor and transfer the data to the PC to be displayed. We will start understanding the light to electron conversion by controlling a single pixel from the
imaging sensor. The different operating cycles of the pixel will be covered: reset, integration and sampling the data. Students will write a state machine in HDL to control the imaging sensor and use oscilloscope to ensure the proper operation of the sensor. More information about the custom CMOS image sensor can be found here.

4. **Filtering and sampling of analog data** will be covered. Signal integrity, amplification and aliasing will be covered as it pertains to imaging sensors.

**Lab:** Design a state machine in the FPGA that will control all digital circuits in the imaging sensor, scan an image and correctly sample the analog data from the image sensor. Data aliasing, filtering and amplification will be covered in terms of acquiring the analog signal from the imaging sensor and correctly digitizing it.

5. **CMOS imaging sensor characterization:** input referred noise, sensitivity, SNR, dynamic range, fixed pattern noise, frame rate.

**Lab:** Design the necessary interface in Python/Matlab/C to receive data from the FPGA to the PC via USB 3.0 and display data from the imaging sensor on the screen. USB 3.0 data transmission will be developed, debugged and tested. Raw data from the sensor will be also saved for analysis.

6. **Instrumentation control via Python/Matlab/C.** Controlling instruments, such as power supplies, function generators, multimeters and oscilloscopes using Ethernet, USB and GPIB interface will be covered.

**Lab:** Data collection from the image sensor using computer controlled instruments will be covered. For example, pixel’s output voltage as a function of light intensity will be measured. A computer controlled power supply will control the Led brightness and oscilloscope will capture the pixel’s output. Instrument synchronization will be covered.

7. **Advanced CMOS sensors:** state of the art imaging sensors will be covered such as time of flight sensor, address event sensor, APD sensors and others.

**Lab:** Students will evaluate the performance of the imaging sensor, such as SNR, FPN, dynamic range, using computer controlled instruments via Python. Note: for students that will not be able to complete the necessary state machines to control the imaging sensor module, a Verilog and Python code will be provided to assist them with the data collection.

8. **Motors and magnetic encoders:** Several different types of encoders will be discussed in class: magnetic, resistive, optical
Lab: Integrate magnetic encoders with a motor and the FPGA environment. More information about the magnetic encoder can be found here. Design and test HDL code to control the motor and evaluate and encoder precision. Combine the ultrasound sensor with a motor to create a 3-d map of the environment.

9. Gyroscopes, accelerometers and compass. Various types of MEMS based position sensors will be covered.

Lab: Test the precession of a compass sensor module. More info on the compass can be found here. Another interesting sensor combines all three sensors together. More info can be found here. Integrate the compass module with the motor/encoder system and test its accuracy and precision.

10. Temperature and humidity sensors. Variety of temperature sensors and humidity sensors will be covered in class.

Lab: A pmod sensor module containing temperature, humidity, proximity, UV and light sensor will be info here. More information about the pmod sensor can be found here.

11. Capacitive sensors. Overview on capacitive sensors will be provided.

Lab: Capacitive sensor will be used for the lab. More information can be found here. Student will test the sensitivity of the capacitive sensor using variety of computer controlled experiments.

12. Final project. Students will combine at least 4 of the sensors covered in the course and integrate them to solve a practical problem. For example, tracking a person in 3-d space. This project will require utilizing an image from the optical sensor to compute relative motion of a target in a room. Motors and encoders will rotate the camera to keep the target in the camera’s field of view. The ultrasonic sensor will estimate the distance of the target. Compass module can indicate the viewing direction of the camera and hence the direction of the target.