SCHOOL OF
INFORMATICS, COMPUTING,
AND ENGINEERING

E210 – Engineering Cyber-Physical Systems
B441 – Digital System Design

Spring 2024

Description:

This course provides an introduction to core topics in cyber-physical and digital systems. The first part of the course lays out a foundation for modern cyber-physical system design. These topics include embedded systems, issues of real-time processing, and sensor mechanisms and control algorithms. Students will study applications of these elements in the Internet of Things and Robotics.

The second part of the course covers digital system design using hardware description languages. We start with basics of digital electronics and learn how digital gates are used to build large digital systems. We will practice modern digital system design by using state of the art software tools and implementation of the digital systems on a programmable hardware platform.

Goals:

Our basic goal is to teach the students how to design and implement digital and cyber-physical systems. You will learn how to efficiently use state-of-the-art tools to design and produce well engineered systems. The course will also prepare you to take the upper-level systems classes and, even more important, you will learn skills and knowledge that will help you throughout your career.

Course Learning Objectives:

After taking this course, you will understand the underlying concepts of cyber-physical and digital systems you will be able to achieve the following objectives:

- Design and create a networked sensor system.
- Apply communication networks using UART, I2C, and SPI.
- Develop Python programs as part of a cyber-physical system.
- Develop System Verilog in the context of a larger system.

- Use a hardware description language along with an appropriate methodology to design and implement digital systems on a programmable hardware platform.
- Demonstrate the ability to utilize a version control system.
- Perform effectively in a small design team.

Prerequisites:

Prerequisites for E210 – Engineering Cyber-Physical Systems

ENGR E110 ENGINEERING COMPUTING ARCHITECTURES

ENGR E201 Computer Systems Engineering

Prerequisite for B441 – Digital System Design:

CSCI-C 335 Computer Structures

Textbooks:

We will cover selected chapters from the textbooks:

- *Introduction to Embedded Systems – A Cyber – Physical Systems Approach*, Second Edition, Edward Ashford Lee, Sanjit Arunkumar Seshia, The MIT Press, ISBN 978-1-312-42740-2.
- *Digital Design: An Embedded Systems Approach Using Verilog*, Peter J. Ashenden, Elsevier, Morgan Kauffman, ISBN-13: 978-012369527.
  Electronic copies are available through the IU library .

Reference materials:

- *ProGit book*, Scott Chacon and Ben Straub, available at: https://git-scm.com/book/en/v2
- Web sites with data sheets will be provided in the lecture slides

Instructor:

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Office Hours: Monday through Wednesday, 1 to 2:45 PM

Assistant Instructors:

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Jesus Garcia	Email: jesbgarc@iu.edu

AI office hours

Instructor	Day and Time	Zoom ID
Caleb Cook	TBA	
Nicole Miller	TBA	
Aidan Myers	TBA	
Jesus Garcia	TBA	

Course Communication Channels:

Canvas will contain most of the course information, including syllabus, lecture slides, introductory information on the labs, exams and grades.

We will post a Canvas announcement in the case of any critical corrections or clarifications. It is your responsibility to ensure you are able to receive Canvas announcements.

Lab assignments will be available at GitHub site:

https://engr210.github.io/

Lectures

Lectures are twice a week, Monday and Wednesday, 9:45 AM to 11:00 AM, in Luddy room 0117.
Lecture notes will be available on Canvas.

Lab projects

Over the course of the semester, we will assign multiple lab projects. Full points will require the project reports to be submitted and demonstrated in due time.

Course Assignments/Assessments and Grade Percentages:

There will be lab projects and two exams.

Grade percentages:

Lab projects	50 %
Exam 1	25 %
Exam 2	25 %

Grading Policies - Late Assignments:

Assignments turned in after the exact time and date on the assignment will receive a zero. We do not generally offer extensions. For example, we do not offer extensions due to crowded computing sites, long queue times or slow response times on the Autograder, internet access problems, accidental erasure or loss of files, or outside conflicting commitments.

We will consider extension requests made in person and at least two weeks in advance, for example, for religious holidays or planned medical procedures. Additionally, we will consider requests for extensions due to documented, unanticipated medical or personal emergencies, as outlined by Indiana University policy. If you can't see the instructor in advance due to the emergency, then contact them as soon as you possibly can.

The Autograder

We will grade some of your programs in an autograder system that is similar to the Linux environment. Your code must be submitted, compiled, and run correctly on the autograder before the deadline. We use a web-based autograder for project submissions. For some projects, the autograder will also evaluate the thoroughness of test cases that you submit.

Note that for security reasons, the autograder website is only accessible from within the IU network. Therefore, you must either be on campus or connected through a VPN to access the website.

Autograder link: https://autograder.sice.indiana.edu

Course Roadmap - Topic Outline

Module 1: Introduction and cyber – physical systems

January 8 – 12

Lecture topics:

Course goals, learning outcomes and policies
Assessment activities and grade calculation
Cyber – physical systems
Raspberry Pi overview
Universal Asynchronous Receiver Transmitter (UART)

Lab project 0: Raspberry Pi setup

In project 0 you will be utilizing a Raspberry Pi board connected via a UART serial port. This interface will allow you to interact with the board from the command line as you would in a typical Linux system. You will use this connection to setup a wireless network connection to your board. Once you have a network connection, you will use this connection to clone your class Git repository.

Learning and Assessment Activities:

Read course syllabus, available on Canvas
Read Chapter 1 and section 10.1.3 from textbook "Introduction to Embedded Systems"
Read about Raspberry Pi at:
https://www.raspberrypi.com/documentation/computers/raspberry-pi.html

Complete Lab project 0 and submit the report in due time
Please check Canvas for announcements and additional instructions.

Module 2: I2C Serial communication

January 16 – 19 (no classes on Martin Luther King Jr. day, January 15)

Topics:

Inter-Integrated Circuit (I2C) synchronous serial communication
Bus connections
Peripheral addressing
Communication protocol
Raspberry Pi and pressure sensor I2C connection

Lab project 1: I2C Pressure/Temperature Sensor

In this project, you will be extending your base Raspberry Pi system to include a pressure and temperature sensor. The pressure and temperature sensors are in the same integrated circuit. For this project, you will use the ST LPS331AP Pressure Sensor. Because the component is surface mounted, the LPS331 has been mounted to a PCB by a company named Pololu.

Learning and Assessment Activities:

Complete lab project 1 and submit the report in due time
More information related to the lecture and lab project can be found at:

Raspberry Pi I2C Tools
ST LPS331AP Pressure Sensor Datasheet
Pololu LPS331AP Carrier Board
Python Classes

Module 3: Pressure sensor and SPI bus

January 22 – 26

Topics:

Pressure sensor and interface
Read and write protocols
Serial Peripheral Interface (SPI)
SPI bus protocol
Using SPI to connect Pi and accelerometer

Lab project 2: SPI Accelerometer

In this project, you will be connecting an accelerometer board to the Raspberry Pi. In the last lab, we used I2C to talk to the pressure sensor. In this lab, we are going to be using Serial Peripheral Interface (SPI) to connect to the ADXL343 accelerometer. You will be creating a python class that enables the Raspberry Pi to interact with the accelerometer.

Learning and Assessment Activities:

Complete lab project 2 and submit the report in due time.
More information related to the lecture and lab project can be found at:

https://learn.sparkfun.com/tutorials/i2c/all
https://www.analog.com/media/en/technical-documentation/data-sheets/adxl343.pdf
Adafruit ADXL343 Reference
spidev documentation

Module 4: Accelerometer and MQTT

January 29 – February 2

Topics:

MEMS accelerometer
Accelerometer interface
Message Queuing Telemetry Transport (MQTT)
Message filtering
Python interface

Lab project 3: MQTT sensor data server

In this project, you will be connecting your system to a sensor network via the MQTT protocol. This will involve creating a python script that communicates the current temperature, pressure, and accelerometer state to the MQTT broker.

Learning and Assessment Activities:

Complete lab project 3 and submit the report in due time.
More information related to the lecture and lab project can be found at:
https://www.analog.com/media/en/technical-documentation/data-sheets/adxl343.pdf
https://iucat.iu.edu/catalog/18457908 (Hands-On MQTT Programming with Python)

Module 5: Parallel input/output

February 5 – 9

Topics:

General Purpose Input/output (GPIO) structure
GPIO library
Input and output setup
Light emitting diode (LED)
Logic gates and circuits
Boolean algebra
Analysis and synthesis of logic circuits

Lab project 4: Sensor LED output

In this project, you will be adding an LED to your system that you can control through MQTT. You will be creating a class that allows you to set the PWM duty cycle and frequency for a GPIO pin attached to an LED. Additionally, you will be modifying your **sensor_node.py** code to enable changing these values though MQTT.

Learning and Assessment Activities:

Read section 10.1 from the textbook “Introduction to Embedded Systems”
Read chapter 1 and sections 2.1.1 and 2.1.2 from the textbook “Digital Design: An Embedded Systems Approach Using Verilog”
More information related to the lecture and lab project can be found at:
https://sourceforge.net/p/raspberry-gpio-python/wiki/Examples/

Module 6: HDL and Exam 1 Review

February 12 – 16

Topics:

Hardware description languages
Gate level modeling
Dataflow modeling
Behavioral modeling
Hierarchical models
Exam 1 review

Lab project: No new lab project this week

Learning and Assessment Activities:

Read section 2.1.3 from the textbook “Digital Design: An Embedded Systems Approach Using Verilog”
Review the lecture material and notes from the projects of the modules 1 through 5 (inclusive)

Module 7: Exam 1 and Vivado

February 19 – 23

Topics:

Exam 1 will be on Monday, February 19, in the class.
Vivado projects
Design and constraints files
Hardware synthesis
Program hardware target
Simulation

Lab project 5: Demultiplexer

For this project, you will design and implement a 3-to-8 Demultiplexer. Demultiplexers help control the logical flow of the digital circuits, and are used in addressing memory and many types of data communication.

Learning and Assessment Activities:

Complete Exam 1 on Monday, February 19, during the class
Complete and demo your lab project in due time
Vivado tutorials are available at:
https://docs.xilinx.com/r/en-US/ug949-vivado-design-methodology/Vivado-Design-Suite-Tutorials

Module 8: Combinational logic

February 26 – March 1

Topics:

Combinational logic circuits
Standard combinational circuits: decoder, multiplexer, demultiplexer, adder
Subtraction
Overflow detection
Arithmetic and logic unit
D flip-flop and D register

Lab project 6: Arithmetic and logic unit

You will design and implement an 8-bit Arithmetic Logic Unit (ALU). You can use the same design procedure to expand to a functionally complete 16-, or 32-bit ALU. You will also get to implement a basic D Flip-Flop. Flip Flops are used to add state to your digital systems.

Learning and Assessment Activities:

Complete and demo your lab project in due time
Read section 2.3 and 4.1.1 and appendix C.2 from textbook "Digital Design: An Embedded Systems Approach Using Verilog"

Module 9: Sequential logic

March 4 – March 8

Topics:

Sequential logic circuits
Latches and flip – flops
Modelling sequential circuits
State tables and state diagrams

Lab project 7: Saturating counter

In this lab you will practice design of simple state machines by implementing a 2-bit saturating counter.

Learning and Assessment Activities:

Complete and demo your lab project in due time
Read sections 4.1 and 4.2 from textbook "Digital Design: An Embedded Systems Approach Using Verilog"

Note:

March 10 – March 17 is spring break, no classes.

Module 10: Registers and counters

March 18 – 22

Topics:

Data storage registers
Register file
Shift registers
Counters: ripple counters, synchronous counters and counters with parallel load

Lab project 7: Saturating counter (continued)

In this lab you will practice design of simple state machines by implementing a 2-bit saturating counter.

Learning and Assessment Activities:

Complete and demo your lab project in due time
Read section 4.1 and 4.2 from textbook “Digital Design: An Embedded Systems Approach Using Verilog”

Module 11: Finite state machines

March 27 – March 31

Topics:

Verilog structured procedures
SystemVerilog procedural blocks
Finite state machines (FSM)
Elevator simulator
Output bus
Example: Multiplexing displays

Lab project 8: Elevator control

In this lab you will practice using state machines by designing and implementing a simulator of a 4-floor elevator system. You will also learn to use 7-segment displays.

Learning and Assessment Activities:

Complete and demo your lab project in due time
Read section 4.3 from textbook “Digital Design: An Embedded Systems Approach Using Verilog”

Module 12: Memory

April 3 – 7

Topics:

Memory operations
Random access memories (RAM) and read only memories (ROM)
Memory design
Programmable logic devices

FPGA
Programming techniques

Lab project 8: Elevator control (continued)

In this lab you will practice using state machines by designing and implementing a simulator of a 4-floor elevator system. You will also learn to use 7-segment displays.

Learning and Assessment Activities:

Complete and demo your lab project in due time
Read sections 5.1, 5.2 and 6.2 from textbook "Digital Design: An Embedded Systems Approach Using Verilog"

Module 13: Processor

April 8 – 12

Topics:

Clock synchronization
Sending and receiving SPI signals
Modular design
Datapath and control unit
Central processing unit
Instruction execution
Verilog implementation

Lab project 9: SPI interface

In this lab you will construct a Serial-Peripheral Interface (SPI) link between the Basys3 FPGA and a Raspberry Pi.

Learning and Assessment Activities:

Complete and demo your lab project in due time
Read section 8.4 and chapter 7 from textbook "Digital Design: An Embedded Systems Approach Using Verilog"

Module 14: Review and Exam 2

April 15 – 19

Topics:

Exam 2 rules, format and grading

Review:

Combinational logic
Sequential logic
Registers and counters
Finite state machines
Memory

Exam 2, Wednesday, April 17

Lab project 9: SPI interface (continued)

In this lab you will construct a Serial-Peripheral Interface (SPI) link between the Basys3 FPGA and a Raspberry Pi.

Learning and Assessment Activities:

Complete and demo your lab project in due time
Review modules 8 through 13 (inclusive)
Complete Exam 2 on Wednesday, April 17

Module 15: Cache memory

April 22 – 26

Topics:

Locality of memory references
Memory hierarchy
Cache memories
Cache performance metrics
Performance impact of caches
Course conclusions

No lab project this week.

Learning and Assessment Activities:

Read section 7.3.1 from textbook "Digital Design: An Embedded Systems Approach Using Verilog"

General Information

Course Policies:

- This course follows Indiana University's academic calendar for spring 2023. The course ends with submission of final grades.
- Students are expected to carry out all activities within each unit. Each unit has a small number of activities associated with it.
- Students are expected to maintain more than one copy of their assignments in case of equipment failures (disk crash).
- Students are expected to do the lesson readings and watch lesson videos before the discussion of the lesson.
- It is expected that a student will put in 6-7 hours a week every week into the course which includes time spent in readings, reflections, and engaging with instructional content.

Incomplete Policy:

Circumstances Permitting Incompletes:

(Approved: Faculty Council 11/5/52, amended 2/19/63)

The grade of Incomplete used on the final grade reports indicates that the work is satisfactory as of the end of the semester but has not been completed. The grade of Incomplete may be given only when the completed portion of a student's work in the course is of passing quality.

Instructors may award the grade of Incomplete upon a showing of such hardship to a student as would render it unjust to hold the student to the time limits previously fixed for the completion of his/her work.

Departmental Records:

Each academic unit shall maintain a record of incomplete grades recorded in its courses. This record, completed by the instructor, should include (l) the name of the student and the student's identification number, (2) the course number, section number, and hours of credit, (3) semester and year of enrollment, (4) the signature of the instructor, (5) a brief statement of the reason for recording the Incomplete, and (6) an adequate guide for removal of the Incomplete grade (with a suggested final grade) in the event of the departure or extended absence of the instructor from the campus.

Removal of Incompletes:

Methods. A grade of Incomplete may be removed (a) by the student completing the course within the time limit and the instructor sending the appropriate Removal- of-Incomplete form to the Office of the Registrar, and (b) by the dean of the student's school authorizing the change of Incomplete to W.

Limits. The time allowed for the removal of an Incomplete is one calendar year from the date of its recording, except that the dean of the student's college or school may authorize adjustment of this period in exceptional circumstances. By assigning an Incomplete an instructor implicitly authorizes and requires the "I" to be changed to an "F" at the end of the appropriate time period, if that instructor does not otherwise act to remove the "I". The Registrar will automatically change the "I" to "F" at the end of the appropriate time period except when an adjustment of the period has been authorized or the student has received a degree since that date. Both the student and the instructor in whose course the student received the Incomplete will be notified of this change of grade.

A student may not re-enroll in a course in which a grade of Incomplete has been recorded. The student may be denied the right to make up an Incomplete if it seems to the unit dean and the instructor that it is impractical for the student to complete the course. In this case, the student should be given the opportunity to withdraw from the course.

Drop Policy:

Before you drop or add a class, make sure you understand the rules. Your timing makes all the difference when it comes to whether or not you're hit with extra fees or a bad grade.

Dropping or adding classes can affect your financial aid, scholarship status, or tuition cost. If you do decide to drop or add a class, be sure to talk with your academic advisor first. If you're worried about what will happen with your finances, contact us. We'll talk you through it.

Making changes during the continuous drop/add period:

Continuous drop/add is available from the beginning of early registration through the Sunday following the first week of classes. If you drop a class during this time, it won't show up on your transcript or grade reports. So if you want to avoid a W ("Withdrawn") grade, make sure to drop by this deadline.

Schedule adjustment fees:

You'll be charged a drop/add access fee of $8.50 each day you make a schedule change after two business days from the date you register for the term.

If you drop courses after the first week of classes, you'll be charged an additional fee for each course you drop.

Student Integrity Policy:

Students are expected to conduct themselves in a manner befitting their status as a student of a respected and distinguished institution of higher education. In college courses, we are continually engaged with other people's ideas: we read them in texts, hear them in lecture, discuss them in class, and incorporate them into our own writing. As a result, it is very important that we give credit where it is due. Plagiarism is using others' ideas and words without clearly acknowledging the source of that information.

See http://www.indiana.edu/~wts/pamphlets/plagiarism.shtml for help in addressing plagiarism in your own work.

Work you submit must be your own. Doing your own work means that you must turn in your own, original work. It means you do not turn in a solution copied from somebody else or found on the web. In programming projects, working together may extend to figuring out overall strategies for solution, but you may not work together to write the actual code that you submit.

Articles and data posted to Canvas for this course are for the convenience of students only and should not be shared outside the course.

Students with Disabilities Accommodations:

Arranging Accommodations:

Once you have submitted a request for service, provided appropriate documentation verify your disability, and met with your DSS Coordinator, it is time to arrange your reasonable accommodations with your instructors.

What is a Reasonable Accommodation?

A reasonable accommodation is any modification or adjustment that will enable a qualified student with a disability to participate in a course, program, activity or service. Reasonable accommodations assure that individuals with a disability have rights and privileges equal to

students without disabilities. Reasonable accommodations may include academic adjustments, auxiliary aids or adaptive technology, services, or modifications for facilities.

Academic Accommodation Memorandum (Memo):

The DSS office prepares an Academic Accommodation Memorandum (Memo) for each student receiving accommodations. This document explains the reasonable accommodations to be provided to you as a student of IU to your instructors. It is your responsibility to give a copy of our memo to each of your instructors at the beginning of each academic term.

Request an Academic Accommodation Memo.

Submitting Memos to Your Instructors:

As a student receiving accommodations, you are required to meet with each of your professors in person either during office hours or by individual appointment. Electronic web meeting may be substituted for online students. It's necessary for you to meet your professor early in the semester - within the first two weeks if possible. By the time you leave your meetings with professors, you should have an understanding of how the professor will handle your accommodations during the semester. If you have any questions about the memo or any part of the DSS system and process, don't hesitate to reach out to your coordinator.

Campus Safety

The IU public safety plan can be found at:

https://protect.iu.edu/

It contains a comprehensive listing of university policies, procedures, statistics, and information relating to campus safety, emergency management, and the health and welfare of the campus community.

Sexual Misconduct and Title IX

As your instructor, one of my responsibilities is to create a positive learning environment for all students. IU policy prohibits sexual misconduct in any form, including sexual harassment, sexual assault, stalking, sexual exploitation, and dating and domestic violence. If you have experienced sexual misconduct, or know someone who has, the University can help. If you are seeking help and would like to speak to someone confidentially, you can make an appointment with the IU Sexual Assault Crisis Services at (812) 855-5711, or contact a Confidential Victim Advocate at (812) 856-2469 or cva@indiana.edu .

It is also important that you know that University policy requires me to share certain information brought to my attention about potential sexual misconduct, with the campus Deputy Sexual Misconduct & Title IX Coordinator or the University Sexual Misconduct & Title IX Coordinator. In that event, those individuals will work to ensure that appropriate measures are taken and resources are made available. Protecting student privacy is of utmost concern, and information will only be shared with those that need to know to ensure the University can respond and assist. I encourage you to visit http://stopsexualviolence.iu.edu/index.html to learn more.

Mental Health and Well-being Resources for Students

Many students are struggling with a variety of challenges. If you are concerned about your mental health or well-being, please visit the Counseling and Psychological Services (CAPS) website at https://healthcenter.indiana.edu/counseling/index.html . You may also want to visit the Dean of Students' Office https://studentaffairs.indiana.edu/student-support/get-help/index.html for information on where to find a wide range of support services.