Embedded System Design Syllabus
ECEN 5613 – Fall 2015

Lectures: Monday Evenings, 6:30pm-9:00pm, ECCS 1B14
Instructor: Professor McClure, Department of Electrical, Computer, and Energy Engineering
E-mail: Linden.McClure@Colorado.EDU
Instructor Office Hours: TBD, available by Skype and Zoom
Course Web Site: http://ece.colorado.edu/~mcclure/index.html Lab: ECEE 1B28
TAs: Umang Patel, Aniket Lata, Ashwin Raman
TA Office Hours: weekdays, evenings, weekends, and by appointment
Office Hour Schedule: http://ece.colorado.edu/~mcclure/office_hours.html

Course Description
In this class, the fundamentals of embedded system hardware and firmware design will be explored.
Issues such as embedded processor selection, hardware/firmware partitioning, glue logic, circuit design,
circuit layout, circuit debugging, development tools, firmware architecture, firmware design, and
firmware debugging will be discussed. The Intel 8051, a very popular microcontroller family, will be
studied. The architecture and instruction set of the microcontroller will be discussed, and a wirewrapped
microcontroller board will be built and debugged by each student. The course will culminate with a
significant final project which will extend the concepts covered earlier in the course. Learning may be
supplemented with periodic guest lectures by embedded systems engineers from industry. Depending on
the interests of the students, other topics may be covered.

Required Background
Knowledge of and skills in microprocessor architecture and assembly language, microprocessor
peripherals, digital design, and the C programming language is a prerequisite for this course. The
Corresponding CU-Boulder courses are ECEN 2120/2350, ECEN 3100/3350, and ECEN 1030/1310/CSCI
1300. Although not listed as formal prerequisites, circuits/electronics (ECEN 3250) and computer
organization (ECEN 4593) are highly recommended. An understanding of compilers, assemblers, linkers,
operating systems, analog design, diodes, transistors, and electromagnetic fields and waves will be useful.
Refer to the course FAQ for more information.

Course Context
Embedded systems are involved in almost every facet of modern life. Cell phones, tablets, MP3 players,
pagers, energy conversion systems, answering machines, microwave ovens, televisions, VCRs/DVRS,
CD/DVD players, video game consoles, GPS devices, network routers, fax machines, cameras, music
synthesizers, planes, drones, spacecraft, boats, and cars all contain embedded processors. Late model cars
may contain more than 65 embedded microprocessors, controlling such tasks as antilock braking, traction
and stability control, climate control, engine control, entertainment system control, navigation, airbag
deployment, etc. The Boeing 777 aircraft contains over 1,200 processors and more than 4 million lines of
software! Logic analyzers and digital storage oscilloscopes utilize embedded processors to support real-
time operation. Even PCs, which are designed around powerful CPUs, contain embedded systems.
Storage drives (hard disk, solid state, CD-RW, DVD+RW, Blu-ray), and external peripherals such as
printers, scanners, and other SCSI, SAS, SATA, USB, or IEEE 1394 devices all contain embedded
processors. During 2007, microprocessor manufacturers sold on the order of 100 million processors for
use as computer CPUs. In comparison, during the same time frame, microprocessor manufacturers sold
more than 3 billion embedded processors, primarily consisting of 32-bit, 16-bit, 8-bit, and 4-bit devices.
The tremendous number of applications for embedded computing has given rise to high demand for
engineers with experience in designing and implementing embedded systems. This course will give
students hands-on experience and opportunities for experimentation in this exciting field.
Course Mechanics

This course is meant to be a hands-on type course, giving students a chance to hear and read about embedded system topics, and then put those concepts to work by developing and debugging embedded system hardware and firmware. Student participation in active discussions of the course topics will be expected. Lecture periods will include a short break sometime in the middle. The course grade will be based on class attendance and participation, lab assignments, presentations, quizzes, teamwork, and an embedded system term project. Four structured individual lab assignments will be given. Lectures will be closely integrated with the lab assignments and will be organized to provide students with the information necessary to successfully complete each assignment. Students may work independently or in groups of up to three on the term project. Team members will be expected to share the workload equally. Various homework assignments will be given to guide students through the course material, but most of these will be optional. The instructor and TAs will be available to help students during office hours, by appointment, and by e-mail. Students with questions should send e-mail to the TAs and the instructor to ensure the quickest response time. All e-mail correspondence related to this class should include the text "ESDF15" and a specific subject as the subject line of the message, so that e-mail may be filtered automatically. Course information and documents will be available on the course web site, which will be updated throughout the semester.

Course Organization

The course has several goals. First, it will expose students to the field of embedded systems, and will provide a knowledge foundation which will enable students to pursue subsequent courses in real-time embedded systems software and computer design. Students will become familiar with the associated technical vocabulary and will learn about potential career opportunities in the field of embedded system design. Second, students will have the opportunity to develop an embedded system from the ground up, starting with electronic components and data sheets, and progressing through construction of hardware and implementation of firmware. This will provide students with an opportunity to gain a thorough understanding of the phases of embedded system development and familiarity with hardware and software development and debugging tools. Third, students will be given the opportunity to develop design skills, through well-bounded design assignments as well as open-ended design assignments. Fourth, students will have the opportunity to learn how information gained in multiple other core engineering classes comes together to be applied to real-world design. Fifth, students will be given an opportunity to experience embedded system design in a manner similar to that practiced in industry, and will gain knowledge beneficial for obtaining a job in this field.

The course will be structured around several key lab assignments and the final project. During the first part of the course, students will focus primarily on basic embedded system concepts, and will develop a basic hardware platform consisting of an 8051 microcontroller family derivative and supporting circuitry. At the same time, students will become exposed to the 8051 instruction set, and learn how to use a cross assembler and simulator to develop code. During the middle of the course, students will focus more on firmware concepts, and will develop code in assembly and C to control the basic hardware. In addition, during this period students will add additional hardware elements to their boards, and will develop the firmware to control this new hardware. During the final weeks of the course, students will focus on significant projects (perhaps with a more advanced processor), and will proceed through design, development, documentation, and presentation of their work. Although the course is scheduled for one evening each week, lectures may not be given on all of these days during the semester; instead, one to three class periods may be used to provide students with additional time to work on their development assignments. In order to give students perspective from multiple viewpoints, class discussions on several topics will be pursued. Guest speakers may discuss embedded systems topics during the semester.
Tentative Syllabus

Note: The following syllabus is tentative, and is provided to give insight into the types of topics to be discussed during the semester. However, not all topics will be discussed in the order given or on the dates shown. **Adjustments will be made as the course progresses. Lecture may be cancelled for lab sessions.**

**Week 1: August 24**
- Course overview, expectations, logistics, processes, syllabus, FAQ, and prerequisite material.
- Embedded systems descriptions, definitions, and vocabulary. Design Engineer's notebook.
- Design considerations and requirements, processor selection and tradeoffs.
- Overview of board development process, wire wrapping vs. soldering.
- Microprocessor/microcontroller architectures and instruction sets, 8051 architecture, busses.
- Lab access, Buff OneCards (access to ECEE 1B28 and east ECEE wing door), computer accounts.
- Lab #1 topics. Design cycle, planning a development project, derivation of requirements, tradeoffs.
- 8051 instruction set, ASM51 assembler and Emily52 simulator. Code development process.
- Device programmers, Intel hex records and Motorola S-records. SPLDs.

**Week 2: August 31**
- Lab #1 & #2 topics. Board layout considerations, signal integrity (noise, crosstalk, etc.), decoupling.
- Manufacturing and test engineering, PCB design, ground and power planes, EMI, EMC.
- Data sheets, power supplies, voltage regulators. Thermal considerations, heat sinks.
- Oscillators and reset circuits. Microprocessor supervisory circuits, watchdog timers.
- Development and debugging strategies and techniques. Logic probes, voltmeters and oscilloscopes.
- Schematics and wiring diagrams, recommended practices, CAD tools. CU Honor Code.
- Parts kits. Introduction to Embedded Systems Laboratory, equipment, and soldering.

**Week 3: September 7** *(Finish Lab #1 this week)* *(Holiday – Labor Day)*
- No in-class lecture due to the Labor Day holiday on Monday, September 7th. Some lecture material may be recorded and available for download. Complete software elements of Lab #1 this week.

**Week 4: September 14** *(Lab #1 submission due this week)*
- Lab #2 topics. Core component circuitry (µP, ROM, RAM).
- Interfacing different logic families, fanout, signal buffering, noise margins, pullups/pulldowns.
- Microcontroller peripherals interfacing. 8051 timing diagrams, program read, data read, data write.
- Debugging using logic analyzers, state and timing information.
- Timing requirements, propagation delay, setup, hold, rise/fall times, timing analysis. Clock skew.
- Memory maps, decoding logic, glue logic, programmable logic (PALs, FPGAs). Memory technology.
- Switch debouncing in hardware and firmware, keypad decoding. 8051 timers/counters.

**Week 5: September 21** *(Finish Lab #2 required elements this week)*
- KiCAD? Debug session in lab? Work on current topics presentations? Student/professor meetings?

**Week 6: September 28** *(Lab #2 submission due this week)*
- Lab #3 topics. Class eval. Intro to Atmel AT89C51RC2. C programming review?
- Serial communication, RS-232/485, line drivers/receivers, charge pumps, terminal emulation, USB.

**Week 7: October 5**
- Lab #3 topics. Cross-assemblers, cross-compilers, linkage editors, disassemblers, other tools.
- Intro to SDCC, makefiles, and IDEs (Code::Blocks, Eclipse).
- C variables, bit operations, pointers. Interrupts in C. Interfacing C and assembly.
- Software development, version control, coding standards, code reviews.
Week 8: October 12  (Finish Lab #3 required elements this week)
- No lecture? Debug session in embedded systems laboratory. Work on Lab #3.

Week 9: October 19  (Lab #3 submission due this week)
- Lab #4 topics. EEPROMs and synchronous serial communication (I²C, SPI, etc.). LCDs.

Week 10: October 26
- Final Project Design Review (PDR). Each project team presents development plan and milestones.

Week 11: November 2
- Guest Speaker?
- Analog-to-Digital Converters (ADCs), Digital-to-Analog Converters (DACs).
- Code review exercise. Firmware design, main loop/interrupt driven designs, device drivers.
- Debug session in embedded systems laboratory?
- **Student presentations?** Work on final projects. Informal evaluations?

Week 12: November 9  (Finish Lab #4 required elements this week)
- Guest Speaker? **Student presentations?** Work on final projects.
- Passive components. Designing with tolerances and margins.

Week 13: November 16  (Lab #4 submission due this week)
- ARM architecture lecture? Informal evaluations? **Student presentations?**

Week 14: November 23  (*Fall Break Nov 23-27*)
- No lecture, class cancelled.

Week 15: November 30
- Last lecture. Current events, emerging technologies. Possible topics also include migrating C code, jump tables, POST, memory testing, little/big endian issues, math functionality.
- Semester wrap-up. Review of vocabulary. Course evaluations (on-line FCQs).

Week 16: December 7
- Last Class. Final project presentations. Students will demonstrate their final projects to the class in the embedded systems laboratory. In order to complete all presentations, it may be necessary to extend the class period until 9:30pm on this evening.

Week 17: No Final Exam

<table>
<thead>
<tr>
<th>Assignment Overview</th>
<th>Signature Due Dates</th>
<th>Submission Due Date</th>
<th>Cutoff Date</th>
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</thead>
<tbody>
<tr>
<td>Lab #1: Basic hardware, SPLD, assembly, simulator</td>
<td>9/09 – 9/16</td>
<td>9/17/2015</td>
<td>9/30</td>
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<tr>
<td>CTP: Current Topic Choice Submission</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
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<tr>
<td>Lab #2: Decode logic, EPROM, timer ISRs</td>
<td>9/25 - 9/30</td>
<td>10/01/2015</td>
<td>10/14</td>
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<tr>
<td>Lab #3: SRAM, RS-232, assembly, intro to 8051 C</td>
<td>10/16 - 10/21</td>
<td>10/22/2015</td>
<td>11/11</td>
</tr>
<tr>
<td>PDR: PowerPoint Submission</td>
<td>10/25/2015</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTP: PowerPoint Submission</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>Lab #4: EEPROM, LCD, and C programming</td>
<td>11/13 - 11/18</td>
<td>11/19/2015</td>
<td>12/02</td>
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<tr>
<td>Final Project: Demo Presentation Submission</td>
<td>12/06/2015</td>
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<tr>
<td>Final Project/Lab #5: Student's choice</td>
<td>Demo 12/07</td>
<td>12/12/2015</td>
<td></td>
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<tr>
<td>Final Project report</td>
<td>12/12/2015</td>
<td>12/13</td>
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Lab assignments will be scored per the CU grading standards. Assignments which are not completed (signatures obtained) by the **Signature Due Date** or which are not submitted by the **Submission Due Date** will be late and will receive a late penalty deduction. The final project may not be submitted late. Assignments will not be accepted after their **Cutoff Date**; however, incomplete work will be considered.
Course Requirements

- 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. The goal of the course is to allow you to learn the material, and not to stress you out. However, the longer you are confused, the more material you miss, so try to stay on top of things. It is fine to ask lots of questions, as long as you are putting in the effort to learn the material.

- It is the student’s responsibility to obtain materials handed out in a lecture which the student missed.

- You are responsible for any damage or missing equipment resulting from your negligence.

- Treat all lab equipment with care, as it is expensive. If the equipment is damaged, we may not be able to afford replacements. No equipment may be removed from the lab.

- All homework and reports must be legibly written or typed. Sloppy work will receive deductions.

- All programming code must be well structured/commented. Code must be robust (error handling). Code and comment quality will be evaluated as part of each assignment's grading.

- Schematics must be well drawn and should follow the guidelines to be presented in class.

- When requesting help from the TA or the instructor, students must present a complete and accurate schematic of their circuitry. Update schematics as you add or change circuitry.

- An electronic copy (and optionally a hard copy) of each final project report including schematics and source code will be submitted for grading and will become the property of the instructor.

- Students are expected to complete assignments on time. Lab assignments will be accepted late, but the grade earned on the assignment will be reduced. Since each lab depends on the results from the previous labs, students should be careful not to fall behind. Students are responsible for getting the TA or instructor to sign off on their lab work prior to the due date. Due to limited lab station availability, it is wise to plan ahead. Consider scheduling an appointment with the TA.

- University policies on academic integrity (http://www.colorado.edu/policies/student-honor-code-policy) will be followed. Students must understand the CU Honor Code. Cheating and plagiarism will not be tolerated. Credit must be clearly given for code or hardware designs legally borrowed from others. Submission of project work performed previously or concurrently for a different course constitutes cheating, if instructor consent is not obtained prior to submission. When in doubt, ask the instructor for clarification.

- Students are expected to maintain a design engineer's notebook. This notebook should contain class notes, lab notes, designs, and references. This notebook must be legible and should be written in ink.

- 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 who are experts in a particular area of embedded systems may choose to give a short presentation to the class as part of their class participation grade.

- In lieu of a required text, students should expect to spend some amount of money to purchase supplies for the class, including hardware, tools, integrated circuits, discrete components, and other parts for the final project.

- Students will be expected to obtain data sheets from the course web site or various manufacturers' web sites, and print them out at CU, their place of work, or at home.

- If you must miss a lecture, please let the instructor know in advance, if possible.
Academic Accommodations
Students with disabilities who qualify for academic accommodations must provide a letter from Disability Services (DS) and discuss specific needs with the professor as soon as possible, preferably during the first two weeks of class. DS determines accommodations based on documented disabilities (303-492-8671, Willard 322). Other accommodations may be made in accordance with CU policies (http://www.colorado.edu/policies/index.html). It is the student's responsibility to notify the instructor of anticipated conflicts as early in the semester as possible so that there is adequate time to make necessary arrangements. If you have a temporary medical condition or injury, see Temporary Injuries under Quick Links at Disability Services website http://www.colorado.edu/disabilityservices/ and discuss your needs with the professor. Disability Services' letters for students with disabilities indicate legally mandated reasonable accommodations. Answers to Frequently Asked Questions can be found at http://www.colorado.edu/disabilityservices.

Religious Observances
Campus policy regarding religious observances requires that faculty make every effort to reasonably and fairly deal with all students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. In this class, notify the professor of anticipated conflicts as early in the semester as possible so that there is adequate time to make necessary arrangements. See policy details at http://www.colorado.edu/policies/fac_relig.html

Honor Code
All students of the University of Colorado at Boulder are responsible for knowing and adhering to the academic integrity policy of this institution. Violations of this policy may include: cheating, plagiarism, aid of academic dishonesty, fabrication, lying, bribery, and threatening behavior. All incidents of academic misconduct shall be reported to the Honor Code Council (honor@colorado.edu; 303-725-2273). Students who are found to be in violation of the academic integrity policy will be subject to both academic sanctions from the faculty member and non-academic sanctions (including but not limited to university probation, suspension, or expulsion). Additional information on the Honor Code can be found at http://www.colorado.edu/policies/honor.html and at http://honorcode.colorado.edu.

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 differences of race, culture, religion, politics, sexual orientation, gender, gender variance, and nationalities. 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. See policies at http://www.colorado.edu/policies/classbehavior.html and at http://www.colorado.edu/studentaffairs/judicialaffairs/code.html#student_code

Discrimination and Harassment
The University of Colorado Boulder (CU-Boulder) is committed to maintaining a positive learning, working, and living environment. The University of Colorado does not discriminate on the basis of race, color, national origin, sex, age, disability, creed, religion, sexual orientation, or veteran status in admission and access to, and treatment and employment in, its educational programs and activities. (Regent Law, Article 10, amended 11/8/2001). CU-Boulder will not tolerate acts of discrimination or harassment based upon Protected Classes or related retaliation against or by any employee or student. For purposes of this CU-Boulder policy, "Protected Classes" refers to race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, or veteran status. Individuals who believe they have been discriminated against should contact the Office of Discrimination and Harassment (ODH) at 303-492-2127 or the Office of Student Conduct (OSC) at 303-492-5550. Information about the ODH, the above referenced policies, and the campus resources available to assist individuals regarding discrimination or harassment can be obtained at http://hr.colorado.edu/dh/
Grading
Expectations for students will be high. Student performance in this class will be compared to student performance across ECE undergraduate and graduate classes. A grade of 'A' will be reserved for students who have delivered outstanding work and who have clearly demonstrated a superior mastery of the course material. The majority of each student's course grade will be determined by the quality of the hardware and firmware assignments and the final project completed by the student during the semester. The rough weighting of each course element is shown below:

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<thead>
<tr>
<th>Percentage</th>
<th>Course Element</th>
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<tbody>
<tr>
<td>15%</td>
<td>Lab #1 and Lab #2</td>
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<tr>
<td>20-25%</td>
<td>Lab #3</td>
</tr>
<tr>
<td>20-25%</td>
<td>Lab #4</td>
</tr>
<tr>
<td>28-38%</td>
<td>Final Project (including PDR)</td>
</tr>
<tr>
<td>0-10%</td>
<td>Quizzes/Assignments, Lab Practical, Student Current Topics Presentations</td>
</tr>
<tr>
<td>7%</td>
<td>Class Participation, Attitude, Teamwork, Effort/Subjective</td>
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The normal CU grading standards as shown below will be applied to this class. See the following site for more information: [http://ecee.colorado.edu/~mcclure/grading.html](http://ecee.colorado.edu/~mcclure/grading.html)

A  Superior, outstanding
A-    
B+   Above average
B-   
C+   Average, has adequately met course requirements
C-   
D+   Below average
D-   Minimum passing grade
F   Fail, has not met course requirements

References
The course will be taught using technical application notes, data sheets, and technical articles. For those students who desire additional references, a list is provided below. In addition, a tremendous amount of useful information can be found on the Internet. Documentation and links to useful web sites will be available on the course web site. A copy of the following books will be on reserve for the class in the Engineering Library on the CU-Boulder campus.