Engineering
ECE 802: Introduction to Quantum Sensor and System Engineering
Spring 2022 Syllabus (Semester starts Jan. 10, 2022)

Part 1: Course Information

Instructor Information
Instructor: Prof. Timothy Grotjohn
Office: Engineering Research B113
Office Hours: Timothy Grotjohn, grotjohn@egr.msu.edu,
Zoom Office Hours: Monday 4-5 pm and Thursday 2-3 pm,
https://msu.zoom.us/j/7329335895

The course instructor will answer questions by email and on-line by zoom. Other times can be arranged by appointment.
Please send me an email if you want to ask questions by phone so that I can call you.
E-mail: grotjohn@egr.msu.edu In the subject line of the email put “ECE 802”. This helps me to avoid missing your email. My goal is to respond to email within 24 hours.

Course Description
Quantum information systems including quantum sensor, communication and computing are topics of contemporary interest for their potential to revolutionize the next generation of sensor, communication and computing systems. Quantum mechanics is the study of how microscopic systems dynamically behave in nature. Quantum information systems abstracts some of the quantum mechanics of the system and works with qubits. Qubits are analogous to bits (0 or 1) in digital systems with the difference that a qubit state is continuously valued but also impossible to measure the precise value. Important concepts from quantum mechanics used in quantum information systems are superposition and entanglement. In quantum information systems the typical operations are the qubit is initialized, operations on the qubit are performed and the state of the qubit is read out. The operations can be done so that computations are done, a physical property of the system is measured or information is communicated to a new location with encryption.

This course will provide an introduction to quantum sensors and systems with an engineering perspective. The operation of quantum sensor and systems will be presented from the quantum mechanics level to the more abstract quantum system level. The basic operation of important quantum physical systems will be covered including polarization of photons, superconductivity circuits, trapped ion systems, and two energy level systems in solids. The abstraction of this systems to qubits will be done. The understanding of qubits using linear algebra with complex numbers and operations as density matrices will abstract the physical systems to a mathematical description than describes qubit behavior in sensor, communication and computing systems. The operation and performance of quantum sensors will be studied.
**Prerequisite**
Graduate student standing in Engineering, Physics, Chemistry (or permission of instructor)

**Textbook & Course Materials**

Both textbooks are available electronically at the MSU library. I have made it easy for you to use the textbooks by downloading them to the course D2L website.

**Course Requirements**
- Internet connection (DSL, LAN, or cable connection desirable)
- Access to Desire2Learn (D2L).

**Course Structure**
This course will be delivered online through the course management system and you will need your MSU NetID to login to the course from the D2L homepage (http://d2l.msu.edu).

In D2L, you will access online lessons, course materials, and additional resources. The course will consist of the 29 units. The pace of the course will be two units per week. The course material will consist of pre-recorded lectures, class notes and textbook sections or papers to read. This is an internet course so it can be completed on your time schedule each week. You are expected to complete two units each week. Material will be posted and work will be done in the D2L learning environment.

**Technical Assistance**
If you need technical assistance at any time during the course or to report a problem you can:
- Visit the Distance Learning Services Support Site
- Visit the Desire2Learn Help Site (http://help.d2l.msu.edu/)
- Or call Distance Learning Services: (800) 500-1554 or (517) 355-2345

**Resource Persons with Disabilities (RCPD)**
- To make an appointment with a specialist, contact: (517) 353-9642
  Or TTY: (517) 355-1293
- Web site for RCPD: http://MYProfile.rcpd.msu.edu
Part 2: Course Objectives

The primary learning objectives for this course are:

- Be able to describe the concepts of qubits, superposition and entanglement.
- Describe and understand physical systems for qubits.
- Utilize linear algebra for the mathematical description of qubits and operations on qubits.
- Describe and understand the concepts of quantum gates and circuits.
- Describe and understand the initialization, transformation and read out of single and multiple qubit systems.
- Describe and understand quantum sensors and their detection limits.
- Survey applications of the state-of-the-art of quantum sensor systems.

You will meet the objectives listed above through a combination of the following activities in this course:

- Reading textbook sections and papers from the journal literature.
- Watching the recorded lectures and studying the associated lecture notes.
- Completing homework assignments on approximately a weekly basis.
- Preparing one project.
- Completing midterm and final exams.
Part 3: Course Outline/Schedule

Important Note: Refer to the course calendar for specific dates and times. Activity and assignment details will be explained in detail within each week's corresponding learning module. If you have any questions, please contact your instructor.

Part 1--- Weeks 1-3 Introduction using “Quantum Computing for Everyone” book
Week 1- Jan. 10
   Module: Introduction to Course
   Module: Intro to Linear Algebra, Spin and Qubits
Week 2- Jan. 17
   Module: Entanglement and Bell’s Inequality
   Module: Quantum Gates and Circuits
Week 3- Jan 24
   Module: Quantum Algorithms
   Module: Quantum Sensors

Week 4- Jan 31
   Module: Single-Qubit Quantum Systems 1
   Module: Single-Qubit Quantum Systems 2
Week 5- Feb. 7
   Module: Multiple-Qubit Systems 1
   Module: Multiple-Qubit Systems 2
Week 6- Feb 14
   Module: Measurement of Multiple-Qubit States 1
   Module: Measurement of Multiple-Qubit States 2
Week 7- Feb. 21
   Module: Quantum State Transformation 1
   Module: Quantum State Transformation 2
Week 8- Feb. 28
   Module: Realizing Quantum Transformation as Quantum Circuits
   Module: Example Quantum Circuits

MIDTERM

Part 3—Weeks 9-11 Physical Systems for Qubits
Week 9 Physical Systems for Qubits- March 14
   Module: Harmonic Oscillator
   Module: Superconducting Circuits
Week 10- March 21
   Module: Trapped Ions
   Module: Solid State Two level Systems

Week 11- March 28
Module: Examples of Sensing with Diamond Nitrogen Vacancy Sensors (Room Temperature operation)
Module: Examples of Sensing with Diamond Nitrogen Vacancy Sensors

Part 4—Weeks 12-14: Quantum Sensors (Paper: Quantum Sensing, Degan, Reinhard, Cappellaro and other assigned readings)

Week 12- April 4
Module: Quantum Sensors- Physical Systems
Module: Quantum Sensor Protocol

Week 13- April 11
Module: Sensitivity- noise
Module: Sensing with ac Signals

Week 14- April 18
Module: Ensemble Sensing with and without entanglement
Module: Advanced quantum sensor systems

Week 15- April 25
Module: Outlook and status of quantum sensors and information systems
Student Project Due

Final Exam- Final Exam week (Open book, student picks the time)
Part 4: Grading Policy

Graded Course Activities

The table below describes the graded course activities including points and activity description. The first column includes the points possible, and the second column includes a description for each activity.

<table>
<thead>
<tr>
<th>Points</th>
<th>Description</th>
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<tbody>
<tr>
<td>30%</td>
<td>Homework</td>
</tr>
<tr>
<td>20%</td>
<td>Project</td>
</tr>
<tr>
<td>20%</td>
<td>Midterm</td>
</tr>
<tr>
<td>30%</td>
<td>Final Exam</td>
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</tbody>
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Homework: The course will have homework questions associated with each of the weeks. One homework will be given out each week and will be due the following Tuesday. The questions need to be completed and submitted. Homework accounts for 30% of the course grade. Doing the homework is important for learning the course material, to pass the course you must turn in at least 80% of the homework assignments.

Course work will also include one project, one midterm exam and one final exam.

Final Exam: At the end of the course will be a final exam worth 30% of the grade. It will test the topics covered in the class homework.

Late Work Policy

Up to two assignments will be accepted late (up to 2 days late). After two late assignments a deduction will be taken for late assignments unless prior arrangements are make. The final exam needs to be completed on time.

Viewing Grades

Your graded assignments will be on D2L. My goal is grade assignments within a week of their turn-in date.
Part 5: Course Policies

Inform Your Instructor of Any Accommodations Needed

From the Resource Center for Persons with Disabilities (RCPD): Michigan State University is committed to providing equal opportunity for participation in all programs, services and activities. Requests for accommodations by persons with disabilities may be made by contacting the Resource Center for Persons with Disabilities at 517-884-RCPD or on the web at rcpd.msu.edu. Once your eligibility for an accommodation has been determined, you will be issued a Verified Individual Services Accommodation ("VISA") form. Please present this form to me at the start of the term and/or two weeks prior to the accommodation date (test, project, etc.). Requests received after this date may not be honored.

Understand When You May Drop This Course

Drops and Adds
Monday, January 14: last date to add a course for SS22
Friday, February 4: last date to drop a class with tuition refund
Wednesday, March 2: last date to drop a class with no grade reported. While not required, having some graded work returned by this date is extremely helpful. Dropping a course after this date is rare, and requires documentation of extenuating circumstances beyond control of the student.

Commercialized Lecture Notes
Commercialization of lecture notes and university-provided course materials is not permitted in this course.*

*Note: The Code of Teaching Responsibility requires instructors who permit students to commercialize their class lecture notes to include a statement in their course syllabi that gives such permission. Absent such permission, students may not do so.

Complete Assignments
Assignments for this course will be submitted electronically through D2L unless otherwise instructed. Assignments must be submitted by the given deadline or special permission must be requested from instructor before the due date.