EE445M Embedded and Real-Time Systems Lab, Spring 2016
EE380L.6 Real-time Operating Systems, Spring 2016

Credit for both EE445M and EE380L.6 will not be allowed. Graduate students should register for EE380L.6 and undergraduates should register for EE445M.

Class: UTC 1.146, Tuesday/Thursday 5:00-6:30pm
Unique Numbers (445M/380L), Lab ECJ 1.318A:
16355/16670 MW 10:30-12:00PM
16360/16685 TTh 2:00-3:30PM
16365/16675 TTh 3:30-5:00PM
16370/16680 MW 6:30-8:00PM
16375/16690 TTh 6:30-8:00PM

Instructor:
Andreas Gerstlauer, POB 6.118, (512) 232-8294, gerstl@ece.utexas.edu
http://www.ece.utexas.edu/~gerstl
Office hours (tentative): Monday 3:30-5:00pm, Wednesday 2:00-3:30pm

TAs:
Kishore Punniyamurthy, kishore.punniyamurthy@gmail.com
Zichong Li, zichongli2552@utexas.edu
Kevin George, kevingeorgetm@utexas.edu
Office hours: see **Weekly Class Schedule**

Mailing list (all TAs and professor): s16_ee445m@utlists.utexas.edu

Class web page (lecture notes and lab assignments):
http://www.ece.utexas.edu/~gerstl/ee44m_s16/
Data sheets: http://www.ece.utexas.edu/~valvano/Datasheets/
Starter files: http://www.ece.utexas.edu/~valvano/arm/
Old Exams: http://www.ece.utexas.edu/~valvano/EE345Moldquiz/

Course Catalog Description:
Embedded microcomputer systems; implementation of multitasking, synchronization, protection, and paging; operating systems for embedded microcomputers; design, optimization, evaluation, and simulation of digital and analog interfaces; real-time microcomputer software; and applications, including data acquisition and robotics.

Prerequisites:
EE445L or EE445S, and EE333T with a grade of at least C-. This class is the third in a sequence of three microcontroller laboratories. We expect you to have experiences with assembly language, serial ports (UART and SPI), periodic interrupts, ADCs, edge-triggered interrupts, FIFO queues and C programming. We will be using the same ARM Cortex-M used (since Fall 2013) in EE319K and EE445L, but we do not require prior experiences with the same microcontroller. You are also expected to understand how a DFT is used to observe digitally sampled data in the frequency domain.

Text: Embedded Systems: Real-Time Operating Systems for ARM Cortex-M Microcontrollers, Volume 3, third edition, September 2014, ISBN 978-1466468863, by Jonathan Valvano. Available on Amazon. Available on CreateSpace.

Additional reference materials:

- uC/OS-III: The Real-time Kernel for Texas Instruments Stellaris, by Jean J. Labrosse. This is a nice book (available in electronic format or from Amazon). It covers general OS topics, explains the use of uC/OS-III (a minimal but complete RTOS), and includes details of the ARM Cortex-M3 specifically on a Texas Instrument Stellaris LM3S board (not our board, but similar). There is also a second edition uC/OS-II that covers an earlier, simpler and generic OS not tied to a specific board (available on Amazon). The 3rd edition is nicely written, but specific to uC/OS-III and the given board.
- For programming in C, see the EE312 text, or the Embedded Software in C online reference by Jon Valvano and Ramesh Yerraballi.
- EE445L textbook: Embedded Systems: Real-Time Interfacing to ARM Cortex M Microcontrollers, Volume 2, fourth edition, 2014, ISBN: 978-1463590154.
- Data sheets for most of the devices used in this class are available at http://www.ece.utexas.edu/~valvano/Datasheets

Development board:
We will use the TI EK-TM4C123GXL LaunchPad plus graphics display. Each group of students must buy/borrow one kit. However, I strongly suggest each student purchase their own kit. We have been using the TM4C123 board in EE319K since Fall 2013, so you might be able to find one used. If you do purchase a used board, ask a TA or me to run the board tester to make sure it works. If it still works at the end of the semester, you will be able to sell this board to students in the Fall 2016 classes. Otherwise, the easiest way to purchase the LaunchPad is from the TI.com E-store or any of the buying options listed on Octopart.com.

Other equipment and parts:

1. Since the LaunchPad does not have a display you will need to purchase a Sitronix ST7735R 18-bit color 1.8" TFT LCD display, http://www.adafruit.com/products/358
2. We will provide all other components and parts to assemble your final robot, including the mechanical platform as well as PCBs for a sensor and motor board into which you will plug your LaunchPads and display. You will, however, be allowed to upgrade your robot with additional sensors, circuitry and parts (except motors and battery, and within a limited budget).
3. You will need own your own digital multimeter to build and debug your robot. You must be able to measure voltage and resistance, so a meter costing around $20 will suffice.
4. Places to buy parts in Austin:
    - AlTex Electronics
    - Frys Electronics
    - Radio Shack
5. Full service online sales:
    - Digikey, http://www.digikey.com/
    - Mouser Electronics, http://www.mouser.com/
    - Newark, http://www.newark.com/
    - Sparkfun, http://www.sparkfun.com/
    - Jameco, http://www.jameco.com/
    - Arrow, http://parts.arrow.com/

6. Surplus sales:
    - BG Micro, http://www.bgmicro.com/
    - All Electronics, http://www.allelectronics.com/

Software:
We will use the 32k limited version of Keil uVision, Version 4.74, available for download at https://www.keil.com/demo/eval/armv4.htm. Information about the compiler/debugger system is at http://www.keil.com/uvision/. A large number of software examples for the board will be available by installing Prof. Valvano's starter files. To complete the labs, it will take time outside of the 3 scheduled lab hours. It will be important for you to configure a development system on your laptop (Keil version 4.74 and PuTTy). This way you will be mobile and flexible about where and when you work on lab.

Course Outcomes
The purpose of EE445M/EE380L.6 is to provide students an in depth understanding of real-time operating systems, real-time debugging, and embedded systems. After the successful conclusion of EE445M/EE380L.6, students should be able to design real-time embedded systems, such as motor controllers, data store systems, data acquisition systems, communication systems and robotic systems.

Specific Objectives of EE445M/EE380L.6
The primary objective of EE445M/EE380L.6 is for students to develop the ability to design real-time systems. This class allows students to combine principles of microcomputer interfacing, software development, digital logic and analog circuits into the design of microcomputer-based systems:

1. *ARM architecture, and C programming*
   Minimally intrusive debugging
   Performance measures
2. *Synchronization methods*
   Busy-wait, interrupt, DMA, periodic polling, priority interrupts
3. *Embedded Communication Systems*
   Serial network protocols, layered software, CAN, Ethernet, and USB
4. *Real time operating systems*
   Foreground and background thread scheduling
   Synchronization using spinlock and blocking semaphores
   Interthread communication
5. *Digital Device Interfaces*
   SD drive interface using SPI, file systems
   Diodes, transistors, DC motors, servos, stepper motors, relays, solenoids,
   Optical sensors, IR distance sensors and contact switch sensors
6. *Time Domain Interfaces*
   Input capture/output compare, frequency, period and pulse width measurements,
   Pulse-width modulation
7. *Data Acquisition Systems*
   Op amp amplifiers, analog low pass filters, ADC, FIFO queues, digital filters
8. *Control systems*
   Open loop and closed loop, Linear and Nonlinear,
   Bang-bang control, incremental control, PID Control

Teaching philosophy
I strongly encourage students to take an active role in class. There will be a copious amount of action in this class: debugging, soldering, screwing, cutting, and testing. Questions are welcome before, during and after class. Please feel free to email, visit or call me if you have questions.

Grading

50% Laboratory
25% Midterm, Thursday**,** March 24, 2016, 5:00-6:30pm, UTC 1.146
25% Final, Thursday, May 12, 2016, 7:00-10:00pm, regularly scheduled

Please notice the dates for the exams; there will be no re-tests, make-ups, or incompletes.

Attendance: Class attendance will be used for deciding grades in borderline cases. Students are expected to attend all lectures. Fundamental material will be presented in class, and the details can be found in the book, the data sheets and the library files provided by the manufacturer. Some lecture material will be posted on the web, while other material will only be presented in class. If you decide that you do not want to come to every lecture, please drop this class.

EE380L.6 Grading:

80% Regular EE445M grade
20% Project

EE380L.6 Project: Graduate students will attend the lectures, take the exams, and perform the labs. In addition to all the regular EE445M assignments, they will perform an extra lab project involving the design, implementation and testing of an embedded system with a real-time operating system. The complexity of this project should be equivalent to one of the regular labs. The project should be approved in advance by the instructor (come see me to discuss project ideas or if you want to brainstorm potential projects). A 1/2 page written proposal concerning the project is due by the end of February. The project must be demonstrated to the instructor or a TA, and a project report is due to the instructor the first Monday after classes are over. You are free to choose a project in your field of interest. It must include an embedded system and a real-time operating system of your design. You must write microcomputer software and/or build microcomputer hardware. It must actually be built and tested. The report will be typed double spaced. The minimum page count is 15 and the maximum page count is 20 (including hardware diagrams, but not software listings.) The grading policy for the report has four parts:

25% English style, grammar, spelling, clarity of discussion, logical organization
25% Neatness and presentation, figures, diagrams, graphs
25% Engineering quality, originality, creativity, correctness
25% Evaluation and test procedures, how do you verify its correctness.

Lab Partners: All labs up to and including Lab 5 should be performed with a partner (teams of 2). Labs 6 and 7 will be performed in teams of 3 to 5 students. The lab partnerships must be registered with your TA (a simple hand written note signed by students will suffice) at least a week before the assignment is due. Once registered, the partnership will continue. A partnership can be dissolved only after discussion with the TA. All partners must be present during the demonstration. It is expected that both partners will contribute to all aspects of each lab, and all partners are expected to be present during the check out. The point values are the same for all labs. The TA will sign your software listing when you demonstrate your system. All parts of the assignment must be demonstrated to a TA by the end of your lab period the week the "Demo/Report" is due. Any EE345M/EE380L TA is authorized to checkout your lab. The report (hardware, software, data and plots) are due one day after the demonstration is due. Please consult with your TA for specific due dates for your lab section.

EE445M/EE380L Laboratories

1. Real-time clock, Sitronix ST7735R Display, ADC and graphics drivers on the TM4C123 board running on an ARM Cortex-M4 (review of EE445L)
2. Real-time operating system kernel (thread switching and synchronization)
   Part 1) is cooperative and preemptive schedule
   Part 2) has periodic and switch interrupts, and spin-lock semaphores
3. Blocking semaphores, priority scheduling, performance measures, dumping RTOS profile data to the PC
4. Solid state disk, SSI, address translation, layered software, file system
5. Memory management, process loader, process creation and linking
6. Robot interfaces, distributed data acquisition using a CAN network of IR distance sensor, Ping))) distance, motor PWM (teams of 3, 4 or 5)
7. Formula 0001 Racing Robot (teams of 3, 4 or 5)
   A. Moving and turning, basic control algorithm
   B. Autonomous operation, system performance analysis (pre-qualification)
   C. Race competition (qualifying & finals)

Lab Schedule (tentative)

Week	1st session	2nd session	Friday 5pm	Comments
1/18	-	-		*No lab activities*
1/25	Meet the TA	Select partners		Sensor board soldering, Keil demo
2/1	Lab 1 Prep			Spectrum analyzer demo
2/8	Lab 1 Demo	Lab 2.1 Prep	Lab 1 Report	
2/15	Lab 2.1 Demo	Lab 2.2 Prep		Lab 2.1 has no report
2/22		Lab 2.2 Demo	Lab 2.2 Report	
2/29	Lab 3 Prep			
3/7	Lab 3 Demo		Lab 3 Report	Hard deadline on Lab 3.
3/14	*Spring Break*			If Lab 3 is not demonstrated, revert and complete rest with Lab 2 OS.
3/21	Lab 4 Prep			**Midterm is 3/24**
3/28	Lab 4 Demo	Lab 5 Prep	Lab 4 Report	
4/4	Lab 5 Demo	Lab 6 Prep	Lab 5 Report	
4/11	Lab 6 Demo	Lab 7.A Prep	Lab 6 Report	
4/28		Lab 7.A Demo		
4/25		Lab 7.B Demo		
5/2		Lab 7.C Demo	Lab 7.C Report	Turn in equipment by 5/6

Prep = you turn in your lab preparation
Demo = you demonstrate your lab to the TA
Report = you turn in your complete lab report (online)

No lab activities occur during the week of January 18. During the week of January 25-28, please go to your scheduled lab sessions in ECJ 1.318A to get a demonstration of the lab equipment. Lab partners will be selected in your lab the week of January 25-28.

The lab preparations (syntax error-free software source code and documentation) are due at the beginning of your lab period. In other words, please type your software into the PC before the lab. Attendance in lab is required. All software for lab, and tests must include comments. Students are encouraged to go to the last 1 hour of the other lab periods, but the first priority will be to the regular students. During the first 15 minutes of lab, the TA will collect preparations. For the next 15 minutes, the TA will lead a lab discussion session. The remaining lab time is available for debugging and lab checkout.

At the end of the semester, please verify with the checkout counter that your record is clear and you have returned all equipment or a bar will be put on your registration for next semester. All reports must be given to the TA by Friday May 6, 5pm in order to be considered for grading.

Lecture Schedule (tentative)

Week	**Book**	**Topic**
1 (1/18)	1.1-1.6, 2.3-2.9, 2.12	Course introduction, ARM architecture, instruction set, stack, uVision4 compiler, quality software, device drivers, GPIO, timer, UART, ADC, interrupts
2 (1/25)	2.1, 3.1, 3.7	Modular programming, call & data flow graphs, flowcharts, I/O synchronization, debugging techniques, lab environment, intrusiveness, monitor, output to scope, simulator
3 (2/1)	3.3, 4.1-4.2	Threads, interrupt servicing, operating modes, context switching, RTOS, TCB, cooperative multitasking, round-robin scheduler
4 (2/8)	3.4-3.7	Thread communication & synchronization, critical sections, FIFO, mailbox, debugging, testing, performance measures (response time, jitter, throughput)
5 (2/15)	4.3-4.5, 4.7.2	Spinlock and blocking semaphores, monitors, deadlocks, path expressions
6 (2/22)	4.1, 4.6	Real-time scheduling, priority scheduler, scheduling anomalies, fixed-rate scheduler, process networks
7 (2/29)	2.10, 6.1-6.4, 6.6	SD and flash disc interface using SSI, high-speed interfacing, DMA
8 (3/7)	7, 3.2	File system Memory management, heap, virtual memory
3/14		*Spring Break*
9 (3/21)	**1-4**	Review, **Midterm, Thursday, 3/24**, in class, covering material in Labs 1-3
10 (3/28)	5, 8	Sensor interfacing, input capture, period measurements, signal processing, Motor interfacing, transistor interfaces, pulse width modulation (PWM)
11 (4/4)	9	Microcontroller networking, Controller area network (CAN), Ethernet Internet, protocol stacks, ISO/OSI model, TCP/IP
12 (4/11)	10, 8.6	Robots, team work, testing & debugging, design process, Control systems, PID control systems, fuzzy logic and control, odometry

13 (4/18)	4.8	Commercial RTOS, uC/OS, VxWorks. Team work, testing and the design process
14 (4/25)		Course review and course evaluations
15 (5/2)		**Robot competitions (preliminary and final), room TBD.** All lab reports are due Friday 5pm. Turn in lab equipment by Friday so we won't bar your registration.
Finals (5/9)	**1-10**	**Final exam**, **Thursday, 5/12, 7-10pm**, room TBD (regularly scheduled)

Legal Notes:
The 12th class day is February 3. The drop policy is extremely complicated. See your academic advisor or the Dean of Students for more information. Course evaluation is conducted on the last class day in accordance with the Measurement and Evaluation Center form. The final exam is at the time and place stated in the course schedule. April 4 is the last day an undergraduate student may, with the Dean’s approval, withdraw from the University or drop a class except for urgent and substantiated, nonacademic reasons.

Students with disabilities: The University of Texas at Austin provides upon request appropriate academic adjustments for qualified students with disabilities. Students with disabilities may request appropriate academic accommodations from the Division of Diversity and Community Engagement. For more information, contact Services for Students with Disabilities, 471-6259, http://www.utexas.edu/diversity/ddce/ssd/.

Religious Holy Days: By UT Austin policy, you must notify the instructor of your pending absence at least fourteen days prior to the date of observance of a religious holy day. If you must miss a class, an examination, a work assignment, or a project in order to observe a religious holy day, we will give you an opportunity to complete the missed work within a reasonable time after the absence.

Electronic mail notification policy: In this course, e-mail will be used as a means of communication with students. You will be responsible for checking your e-mail regularly for class work and announcements. The complete text of the University electronic mail notification policy and instructions for updating your e-mail address are available at http://www.utexas.edu/its/policies/emailnotify.html.

Use of Canvas and class web site: This course uses the class web page and Canvas to distribute course materials, to communicate and collaborate online, to submit assignments and to post solutions and grades. You will be responsible for checking the class web page and the Canvas course site regularly for class work and announcements. As with all computer systems, there are occasional scheduled downtimes as well as unanticipated disruptions. Notification of disruptions will be posted on the Canvas login page. Scheduled downtimes are not an excuse for late work. However, if there is an unscheduled downtime for a significant period of time, we will make an adjustment if it occurs close to the due date.

Classroom Evacuation and Emergency Preparedness: All occupants of university buildings are required to evacuate a building when a fire alarm and/or an official announcement is made indicating a potentially dangerous situation within the building. Familiarize yourself with all exit doors of each classroom and building you may occupy. Remember that the nearest exit door may not be the one you used when entering the building. If you require assistance in evacuation, inform your instructor in writing during the first week of class. For evacuation in your classroom or building:

1. Follow the instructions of faculty and teaching staff.
2. Exit in an orderly fashion and assemble outside.
3. Do not re-enter a building unless given instructions by emergency personnel.

Emergency evacuation route information and emergency procedures can be found at http://www.utexas.edu/emergency and http://www.utexas.edu/safety/preparedness/.

Scholastic Dishonesty

"Faculty in the ECE Department are committed to detecting and responding to all instances of scholastic dishonesty and will pursue cases of scholastic dishonesty in accordance with university policy. Scholastic dishonesty, in all its forms, is a blight on our entire academic community. All parties in our community -- faculty, staff, and students -- are responsible for creating an environment that educates outstanding engineers, and this goal entails excellence in technical skills, self-giving citizenry, an ethical integrity. Industry wants engineers who are competent and fully trustworthy, and both qualities must be developed day by day throughout an entire lifetime. Scholastic dishonesty includes, but is not limited to, cheating, plagiarism, collusion, falsifying academic records, or any act designed to give an unfair academic advantage to the student. The fact that you are in this class as an engineering student is testament to your abilities. Penalties for scholastic dishonesty are severe and can include, but are not limited to, a written reprimand, a zero on the assignment/exam, re-taking the exam in question, an F in the course, or expulsion from the University. Don't jeopardize your career by an act of scholastic dishonesty. Details about academic integrity and what constitutes scholastic dishonesty can be found at the website for the UT Dean of Students Office and the General Information Catalog, Section 11-802."

You are encouraged to study together and to discuss information and concepts with other students. You can give "consulting" help to or receive "consulting" help from such students in oral form. However, this permissible cooperation should never involve one student having possession of a copy of all or part of work done by someone else, in the form of an email, an email attachment file, a portable storage device, or a hard copy. Copying of any part of a program is cheating without explicit reference to its source. We do enter lab assignments turned in by other students through a plagiarism checker, comparing them to assignments of this and previous semesters. If we find two programs that are copied, there will be a substantial penalty to both students, e.g., failure in the course. Students who cheat on tests or in lab will fail. Prosecution of cases is very traumatic to both the student and instructor. It is appropriate to use software out of the book, class website as long as all copy-pasted software is explicitly referenced. Copy-pasting software from current or past students is scholastic dishonesty. Policies concerning the use of other people's software in this class:

- I strongly encourage you to study existing software.
- All applications and libraries must be legally obtained. E.g.,
  - You may use libraries that came when you bought a compiler.
  - You may use software obtained from the web.
  - You may copy and paste from the existing source code.
- You may use any existing source code that is clearly referenced and categorized:

  original: completely written by you,
  derived: fundamental approach is copied but it is your implementation,
  modified: source code significantly edited to serve your purpose,
  copied: source code includes minor modifications.

University Honor Code: "The core values of the University of Texas at Austin are learning, discovery, freedom, leadership, individual opportunity, and responsibility. Each member of the University is expected to uphold these values through integrity, honesty, trust, fairness, and respect toward peers and community." http://registrar.utexas.edu/catalogs/gi09-10/ch01/