ECEN 5823-001, -001BSyllabus

Internet of Things Embedded Firmware
Semester: Spring 2018

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I. Overview

Lectures:

T/TH 2:00-315pm, ECCS 1B14

Rational:

Internet of Things and Mobile Computing are two embedded engineering markets that are growing rapidly and will have a significant impact on the world's economy and society. To meet the demands of these fast growing business segments, students graduating the ESE program will be able to make appropriate engineering decisions based on their product's ecosystem to design products that meet their solution's energy, product lifecycle, and communication requirements while taking into consideration the appropriate security requirements.

Accenture estimates that the Industrial Internet of Things (IIoT) could contribute by 2030 $14.2 trillion US dollars in world output. For the US, it could contribute $6.1 to $7.1 trillion US dollars by 2030 which could result in the US GDP growing an additional 2.3% more than currently forecasted. The growth of IIoT solutions disrupt many markets as these markets transform from service economies to outcome economies. Per the World Economic Forum, an Outcome Economy is a marketplace where businesses compete on their ability to deliver quantifiable results that matter to customers rather than just selling a product or service. The outcome could be measured energy savings, increased product yields, or increased machine uptime. As the IIoT transforms business, it will also transform the labor market as many lower skilled jobs are replaced by intelligent systems that require higher skilled workers to maintain and make creative decisions.

Being able to understand the requirements of these embedded systems and to design to meet their needs will enable students graduating the ESE program to be a part of this transformative industry.

Class structure:

Typically, each week the lectures will be covering both theory and concepts as well as implementing low energy design practices in firmware. Tuesday will be focusing on theory and concepts while on Thursday the lecture will be split between theory and concepts with low energy design practices. Most weeks, these low energy design practices will then have a weekly homework assignment. These assignments will not require the purchase of lab equipment or the use of a lab, but will require access to a computer running Windows, Mac OS, or Linux OS. These homework assignments will explore event driven embedded software design techniques as well as developing Bluetooth Smart and Bluetooth Mesh applications.

The homework assignments will be using the following development kits that will be provided to the student for the course of the semester and will be required to be returned before the final exam. Each student will be given their own development kit for their assignments.

1. Silicon Labs' Blue Gecko STK6101C starter kit. The description can be found at http://www.silabs.com/products/development-tools/wireless/bluetooth/bluegecko-bluetooth-smart-module-wireless-starter-kit

The Silicon Labs' STK6101C will be used to learn Low Energy through Event Driven Firmware concepts as well as implementing an application using Bluetooth Smart and Bluetooth Mesh.

An energy profiler tool will be used with the homework assignments to enable students to receive "real-time" feedback on the energy efficiency of their projects to hit assignment goals.

There will be a course project that will take 5-7 weeks. This project will be taking the low energy design concepts taught in class and combine them to create a Bluetooth Smart or Bluetooth Mesh application.

Distant Learners:

Remote live access to lectures is available for distant students via Zoom. If you require details on how to access Zoom for this course, please contact the instructor for details. Taped lectures will be available as well only to the Distant Learners.

The Zoom conferencing tool currently is not accessible to users using assistive technology. If you use assistive technology to access the course material, please contact the instructor immediately to discuss.

Readings:

Course materials include papers, lecture slides, project guides, and other online materials.

- Required text books
    - "Bluetooth Low Energy," by Robin Heydon, ISBN: 9780132888363
- Recommended text book
    - "Making Embedded Systems," by Elecia White, ISBN: 9781449302146
- Course website
    - Course lecture slides posted weekly on Canvas
    - Course reading list posted weekly on Canvas
    - Course homework assignment and material posted weekly on Canvas
- Other online materials
    - Silicon Labs Blue Gecko, EFR32BG
    - Silicon Labs EFM32 application notes
    - Silicon Labs Blue Gecko STK6101C starter kit
    - Silicon Labs Simplicity Studio

II. Description and Content

The course material will convey both technical and industry requirements to enable proper engineering architectural decisions as well as implementation. The course will explore through weekly and course projects low energy firmware design concepts, extending FLASH memory data retention reliability, Bluetooth, and developing a secure manufacturing process of micro controller firmware and encryption keys. The programming assignments will be "coding to the metal" to control individual micro controller peripherals and utilizing them in the most energy efficient ways.

Topics include:

- Low Energy versus Low Power design
- Wireless Computing tradeoffs: Available resources, application, infrastructure

- Interrupt or event driven firmware
- Wireless standards: applications and tradeoffs
- Bluetooth Smart: protocols, profiles, and services
    - Client, Server
- Bluetooth Mesh: Provisioning, and Client, Services, and Control Models
    - Relay, Proxy, Low-Power, Friend nodes
- Designing for product lifecycle of 20+ years
- Designing embedded systems with security in mind
- Project that will incorporate Bluetooth communications, low power sensors, and low energy design concepts

III. Objectives and Expected Outcomes

1. Maximize the battery life of Internet of Things Applications
2. Analyze Internet of Things memory requirements
3. Overcome technical weaknesses of flash memory technology
4. Match the correct low power RF networking technology to the end application
5. Develop a Bluetooth Smart peripheral/device product
6. Develop a Bluetooth Mesh Proxy, Node, Relay, Friend, and Low Power device
7. How energy harvesting powers the Wireless Sensor Networks
8. Maximizing the value of embedded systems using Near Field Communications (NFC)

At the end of this course, students will be able to:

- Develop event based “code to the metal” firmware to extend the battery life of Internet of Things applications using a scheduler
- Debug low level / machine centric firmware
- Select the wireless protocol that best addresses the end application requirements
- Develop an interoperable Bluetooth Smart device/peripheral product
- Develop a Bluetooth Mesh proxy, relay, friend, and low power node
- Match the appropriate memory technology to the end application
- Extend flash data retention to 20+ years to meet the requirements of industrial applications
- Implement secure Bluetooth Smart Over The Air, OTA, firmware updates

IV. Requirements and Format

Prerequisites:

Knowledge of assembly and C programming, digital logic design, and embedded computer architecture. Students should have had at least one course in each of these subjects. ECEN 5013, Embedded Software Essentials, is a recommended prerequisite. Students should also have experience using a microcontroller Integrated Development Environment (IDE) and its associated tools including its debugger and register views.

Expectations:

Lectures, Programming Assignments/Course Project, Readings, and Quizzes will require on average 10-14 hours per week of work. For on campus students, class attendance is expected. For distant learners, live video streaming and videos will be made available. Please note that the course lecture videos are for distant students only.

Attendance and Participation:

Attendance at class is expected. It is the student's responsibility to obtain materials handed out in a lecture which the student missed. Students are expected to keep up with the course material. If you get confused or start to fall behind, attend office hours or schedule an appointment with the professor or TA as soon as possible. If you must miss a lecture, please let the instructor know in advance, if possible.

Students are expected to participate in class discussions of course topics. In addition, students are expected to assist other students in understanding course material and assignments.

Students are expected to complete assignments on time. Project assignments will be accepted late, but the grade earned on the assignment will be reduced. Expectations for Out-of-Class Study: Beyond the time required to attend each class meeting, students enrolled in this course should expect to spend at least an additional 6-8 hours per week of their own time in course-related activities, including reading required materials, completing homework/program assignments, preparing for exams, quizzes, etc.

General Attendance
Going forward, the following will be in effect for ESE program courses, as reported by ESE course instructors:

1) Students enrolled but not engaging in an ESE course for the first week will be moved to the end of any existing waitlist.
2) Students enrolled but not engaging in an ESE course for the first two weeks will be administratively dropped from the course.

Per the Registrar, administrative drops can occur for two reasons:

- nonattendance or
- missing required course prerequisites or corequisites.

Homework:

Homework will be assigned most weeks and will comprise of programming assignments. These assignments will combine material covered earlier in the course as well as the current week. There will be a drop box on Canvas to deliver the assigned code which will be ran to evaluate functionality and energy consumption. The grading will be based on functionality, hitting low energy design goals, and documentation of code.

Projects:

There will be one course project that will combine the low energy design principles and Bluetooth radio taught throughout the course utilizing the Silicon Labs' Blue Gecko development Kit. The course project will include developing a product proposal that will include a Bluetooth Smart or Bluetooth Mesh device in a cohesive application such as home security, retail, etc.. This project will include developing code as a Bluetooth Smart or Bluetooth Mesh device providing the associated services for external sensors. The project/product will need to include Bluetooth Client Profile and Services implementing notifications, indications, as well as attribute writes/reads, and attribute commands or a Bluetooth Mesh network including a Proxy, Friend, and Low Power nodes supporting Publishing/Subscribing and unicast addressing. The course project will be further defined as updates to the Bluetooth Mesh stack becomes available.

Sharing of knowledge between students is highly encouraged; however, each student is expected to independently create and implement their own project files. Students that do not adhere to the CU Honor code will be held accountable to the CU Honor code. Students are encouraged to help other students solve problems, since significant learning can result from such activities. Students may find that they are able to leverage firmware designs from books, magazines, the Internet, or their work environments; however, in these cases, students are expected and required to credit the source of the information clearly and completely. Plagiarism will not be tolerated, and will be reported.

As with the homework assignments, the code will be run to evaluate functionality and energy consumption. The grading will be based on achieving a cohesive application, functionality, hitting low energy design goals, and well-structured and documented code.

Assessments:

Quizzes outside of class will be administered through Canvas. For each quiz, the students will have 5 days to complete and given 2 attempts. There will be a 15-minute time limit per attempt with 2-minute grace period, and the best score will be used. No quizzes will be dropped from the total. It is highly recommended to review the reading assignment and class material before taking the quiz.

Classroom quizzes may be administered via Canvas, programming assignments, or paper.

There will be a mid-term examination and final examination.

The quizzes, mid-term, and final examination are to be done using individual effort alone and adhere to the CU Honor Code.

V. Evaluation and Grading Procedures

The course grade will be based on in-class participation, homework assignments, quizzes, course project, and 2 exams. The grade proportions are as follows:

- Homework and Class Participation 20%
- Course projects 25%
- Quizzes 15%
- Final and Mid-term Exam 40%

Grading will be based on total points accumulated from each of these areas. Assignment of grades will be based on an absolute scale of:

A : 93+

A-: 90

B+: 87

B : 83

B-: 80

C+: 77

C : 73

C-: 70

D+: 67

D : 65

Fail: < 65

Upon the professor's discretion, assignment of grades can be based on both absolute and relative standards if it would be helpful to the overall class. To receive an A grade in this assignment of grades option, a student must show mastery of the material and need to acquire more than 90% of the points possible. A student earning less than 50% of the points possible will be given a failing grade. In between these marks, grades will be assigned on a curve using a mean and standard deviation method.

Make-up Exam Policy: No make-up exams are given except for medical or other similar hardships where advanced arrangements are made with the instructor; or in case of non-selective medical emergencies with physician's note or documentation. Otherwise, failure to take the exam at the scheduled time will result in a zero grade in the exam.

VI. Policies

Academic Integrity:

All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the Honor Code. Violations of the policy may include: plagiarism, cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, submitting the same or similar work in more than one course without permission from all course instructors involved, and aiding academic dishonesty. All incidents of academic misconduct will be reported to the Honor Code (honor@colorado.edu); 303-492-5550). Students who are found responsible for violating the academic integrity policy will be subject to nonacademic sanctions from the Honor Code as well as academic sanctions from the faculty member. Additional information regarding the Honor Code academic integrity policy can be found at the Honor Code Office website.

Any suspected violations of the Honor Code will be submitted to our Honor Code Office. Students found responsible for any violation by our faculty and the Honor Code Office will earn an automatic F in the course. We take these issues seriously and have a responsibility to all students who uphold the Honor Code, and to the highest industry standards for which we are preparing students. If you have any questions whatsoever regarding what collaboration is permissible in the course, consult your instructor directly before proceeding. By default, you are expected to turn in your own original work and cite any and all portions you did not create. All aspects of the Honor Code apply.

Accommodations for disabilities:

If you qualify for accommodations because of a disability, please submit your accommodation letter from Disability Services to your faculty member in a timely manner so that your needs can be addressed. Disability Services determines accommodations based on documented disabilities in the academic environment. Information on requesting accommodations is located on the Disability Services website. Contact Disability Services at 303-492-8671 or dsinfo@colorado.edu for further assistance. If you have a temporary medical condition or injury, see Temporary Medical Conditions under the Students tab on the Disability Services website.

Inclusivity:

Religious Observances

Campus policy regarding religious observances requires that faculty make every effort to deal reasonably and fairly with all students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. In this class, please conduct the instructor to make accommodations.

See the campus policy regarding religious observances for full details.

Sexual misconduct, discrimination, harassment and/or related retaliation

The University of Colorado Boulder (CU Boulder) is committed to fostering a positive and welcoming learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct (including sexual assault, exploitation, harassment, dating or domestic violence, and stalking), discrimination, and harassment by members of our community. Individuals who believe they have been subject to misconduct or retaliatory actions for reporting a concern should contact the Office of Institutional Equity and Compliance (OIEC) at 303-492-2127 or cureport@colorado.edu. Information about the OIEC, university policies, anonymous reporting, and the campus resources can be found on the OIEC website.

Please know that faculty and instructors have a responsibility to inform OIEC when made aware of incidents of sexual misconduct, discrimination, harassment and/or related retaliation, to ensure that individuals impacted receive information about options for reporting and support resources.

Classroom Behavior

Students and faculty each have responsibility for maintaining an appropriate learning environment. Those who fail to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation or political philosophy. Class rosters are provided to the instructor with the student's legal name. I will gladly honor your request to address you by an alternate name or gender pronoun. Please advise me of this preference early in the semester so that I may make appropriate changes to my records. For more information, see the policies on classroom behavior and the Student Code of Conduct.

Use of Electronics in class:

Cell phones need to be on silent and out of site. Laptops may be used in class for taking notes, and may be required for in class work as well as examinations.

VII. Resources:

Please check out the "ECEN 5823 Resources" document which can be found in Canvas under the Course files folder.

VIII. Tentative Course Schedule: (*This can change, and likely will. As the instructor for this course, I reserve the right to adjust this schedule in any way that serves the educational needs of the students enrolled in this course.*)

Date	Topic	Required Reading (Complete Reading Lists will be included in the weekly reading assignments in Canvas to include the appropriate web links.)	Homework/Projects/Exams
2018-08-28	Class Start; Course Goals and Expectations; Project and Tool demo; Internet of Things Embedded Firmware Topics; Where is the money in IoT; IIoT versus IoT		Beginning of class survey (Canvas). Quiz 1 assigned and due EOD Sunday, September 2nd, 2018
2018-08-30	Low Power versus Low Energy Design; What Makes a Low Energy Microcontroller; Micro controller energy modes; Designing Interrupt Based Code Using Low Energy Timer		Exercise: Install Silicon Labs' Simplicity development environment. Pick up Silicon Labs' Blue Gecko STK6101C starter kit by End of Class on January 23rd, 2018. Exercise due via drop box by EOD on Wednesday, September 5th, 2018.
2018-09-04	Designing Interrupt Based Code Using Schedulers, LETIMER; GPIO;		Quiz 2 assigned and due EOD Sunday, September 9th, 2018
2018-09-06	Keeping Energy State Synchronized; Sensors for the Mobile Market		Homework 1: Introduction to the Simplicity development environment and interrupt based programming using the LETIMER including developing a sleep() routine and comparing energy profiles across different energy modes. Due EOD Wednesday, September 12th, 2018
2018-09-11	ESD diodes; Load Power Management; Si7021 temp/humidity sensor		Quiz 3 assigned and due EOD Sunday, September 16th, 2018
2018-09-13	I2C peripheral; Developing your own I2C driver; Bluetooth Classic		Homework 2: Develop a low power routine using the I2C and the Si7021 temp/humidity sensor. Due EOD Wednesday, September 19th, 2018
2018-09-18	Bluetooth Classic; Bluetooth Smart		Quiz 4 assigned and due EOD Sunday, September 23rd, 2018
2018-09-20	Setting up a BLE service; Secured BLE bonding		Homework 3: Using the Blue Gecko to transmit the Blue Gecko temperature to the Silicon Labs' Android/IoS demo application over secured bonded connection. Due EOD Wednesday, September 26th, 2018

Date	Topic	Required Reading (Complete Reading Lists will be included in the weekly reading assignments in Canvas to include the appropriate web links.)	Homework/Projects/Exams
2018-09-25	Bluetooth Smart; Link Layer; Client; Peripheral		Quiz 5 assigned and due EOD Sunday, September 23rd, 2018
2018-09-27	Creating a BLE client; Bluetooth Smart		Homework 4: Using one Bluetooth Gecko set up as a BLE Health Temperature Server, implement a client on another Bluetooth Gecko to access the temperature and indicate when the temperature goes out of range. Due EOD Wednesday, October 3rd, 2018
2018-10-02	Bluetooth Smart;		Quiz 6 assigned and due ED Sunday, October 7th, 2018
2018-10-04	Bluetooth Smart		No Homework assigned
2018-10-09	Mid-Term review		No quiz assigned
2018-10-11	Mid-Term		
2018-10-16	Mid-Term – part 2; Bluetooth Smart; Bluetooth Mesh		Quiz 7 assigned and due EOD Sunday, October 14th, 2018 Assigned: Install the Bluetooth Mesh lighting demo software onto your Blue Gecko development board. Due at class on Tuesday, October 18th, 2018
2018-10-18	Bluetooth Mesh		Homework 5: Bluetooth Mesh assignment. Due EOD Wednesday, October 24th, 2018
2018-10-23	Bluetooth Mesh		Quiz 8 assigned and due EOD Sunday, October 21st, 2018 Course Project: Course project can be Bluetooth Smart or Bluetooth Mesh based on the student's interest in learning. Course Project: Course Project Proposal due EOD Sunday, October 28th, 2018
2018-10-25	Bluetooth Mesh		
2018-10-30	Bluetooth Mesh		Quiz 9 assigned and due EOD Sunday, November 4th
2018-11-01	Lab day		
2018-11-06	Verification test plans; Bluetooth Mesh		Course Project Status Report 1 assigned and due November 11th, 2018

Date	Topic	Required Reading (Complete Reading Lists will be included in the weekly reading assignments in Canvas to include the appropriate web links.)	Homework/Projects/Exams
2018-11-08	In-class programming homework #6 assignment		
2018-11-13	Memory for Portable Applications; NOR; NAND; In-class quiz		Quiz 10 assigned and due EOD Sunday, November 25th, 3018
2018-11-15	Memory for Portable Applications; eMMC; FRAM; EEProm; DDRx; SD card; emulating EEProm using FLASH;		Course Project Status Report 2 assigned and due December 2nd, 2018
2018-11-20	Fall Break		
2018-11-22	Fall Break		
2018-11-27	Infrastructure and Ad-Hoc Networks; Wireless Radios Overview; ZigBee; Thread; Zwave; WiFi		
2018-11-29	WiFi, Thread, ZigBee, and Bluetooth Co-existence		
2018-12-04	Lab day		
2018-12-06	WiFi, Thread, ZigBee, and Bluettooth Co-existence		
2018-12-11	Course project demos		Course Project Due
2018-12-13	Course project expo; On-campus student attendance is mandatory for this class. Lack of attendance for on-campus students will affect your grade.		Course Project Due before class
Week of December 14th	Final Exam		

Examinations:

Mid-Term: October 11th, in class, ECCS 1B14, and programming assessment on October 16th

Final: Week of December 14th, in classroom TBD

Course Project due: Last week of classes, April 30th