Faculty of Engineering and Architectural Science
Department of Electrical and Computer Engineering

Course Outline

ELE604: Sensors and Measurement

Prerequisites
ELE 504 and COE 538

Course Type
Elective

Program Level
ELE 06 (6th Semester)

Website
www.ee.ryerson.ca/~jasmith/courses/ele604

Compulsory Texts
- Custom Course pack (available at the Bookstore), which contains material from:
  - “Digital Signal Processing and the Microcontroller” by Dale Grover and John Deller
  - “Measurement and Data Analysis for Engineering and Science” by Patrick Dunn
  - “Principles of Measurement Systems” by John Bentley.

Reference Texts
- 1. “Measurement and Data Analysis for Engineering and Science” by Patrick Dunn, CRC Press *(two chapters included in the course pack)*
- “Digital Signal Processing and the Microcontroller” by Dale Grover and John Deller. *(one chapter included in the course pack)*
- “Software and Hardware Engineering: Freescale HCS12”, 2nd Edition by Fred Cady
- “HCS12 Microcontroller and Embedded Systems: Using Assembly and C with CodeWarrior” by Muhammad Ali Mazadi and Danny Causey

Calendar Description
The course will cover the theory and principles of sensors and transducers (electrical, chemical and mechanical). The topics covered include transduction techniques, linear/non-linear signal processing, low noise amplifiers, instrumentation amplifiers, data converters. There will be small design projects for the labs to reinforce sensor/transducer interfacing.

Learning Objectives
At the end of this course, the successful student will be able to:

1. Produce a variety of documents using appropriate format, grammar, and citation styles for technical and non-technical audiences; Cite evidence to construct and support an argument *(7a)*
   a. **Assessment Method:** Directly assessed in scores of lab reports.
   b. **Assessment Measure:** Students are given a checklist and rubric (marking guide) ahead of time. The rubric is used to mark them. Example rubric items: Does the student cite relevant peer-reviewed literature using IEEE citation guidelines? Do grammar and spelling permit easy reading at an appropriate level? Is the document free from plagiarism?

2. Use technical knowledge, design methodology, and appropriate design tools and related resources *(4a)*; Distinguish between different design steps and carries out steps;
Analyze/evaluate progress of design. (4c)
   a. **Assessment Method**: Directly assessed in scores as a component in lab projects
   b. **Assessment Measure**: Students are given a checklist and rubric (marking guide) ahead of time.

3. Develop further knowledge of uses of modern instrumentation, data collection techniques, and equipment to conduct experiments and obtain valid data (5a)
   a. **Assessment Method**: Directly assessed in scores as a component of quizzes and examinations and in lab projects
   b. **Assessment Measure**: Relevant questions are posed on the quizzes and final exam. In laboratory reports students are given a checklist and rubric (marking guide) ahead of time.

4. Apply statistical procedures; Verify and validate experimental results; Assess accuracy/precision of results (5b)
   a. **Assessment Method**: Directly assessed in scores as a component of quizzes and examinations and in lab projects
   b. **Assessment Measure**: Relevant questions are posed on the quizzes and final exam. In laboratory reports students are given a checklist and rubric (marking guide) ahead of time.

5. List current tools for analysis, simulation, visualization, synthesis, and design, and is competent in using them; Understand the accuracy/limitations of tools and verifies the results’ credibility (5c).
   a. **Assessment Method**: Directly assessed in scores as a component in lab projects
   b. **Assessment Measure**: Students are given a checklist and rubric (marking guide) ahead of time.

*Note: Numbers in parentheses (e.g. 16a) refer to the graduate attributes required by the Canadian Engineering Accreditation Board. For more information, see: http://www.feas.ryerson.ca/quality Assurance/accreditation.pdf*

**Course Organization**
- 3 hours of lecture per week for 13 weeks, in 1 section
- 2 hours of lab/tutorial every week for 13 weeks
- Lab/tutorial sections of maximum 25 students
- 2 Teaching Assistants, three section for one TA, two sections for the other.

**Course Evaluation**

<table>
<thead>
<tr>
<th>Assignment</th>
<th>Percentage of Final Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assignments</td>
<td>0% of final grade</td>
</tr>
<tr>
<td>3 Scheduled Quizzes</td>
<td>30% of final grade</td>
</tr>
<tr>
<td>Unscheduled “Pop” Quizzes</td>
<td>10% of final grade</td>
</tr>
<tr>
<td>Midterm Exam</td>
<td>n/a</td>
</tr>
<tr>
<td>Final Exam</td>
<td>30% of final grade</td>
</tr>
<tr>
<td>Laboratory</td>
<td>30% of final grade</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
</tr>
</tbody>
</table>

(a) **Assignments**: Assignments will not be graded. Solutions will be supplied for reference.

(b) **Quizzes**: Each scheduled quiz is worth 10% of the student’s final grade. The quiz will be held during regular class hours. Up to ten unscheduled “pop” quizzes will be held throughout the semester. The cumulative weight of the
unscheduled pop quizzes is 10% of the final grade. All quizzes can be based on material from the text, the lecture sessions, and/or the laboratory. A grade of zero for the particular quiz, whether scheduled or unscheduled, will be assigned for absence during the quiz in question. Following university policy, no make-ups will be held for missed quizzes.

(c) **Midterm Exam**: No midterm exam will be held. The grade weighting normally associated with a midterm is taken by two of the three scheduled quizzes.

(d) **Final Exam**: A single final exam will be held.

(e) **Laboratory**: The hands-on laboratory sessions, conducted over the course of the semester, using supplied laboratory kits and testing rigs.

Students are required to pass both (1) the theory and (2) the laboratory components of the course in order to obtain a passing grade for the course. The theory component is assessed via the quizzes and final exam (Quizzes and Final Exam: 70% of final grade), while the laboratory component is assessed on project development and reporting (Laboratory: 30% of final grade).

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**Examinations**

(a) **Scheduled Quizzes**: Three scheduled quizzes will be held over the course of the semester. See “Course Evaluation” section for more details.

(b) **Unscheduled “Pop” Quizzes**: Up to ten unscheduled “pop” quizzes will be held over the course of the semester. See “Course Evaluation” section for more details.

(c) **Midterm Exam**: No midterm exam will be held.

(d) **Final Exam**: A single final exam will be held.

One 8.5” x 11” sheet of paper is permitted in scheduled quizzes, but not pop quizzes. Two 8.5” x 11” sheets of paper are permitted during the final exam. Writing is permitted on anywhere on the paper, on either side. No other reference material will be permitted.

Scheduled quizzes and the final exam will have extra questions, permitting the student to select the questions that he/she wishes to answer. Unscheduled pop quizzes will contain one to three questions, all of which must be answered for full marks.
# Course Content

<table>
<thead>
<tr>
<th>Topic</th>
<th>Chapter &amp; Sections</th>
<th>Hours</th>
<th>Topic, description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>n/a</td>
<td>1</td>
<td>- Introduction to ELE 604 (1 hour)</td>
</tr>
<tr>
<td>Structure of Measurement Systems</td>
<td>Ch. 1 Dunn, Ch. 3 Dunn (partial)</td>
<td>2</td>
<td>- What are measurements, sensors &amp; experiments? What are the structures of Measurement Systems? What are Accuracy and Precision? Stats. Review (2 hours)</td>
</tr>
<tr>
<td>Displays &amp; Static Characteristics</td>
<td>Ch. 11 &amp; 2 (Bentley)</td>
<td>3</td>
<td>- Displays; Matlab (1 hour) - Range, Nonlinearity, Sensitivity, Hysteresis, Resolution, Error Band, Repeatability, Tolerance, Calibration, Units (1 hour) - Accuracy of Measurement Systems in Steady State (1 hour)</td>
</tr>
<tr>
<td>Dynamic Characteristics</td>
<td>Ch. 3 &amp; 18 (Bentley)</td>
<td>3</td>
<td>- DAQs &amp; Serial Communication (1 hour) - Dynamic Errors in Measurement Systems, Dynamic compensation (1 hour) - Sensor “Showcase”: Strain Gauge Sensors (1 hour)</td>
</tr>
<tr>
<td>Loading &amp; 2-port Systems</td>
<td>Ch. 5 (Bentley)</td>
<td>3</td>
<td>- Modeling -&gt; 2-port; Thev., Norton, Electromech, Thermo. (optional: Pneumatic &amp; Hydraulic) (1 hour) - Loading (1 hour) - Sensor “Showcase”: Accelerometers (1 hour)</td>
</tr>
<tr>
<td>Signals &amp; Noise</td>
<td>Ch. 6 (Bentley) &amp; Ch. 9 (Grover)</td>
<td>3</td>
<td>- Autocorrelation, cross-correlation, power spectral density (1 hour) - Noise, coupling mechanisms, noise reduction methods (2 hours)</td>
</tr>
<tr>
<td>Sensing Elements</td>
<td>Ch. 8 (Bentley)</td>
<td>4</td>
<td>- Electrochemical Sensing Elements (1 hour) - Resistive sensing elements, capacitive sensing elements, inductive sensing elements (2 hours) - Electromagnetics, Hall Effect sensors, (1 hour)</td>
</tr>
<tr>
<td>Signal Conditioning</td>
<td>Ch. 9 (Bentley)</td>
<td>6</td>
<td>- Wheatstone (Deflection) bridges (2 hours) - Amplifiers (2 hours) - AC Carrier systems &amp; oscillators (2 hours)</td>
</tr>
<tr>
<td>Signal Processing</td>
<td>Ch. 10 (Bentley)</td>
<td>5</td>
<td>- Analogue to Digital Conversion (3 hours) - Digital to Analogue Conversion (2 hours)</td>
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<tr>
<td>Applications</td>
<td>n/a</td>
<td>3</td>
<td>- Sensor “Showcase”: Ultrasonics (1 hour) - Navigation &amp; odometry (2 hours)</td>
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Laboratory

Labs are an integral part of the course experience. Lab material will be discussed during class time and related to lecture material. Expect to see lab-related material in classroom quizzes and on the final exam.

Labs begin in the second week of class. Lab work is team-based (groups of two). You are expected to find a partner and to purchase, as a group, the lab kit before the second week. Reminder: for the first lab, also bring your oscilloscope probe that you purchased for an earlier ELE class. Review the lab writeup related to the lab prior to attending the lab.

Three sections are scheduled this semester:
- Section 1: Wednesdays, 6 pm – 8pm in ENG307
- Section 2: Fridays, 10 am – 12 am in ENG307
- Section 3: Tuesdays, 10 am – 12 noon in ENG 307
- Section 4: Tuesdays 8am – 10am in ENG 307
- Section 5: Mondays, 6 pm – 8pm in ENG 307.

Reports are expected to include a standard (and signed) FEAS cover sheet. The reports are expected to adhere to IEEE format, including referencing. Refer to the marking and style guides for details on what is required in these reports.

Coding is to be done in C on Technological Arts 9s12c32 Arduino form factor boards, with an option of including inline assembler. Bonus marks are available in many of the labs. See specific lab material for details.

The following is the breakdown of the weight for individual components of the complete lab grade.
- Week 2 report 5%.
- Week 3 report 5%.
- Week 4 report 5%.
- Milestone 1 5%.
- Milestone 2 25%.
- Milestone 3 25%.
- Milestone 4 15%.
- Milestone 5 15%.

<table>
<thead>
<tr>
<th>Week</th>
<th>Title</th>
<th>Detail</th>
<th>Time</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Heartbeats and Time-Keeping</td>
<td>When starting to use a new microcontroller there are two keys things that you need to set up: a “heartbeat” light and an accurate clock. An introduction to the lab will be done, including an overview of safety and equipment.</td>
<td>2 Hours</td>
<td>ENG 307</td>
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<tr>
<td>3</td>
<td>Displaying Data Part 1 – Serial to PC</td>
<td>You’ve got to display the data that’s processed in your Data Acquisition System. The PC is a good device for this because it’s powerful, especially when leveraged with software like Matlab.</td>
<td>2 Hours</td>
<td>ENG 307</td>
</tr>
<tr>
<td>4</td>
<td>Displaying Data Part 2 – Onboard LCD</td>
<td>You need to be able to display measurement data directly on your Esduino board when taking measurements. Here, you’ll build an add-on board with a Liquid Crystal Display</td>
<td>2 Hours</td>
<td>ENG 307</td>
</tr>
<tr>
<td>Milestone</td>
<td>Pre-lab</td>
<td>Lab</td>
<td>Hours</td>
<td>ENG 307</td>
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<td>Milestone 1: Switches and LEDs</td>
<td>In Week 2 you implemented code to flash an LED. This week you’ll design a hardware LED driver and learn how to avoid the biggest problem with switches: contact bounce! MapleSim will be used for design.</td>
<td>2 Hours</td>
<td>ENG 307</td>
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<tr>
<td>Milestone 2: Strain Gauge test</td>
<td>Pre-lab: Prepare Milestone 2 documentation. Lab: In Week 6, implement and test analog circuitry design for strain-gage, and then interface to microcontroller. Implement S/W to provide FORCE function per specifications. Undertake the measurements to characterize the strain-gage sensor &amp; circuitry. Continue to work on integrating FORCE &amp; ANGLE functions per specifications. In Week 8, demonstrate FORCE measurement functions as per specifications &amp; provide your measurement data &amp; analysis on Accuracy, Repeatability, etc of the sensor. Submit Milestone 2: test results, algorithms and source-code listing.</td>
<td>4 Hours</td>
<td>ENG 307</td>
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<tr>
<td>Milestone 3: Accelerometer Angle Sensing</td>
<td>Pre-lab: Prepare Milestone 3 documentation. Lab: In Weeks 9 and 10, Analysis, design and implementation of accelerometer H/W &amp; S/W to display Angle as per specifications. Obtain test results. Analysis, design and simulations of strain-gage circuitry. In Week 11, oral &amp; demo to Lab Instr. during scheduled lab session:- Demonstrate ANGLE measurement function as per specification. Submit test results, algorithms and source-code listing. In Week 11, submit Milestone 3: test results, algorithms and source-code listing in IEEE format, with IEEE-style references.</td>
<td>6 Hours</td>
<td>ENG 307</td>
<td></td>
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<tr>
<td>Milestone 4: Integration &amp; Demonstration</td>
<td>Pre-lab: Schedule presentation time with lab instructor. Lab: In week 12, Work on integrating the Angle and Force functions, per the specifications. Perform Milestone 4 in week 13: that is, in week 13, complete demonstration of all functions per specifications. Seamless deterministic/real-time execution of all functions, and any enhancements implemented. Final source-code version to be compiled/assembled during the demo. A printed copy to be submitted to Lab Instructor.</td>
<td>6 Hours</td>
<td>ENG 307</td>
<td></td>
</tr>
</tbody>
</table>
Post-lab: Hand in Milestone 5 (Final Report) by email to TA by last day of classes at 11:59pm (i.e. before final exams). Show final schematic, algorithms (including flow-chart) and test results. Only one formal report per group is required (following IEEE format for document and referencing). Reports will be graded as per the marking scheme.

Important Notes

1. All of the required course-specific written reports will be assessed not only on their technical/academic merit, but also on the communication skills exhibited through these reports.

2. All assignment and lab/tutorial reports must have the standard cover page which can be completed and printed from the Department website (link to be given at a later date). The cover page must be signed by the student(s) prior to submission of the work. Submissions without the cover pages will not be accepted.

3. Students who miss a final exam for a verifiable reason and who cannot be given a make-up exam prior to the submission of final course grades, must be given a grade of INC (as outlined in the Grading Promotion and Academic Standing Policy) and a make-up exam (normally within 2 weeks of the beginning of the next semester) that carries the same weight and measures the same knowledge, must be scheduled.

4. Medical or Compassionate documents for the missing of an exam must be submitted within 3 working days of the exam. Students are responsible for notifying the instructor that they will be missing an exam as soon as possible.

5. Requests for accommodation of specific religious or spiritual observance must be presented to the instructor no later than two weeks prior to the conflict in question (in the case of final examinations within two weeks of the release of the examination schedule). In extenuating circumstances this deadline may be extended. If the dates are not known well in advance because they are linked to other conditions, requests should be submitted as soon as possible in advance of the required observance. Given that timely requests will prevent difficulties with arranging constructive accommodations, students are strongly encouraged to notify the instructor of an observance accommodation issue within the first two weeks of classes.

6. The results of the first test or mid-term exam will be returned to students before the deadline to drop an undergraduate course in good Academic Standing.

7. Students are required to adhere to all relevant University policies including:

8. Students are required to obtain and maintain a Ryerson Matrix e-mail account for timely communications between the instructor and the students.
9. To facilitate discussion students will be provided with name cards. Students are expected to place their name cards in front of them, on their desks, during class. Students are responsible for bringing them to class.

10. Any changes in the course outline, test dates, marking or evaluation will be discussed in class prior to being implemented.

11. Assignments, projects and/or quizzes handed in past the due date and time will not be accepted for marking and will receive a mark of ZERO, unless otherwise stated in the marking guides.

12. Students found to have plagiarized any portion of their laboratory reports will receive a grade of zero.

Instructor ___________________________  Date ___________________________

Approved by ___________________________  Date ___________________________

Program Director /Chair

______________________________