ECEN 5823-001, -001B
Internet of Things Embedded Firmware

Lecture #1

29 August 2017

Be Boulder.

University of Colorado Boulder

Introductions (continued)

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Agenda

- Class Announcements
- Reading list
- Quiz #1 assigned
- Course Survey assigned
- ESE lab rules
- Course Goals and Expectations
- Project and Tool demo
- Mobile Computing Applications and Covered Topics
- Where is the money in IoT?
- IIoT versus IoT

Class Announcements

- The class currently has 9 students on the waiting list
  - Most likely, I will up the enrollment by 5 students
- Quiz #1 is due at 11:59 on Sunday, September 3rd, 2017
- Course survey is due at 11:59 on Sunday, September 3rd, 2017
- ESE lab, ECEE 287
  - Card access for ESE students and students taking ESE courses only
  - Must apply for card access via web form
    - https://goo.gl/forms/8rTSW3hfbPUb4RFh1

Reading List

Below is a list of required reading for this course. Questions from these readings will be on the weekly quiz.

- Silicon Labs' "Manage the IoT on an Energy Budget" https://www.silabs.com/Support%20Documents/TechnicalDocs/manage-the-iot-on-an-energy-budget.pdf
- "State Machines for Event-Driven Systems" http://www.barrgroup.com/Embedded-Systems/How-To/State-Machines-Event-Driven-Systems
- Silicon Labs' Energy Optimization Application Note, AN0027 http://www.silabs.com/Support%20Documents/TechnicalDocs/AN0027.pdf

Recommended readings. These readings will not be on the weekly quiz, but will be helpful in the class programming assignments and course project.

- Silicon Labs' Simplicity User Guide, AN0822 http://www.silabs.com/Support%20Documents/TechnicalDocs/AN0822-simplicity-studio-user-guide.pdf

Quiz

- Due by 11:59pm on Sunday, September 3rd, 2017
- Will cover topics discussed in the reading material as well as in lecture from August 28th onward

Survey

- This survey will help enable the instructing team to provide any additional resources that are necessary
- Due by 11:59pm on Sunday, September 3rd, 2017

ESE lab rules

- All students enrolled in an ESE course (except ECEN 5613) will be granted access to the ESE Lab (ECEE 287) with completion of the web form
- The policy will be strictly enforced. Students only need to submit the form once for ESE Lab access
- **NOTE:** Students enrolled in ECEN 5613 must use ECEE 1B28 for that course, and NOT the ESE Lab in 287

ESE lab rules

- The link below serves as both an agreement on lab policy and an access request form for the labs
- We will not be accepting student lab access requests through any other means. If students are enrolled in a course that uses a lab, their request will be automatically granted
- If they request non-course access through a faculty member, we will be emailing that faculty member for a response before granting access
  - Https://goo.gl/forms/8rTSW3hfbPUb4RFh1
- Embedded students should not be using the 281/282 labs
  - These labs are for the undergraduate students

Rationale

- To meet the demands of the fast growing markets of mobile computing and Internet of Things, 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.

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.

Description and Content (continued)

- Topics covered:
  - Low Energy versus Low Power design
  - Wireless Computing tradeoffs: Available resources, application, infrastructure
  - Interrupt or event driven firmware
  - Wireless standards: applications and tradeoffs
  - Bluetooth: protocols and profiles
  - Designing for product lifecycle of 20+ years
  - Developing customer Bluetooth Smart Profiles and Services
  - Designing embedded systems with security in mind
  - Implementing secure Over The Air, OTA, Bluetooth Smart firmware updates
  - Project that will incorporate Bluetooth communications, low power sensors, and low energy design concepts

Class Objective

- Maximize the battery life of Internet of Things Applications
- Analyze Internet of Things memory requirements
- Overcome technical weaknesses of flash memory technology
- Match the correct low power RF networking technology to the end application
- Obtain the skills to develop a Bluetooth Smart peripheral/device product
- Obtain the skills to develop a Bluetooth Smart client product
- Provide secure Over The Air, OTA, Bluetooth Smart firmware updates
- How energy harvesting powers the Wireless Sensor Networks
- Maximizing the value of embedded systems using Near Field Communications (NFC)

Expected Outcome

You will be able to …

- Develop event based "code to the metal" firmware to extend the battery life of Internet of Things applications
- Debug low level / machine centric firmware
- Select the wireless protocol that best addresses the end application requirements
- Develop a custom Bluetooth Smart service / peripheral
- Develop an interoperable Bluetooth Smart device/peripheral product
- 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

Class structure

- On average, each week the lectures will be covering both theory and concepts as well as implementing low energy design principles in hardware/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 principles will then have a weekly homework programming 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

Class structure (continued)

- Quizzes
  - Will be published, put on D2L, by the end of Sunday and will be due by the end of the following Sunday
  - Two attempts will be available for each quiz with best grade used for scoring and there will be one hour to complete each attempt
  - One quiz will be dropped from the total
- Homework assignments
  - Will generally be assigned at Thursday's lecture and will be due the end of day the next Wednesday
  - No assignments will be dropped

Class structure (continued)

- 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 5813, Principles of Embedded Software, 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

Development boards provided for ECEN 5823

- 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

Note: These development boards will be provided to the students at no charge, but the boards will be required to be returned upon completion of the course project demo

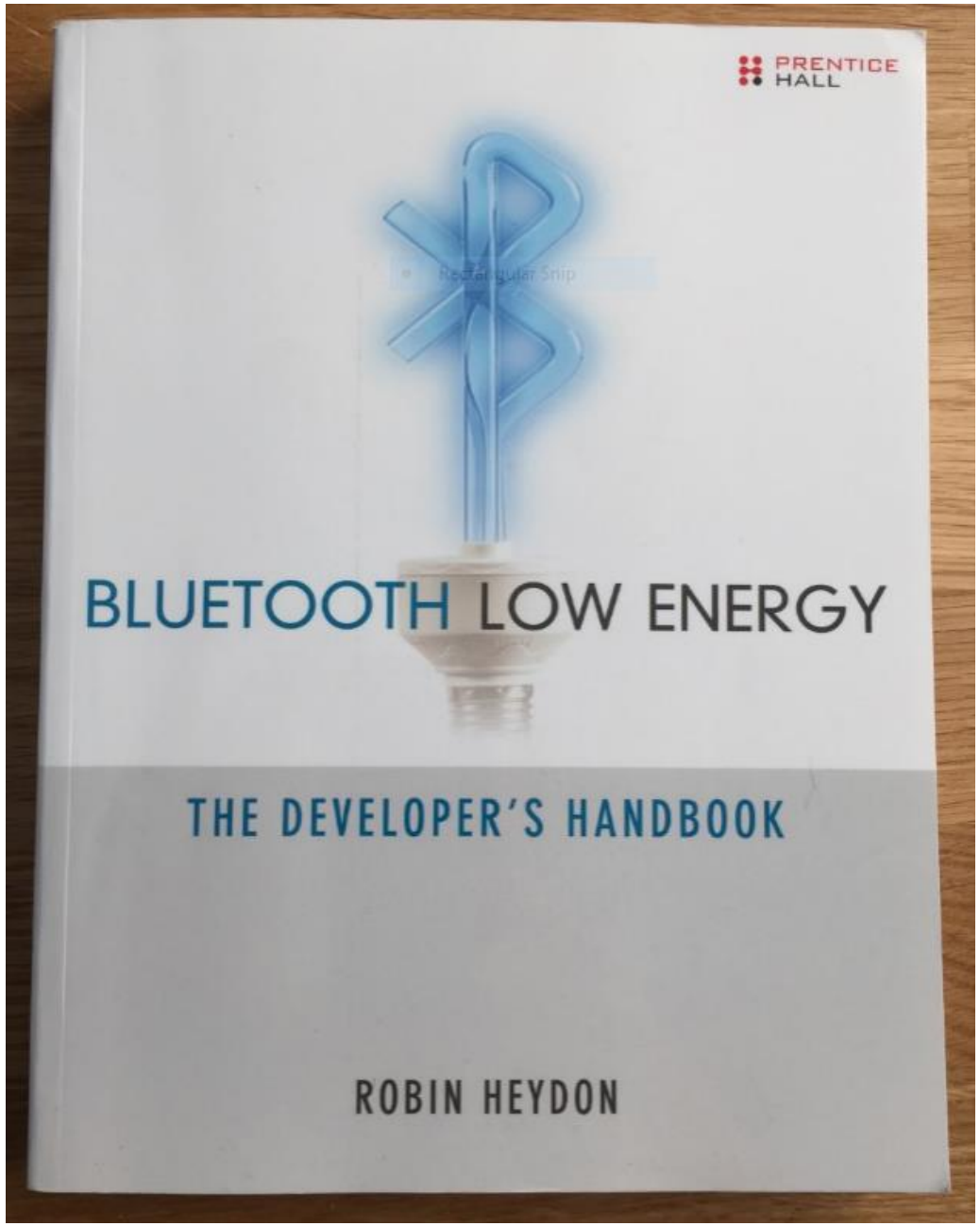
Homework programming assignments

- The homework programming assignments will be designed to build upon previous assignments
- By the start of the course project, the students will already have experienced with event driven firmware as well as low energy firmware concepts (700 – 1000 lines of code)
- Homework assignments (subject to change):
  - Exercise: Introduction to the Simplicity development environment.
  - #1: Interrupt based programming using LETIMER including developing a sleep() routine and comparing energy profiles across different energy modes.
  - #2: Program the ADC to determine the state of an analog joy stick to control a program

Homework programming assignments

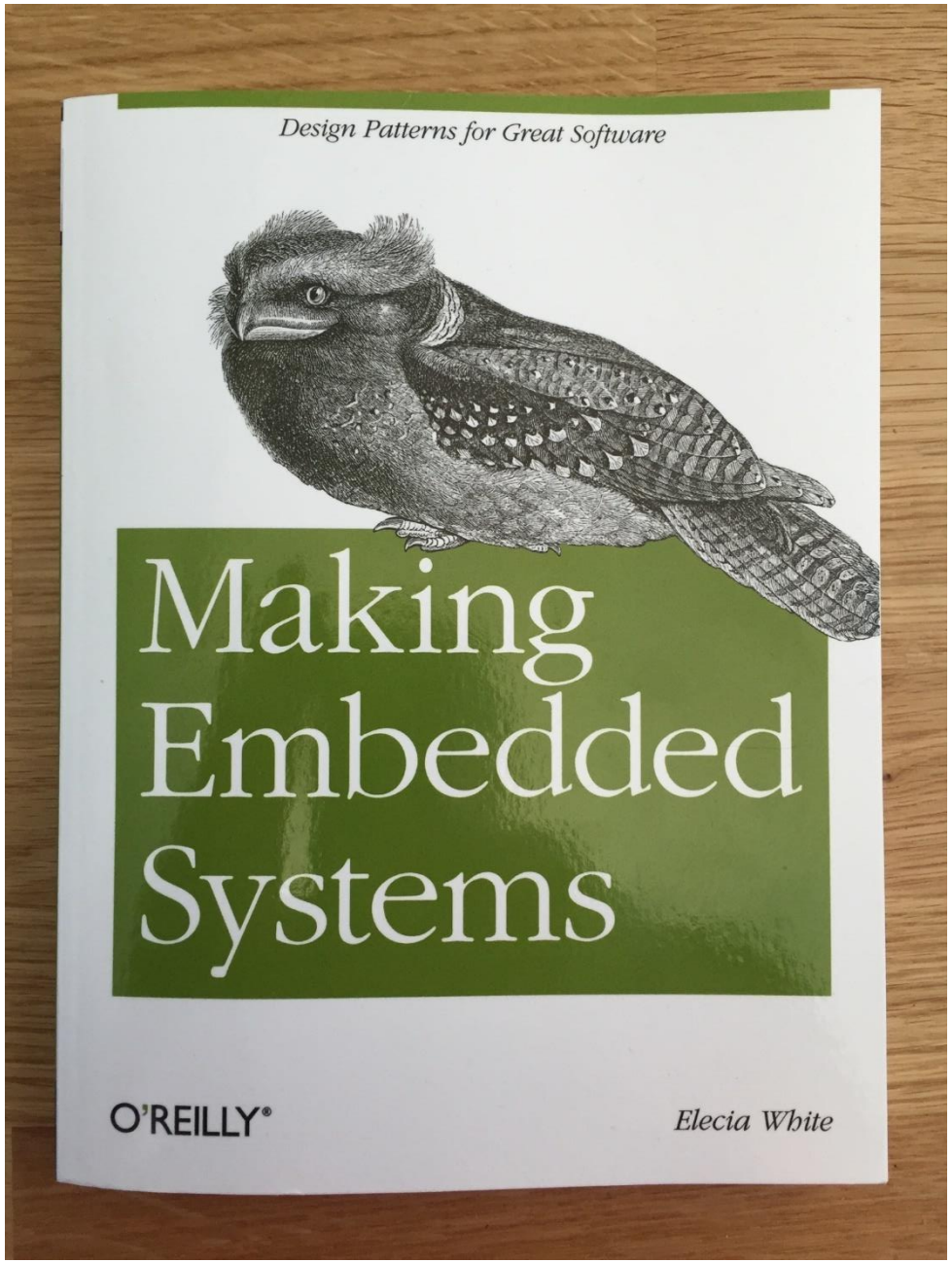
- Homework assignments (continued):
  - #3: Program the BMA280 accelerator to be a tap controller using the SPI and TIMER0 peripherals
  - #4: Minimize energy utilizing Load Power Management on the Si7021 I2C temperature / humidifier sensor
  - #5: Utilize the Blue Gecko's program flash to emulate EEPROM
  - #6: Add Bluetooth to transmit the temperature of the Si7021

Required book for Bluetooth portion of course



"Bluetooth Low Energy, The Developer's Handbook," by Robin Heydon
ISBN: 9780132888363

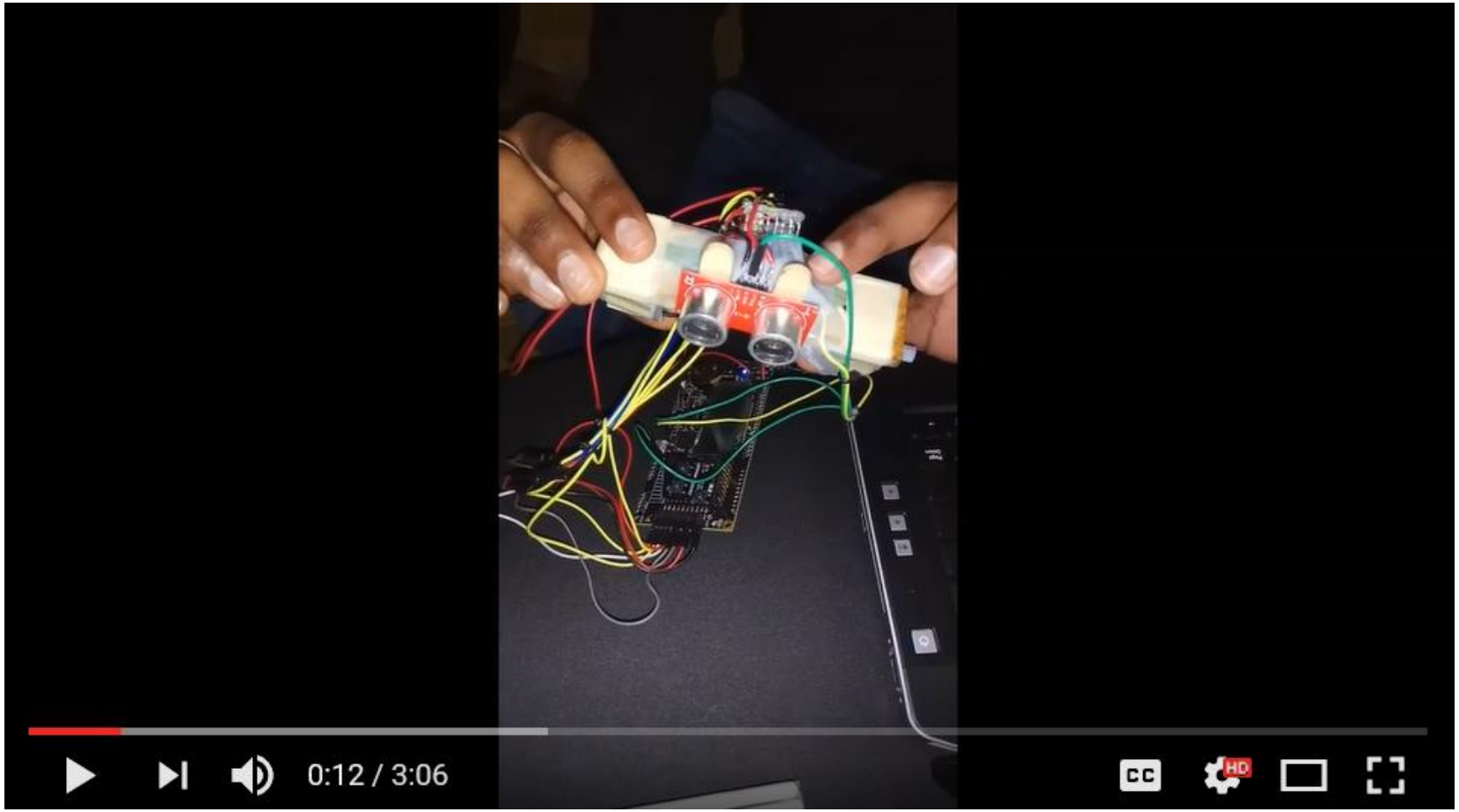
Recommend book for this course for students who would like an embedded C reference book



Course Project

- 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 device in a cohesive application such as home security, retail, etc.. This project will include developing code as a Bluetooth Smart device providing the associated services for external sensors. The project/product will need to support Bluetooth notifications, indications, as well as attribute writes/reads, and attribute commands.

Example project from Fall 2016



Ethics and Expectations

- Sharing of knowledge between students is highly encouraged; however, each student is expected to independently create and implement their own project files
- 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.

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 30%
  - Quizzes 10%
  - 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

Evaluation and Grading Procedures

- 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.

D2L

- Syllabus and other course material will be inside the “Course file” folder
- Lectures, Homework and Reading assignments will be located in their weekly folder
- Quizzes will be administered through the D2L course site
- Homework assignments will be delivered via “drop box” on D2L

Slack

- A Mobile Computing and Internet of Things Security Slack team will be set up for this course
- The Slack channels/forums will be a valuable place to look for answers, ask questions, and to help others. As you work through problems, you may find documentation errors or lack of documentation that may have already been solved in the forum. The forum will be proctored by the instructor and course TAs. As in all engineering projects, collaboration and sharing knowledge of issues and solutions is very productive.
  - Please feel free to create new threads and help out others!


WE LEARN...
10% of what we read
20% of what we hear
30% of what we see
50% of what we see and hear
70% of what we discuss
80% of what we experience
95% of what we teach others
-William Glasser

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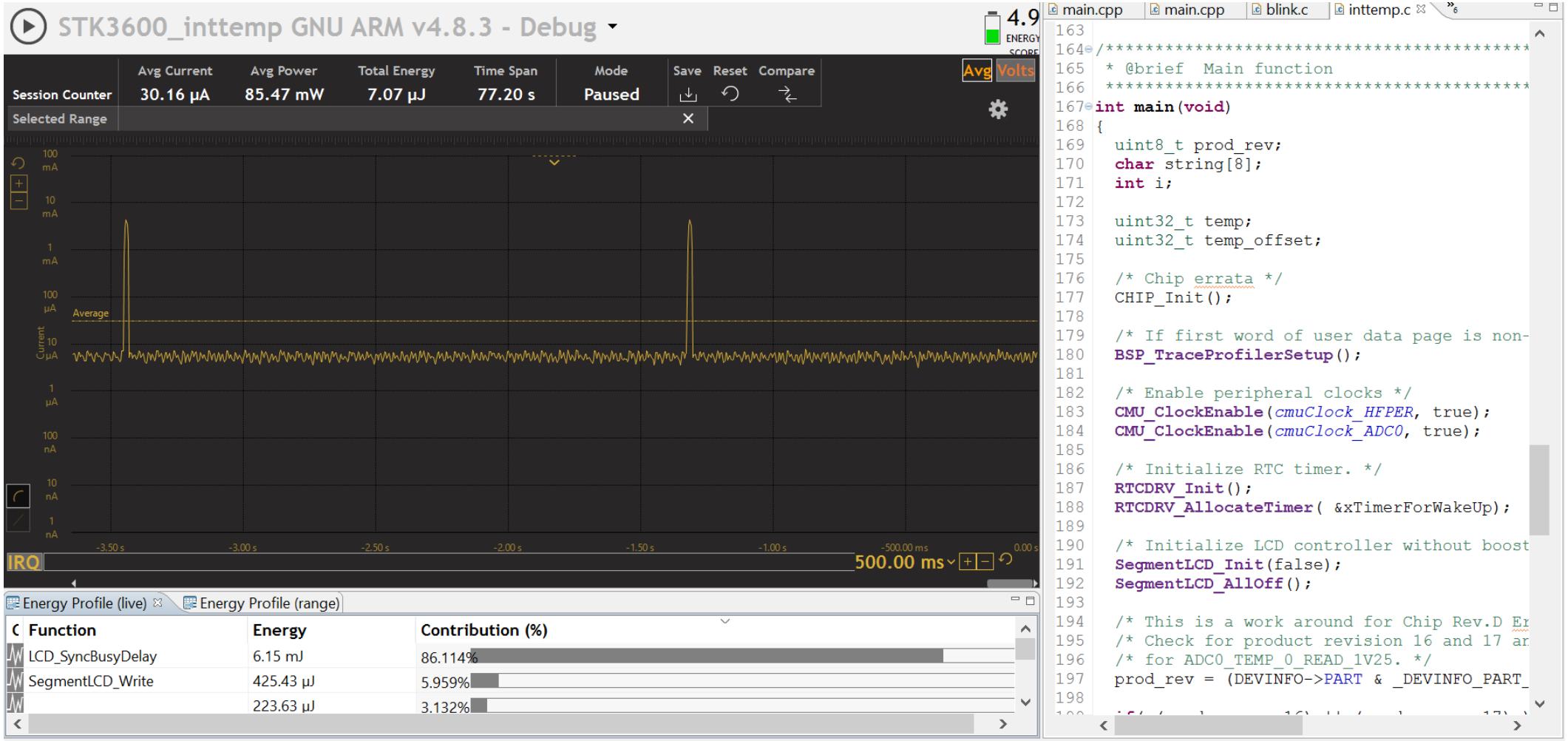
  - Please feel free to create new threads and help out others!
- In the coming week, everyone in the class will be invited to the course Slack team

Energy Profiler demo



What is mobile computing for ECEN 5823?

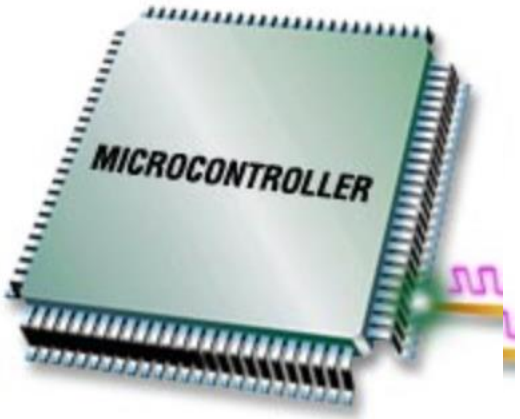
- Wikipedia **Definition**. • **Mobile computing** as a generic term describing ability to use the technology to wirelessly connect to and use centrally located information and/or application software through the application of small, portable, and wireless **computing** and communication devices.

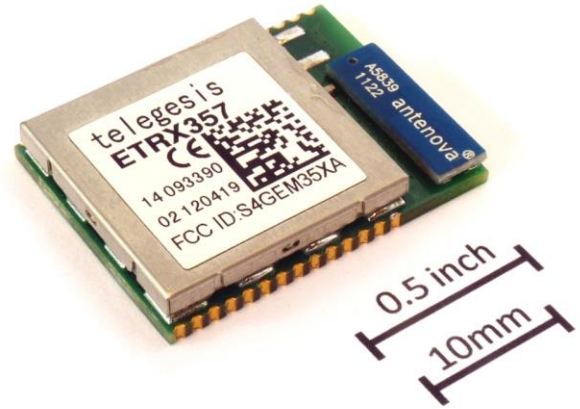
IoT computing for ECEN 5823

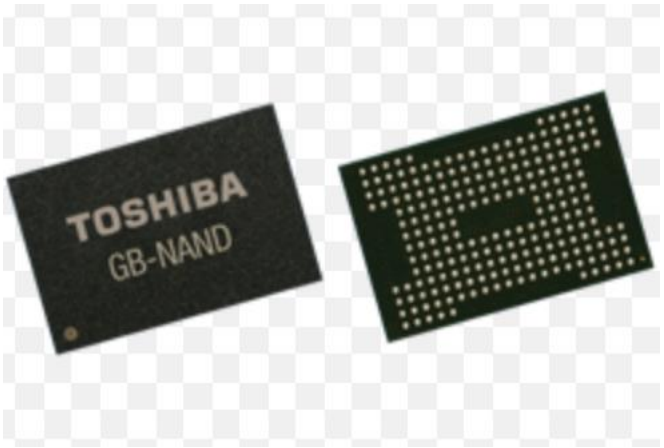
What are key factors in designing for IoT?

- Battery Life
  - Everyone would like their smart phone or watch to last longer.
- Communications (Radios)
  - Different standards for different industries
- Operating Temperature
  - Benign or harsh
- Physical Durability
  - Survive the accidental drop
- Warranty
  - Needs to match the market segment sold into
- Security
  - As these devices are becoming more prevalent, security needs are growing

What components will this class focus on?





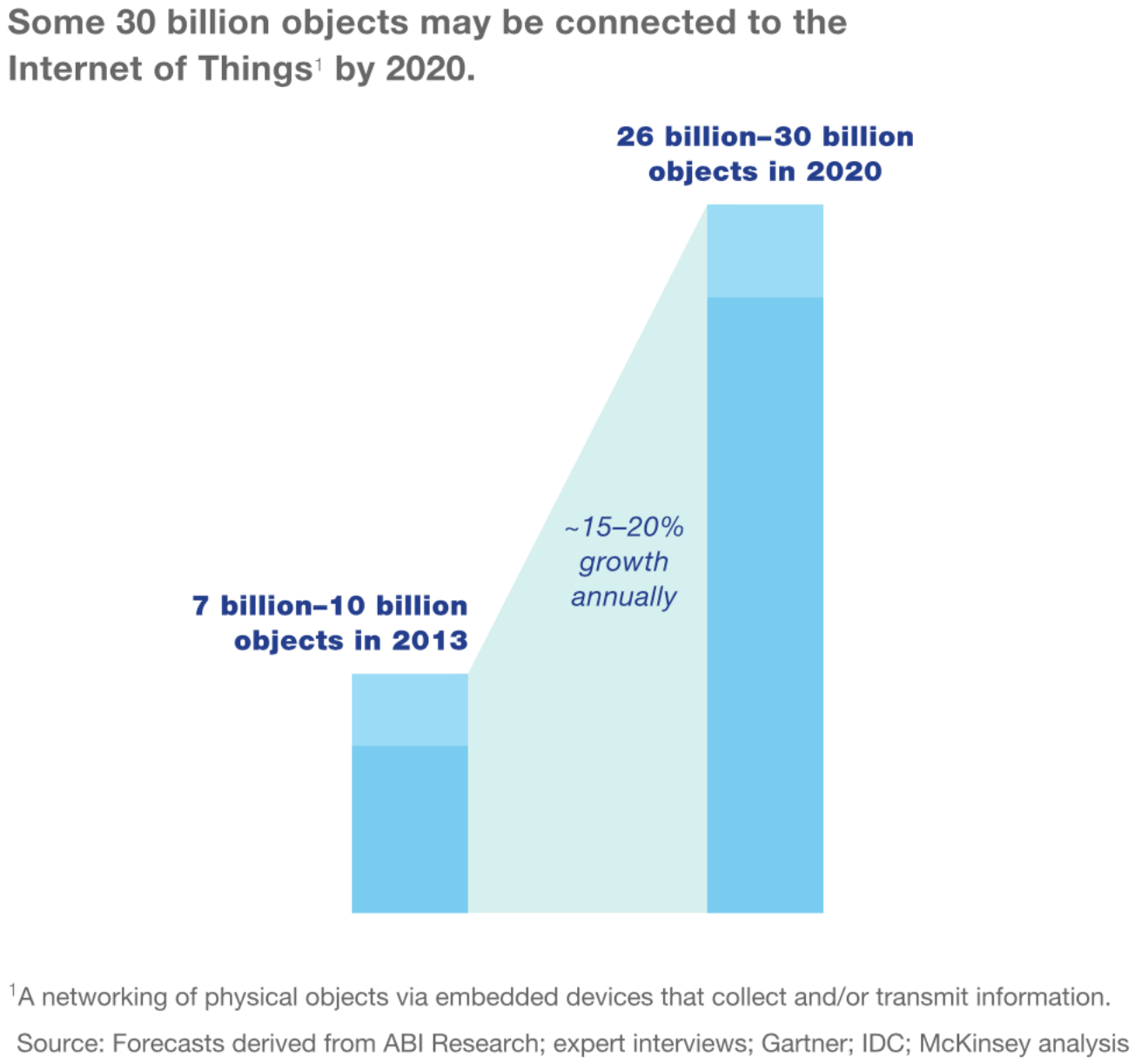


What is an IoT device?

- The **Internet of Things** (**IoT**) is the network of physical objects or "things" embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data.[1] The Internet of Things allows objects to be sensed and controlled remotely across existing network infrastructure,[2] creating opportunities for more direct integration between the physical world and computer-based systems, and resulting in improved efficiency, accuracy and economic benefit.[3][4][5][6][7][8] Each thing is uniquely identifiable through its embedded computing system but is able to interoperate within the existing Internet infrastructure. Experts estimate that the IoT will consist of almost 50 billion objects by 2020.[9]

Growth will generate new problems and create new opportunities

- What will be some of the issues as the number of connected devices grows to 30+ billion and beyond?
  - Capacity?
    - Bandwidth
    - IOPs
  - Security



Where is the money in (consumer) IoT?

- Selling the device?
  - Fitbit, Garmin Running watches, Bluetooth door locks, ….
  - A recent InfoWorld article proclaims "The Internet of Things is not paying the rent." In it, Adobe's VP of Mobile Matt Asay cites data from Vision Mobile and McKinsey & Co. to point out that "less than 10 percent of IoT developers are making enough to support a reasonably sized team," and that "developers need to get real about what they're selling and to whom," which "probably involves a 'dull' enterprise-facing business." This begs the question, how do you make money in the IoT?

Where is the money in (consumer) IoT?

- IoT-as-a-Service?
  - Home/Security Automation, Smart Sprinkler Systems, ….
  - Internet of Things companies could potentially transition away from one-off IoT platform sales and into business models that allow for accretive growth by means of data and feature monetization. In this cloud-based approach, companies could establish service plans or provide additional features to end users similar to how your cell phone or cable company operate, generating recurring streams of income that continue to flow after the initial platform sale (or perhaps, giveaway) to help offset ongoing maintenance, service, and support costs.

Industrial Internet of Things (IIoT)

- The Industrial Internet of Things will combine the reach of the Internet with a new ability to directly control the physical world, including machines, factories, and infrastructure.
- Growth of “digital labour” in the form of smart sensors, intelligent assistants, and robots will transform not just the ability to manage and operate their assets, but also transform the skills and mix of the workforce.
- New jobs will be created in the form of IIoT device and robot designers, internet optimization, and software engineering to create the ecosystem or fabric for these IIoT devices to operate.

Outcome Economy

- Manufacturing economy: A marketplace based on producing and selling products
- Service economy: A marketplace based on providing services rather than manufacturing or producing goods. (Cambridge dictionary)
- Outcome economy: A marketplace where businesses compete on their ability to deliver quantifiable results that matter to customers rather than just selling products or services, e.g. energy saved, crop yield or machine uptime. Delivering customer outcomes requires sellers to take on greater risks. Managing such risks requires automated quantification capabilities made possible by the Industrial Internet. (World Economic Forum)

To achieve the Outcome Economy

- Companies will need to focus on the “why” behind the buy
  - Connected sensors are moving the physical world online making it quantifiable and accessible
  - Applying advanced analytics to this data with the correct external data and domain models will give companies a better understanding of interaction and how to optimize to achieve the desired business outcome
- Reliability will be a key component in the Outcome Economy
  - Industrial products are designed for years or decades. IIoT devices will need to have obsolesces that match these industrial products and can be added to existing machinery without compromising its integrity or reliability
- Real-Time responses are often critical in manufacturing, energy, transportation and healthcare.
  - Today’s internet “real-time” is a few seconds, but real-time in industrial equipment usually means sub-millisecond

Real-Time

- How will Real-Time responses in sub-milliseconds for industrial application over today's internet "real-time" of several seconds drive architecture decisions of an IIoT device?
  - Drive processing power and decision making to the device
  - And/or
  - Localized IIoT routers or access points

Reliability

- How will reliability drive architecture decisions of an IIoT device?
  - If practical, drive the processing power up into the backend/cloud
  - Smaller and simpler design = higher reliability
  - Minimize low reliability components such as mechanical, FLASH memory, electrolytic capacitors
  - Increase costs by utilizing higher quality components

Industry Internet of Things – Reliability example!

- Stupid phone tricks
  - https://www.youtube.com/watch?v=w4H0BR_8wy8