

ECE 510 – Embedded Vision I**Fall 2016 - 4 Credits: Tue, Thu, 10:00AM – 11:40AM**

Class Information

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| Class: | Tue/Thu 10:00AM – 11:40AM | CRN = 14815 |
| Quarter: | Fall 2016 | |
| Location: | FAB 49 (was 40-09) | |
| Holidays: | Thanksgiving (Thursday, Nov. 24) | |
| Credits: | 4 | |
| Track(s): | Embedded Systems (core), Digital IC Design (depth/breadth) http://www.pdx.edu/ece/graduate-tracks | |
| Prerequisites | <p>Knowledge of C/C++ programming is required, since programming projects will be involved in most homework. Class and examples will be in C++. However, OpenCV routines can be called from C++, C, or Python, so any of those languages are acceptable for projects and homework.</p> <p><i>ECE 540 – System Design with Programmable Logic</i> (recommended) or consent of instructor. You must be familiar with Verilog HDL.</p> | |

Contact Information

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| T/A: | Harsh Momaya E-mail: harsh2@pdx.edu |
| Office hours: | Dan: Mon-Wed 5 :00-6 :30 PM, Tue-Thu 1 :30-3 :00, FAB 20-18 or by appointment (email to set time/place) |
| Course website: | https://d2l.pdx.edu/d2l/home/591680 |

Course Description

Embedded computing increasingly involves analyzing and interpreting sensor data from a wide variety of sources. One of the most important, difficult and compute intensive is dealing with the massive amounts of visual data obtained by ubiquitous, inexpensive image sensors. Applications include medical and health care, manufacturing, Internet of Things, security, robotics, infrastructure assessment, environmental sensing, and safe and autonomous vehicles.

This is the first course in a two course embedded vision sequence. The goal of the course sequence is to learn the basic tools and techniques required to implement Computer Vision on small, embedded, portable platforms. The course sequence will be based on OpenCV. The OpenCV library is multi-platform and Open Source. In this first course the primary focus will be on image processing, with a little less focus on machine learning and specialized embedded hardware. The course will cover only basic computer vision (recognizing and tracking objects and faces) and machine learning techniques, all with OpenCV. The last part of the course will involve porting a basic application to the BeagleBone Black SBC, with a connected video camera, to demonstrate real time image processing on a small platform.

The only pre-requisite for the course is to know either C++, C, or Python, any of which can be used to access OpenCV routines. However, all class examples will be given in C++. Since images are a kind of signal processing knowing digital signal processing techniques is helpful, but not required.

Second Course

The first course in the series will cover the basics of image processing with only rudimentary computer vision and machine learning. This second course will go into more depth in computer vision techniques and machine learning. This second course will also make more extensive use of the Beaglebone platform for real time vision processing. Hardware acceleration of vision applications will be studied and there will be some experiments in building specialized computational hardware based on FPGAs (the Digilent Nexys board). The primary focus of the second course will be a project implementing a reasonably sophisticated vision application with FPGA hardware acceleration.

Motivation

From the EE Times May 5, 2016:

- The consensus from the Embedded Vision Summit (May 2–4) in Santa Clara: We have the programming tools, trainable algorithms, growing data sets and powerful processors to build vision systems with deep learning intelligence. Point an intelligent camera at an unfamiliar object (or a picture of an unfamiliar object) and your vision system will tell you exactly what you're looking at.
- The worldwide CMOS image sensor revenue grew 12 percent in 2015 to \$9.9 billion and 2015 was fifth consecutive year of record-high annual sales, according to IC Insights. This growth is expected to continue for another five years ...
- IC Insights forecasts the market for CMOS image sensors growing each year through to 2020 and achieving a CAGR (Compound Annual Growth Rate) of 9.0 percent over the period 2015 to 2020. In the previous five-year period (2010-2015), CMOS image sensor sales increased by a CAGR of 17.0 percent ...

"Internet of Things (IoT): A Vision, Architectural Elements, and Future Directions," Jayavardhana Gubbi et al.:

- Video based IoT, which integrates image processing, computer vision and networking frameworks will help develop a new challenging scientific research area at the intersection of video, infrared, microphone and network technologies. Security, the most widely used camera network application, helps track targets, identify suspicious activities, detect abandoned luggage and monitor unauthorized

access. Automatic behavior analysis and event detection (as part of sophisticated video analytics) is in its infancy and breakthroughs are expected in the next decade.

Intel acquires Computer Vision expert Itseez, <http://opencv.org/intel-acquires-itseez.html>:

- As the Internet of Things evolves, we see three distinct phases emerging. The first is to make everyday objects smart ... The second is to connect the unconnected, with new devices connecting to the cloud and enabling new revenue ... The third is just emerging where devices will require constant connectivity and will need the intelligence to make real-time decisions based on their surroundings. This is the “autonomous era,” and machine learning and computer vision will become critical for all kinds of machines ...

Intel to acquire Movidius: Accelerating Computer Vision through RealSense for the Next Wave of Computing, <https://newsroom.intel.com/editorials/josh-walden-intel-editorial/>.

While much of the past growth is based on the adoption of low-cost CMOS image sensors in smartphones and digital cameras, that growth is now spreading as embedded digital imaging to automotive, drone technology, environmental, security and medical applications.

Instructor Background

Dan Hammerstrom is a Professor in the ECE department. He is just returning to PSU after 4 years as a Program Manager at DARPA in Washington DC. Dan received his PhD from the University of Illinois and was an Assistant Professor at Cornell before joining Intel in Oregon. In 1988 he founded Adaptive Solutions, which developed a special chip (CNAPS) for image processing, pattern recognition and neural network emulation. In 1998 he joined the Oregon Graduate Institute and in 2005 moved to Portland State, where he was Associate Dean for Research in the Maseeh College of Engineering and Computer Science. His interests include specialized architectures/hardware and algorithms for power efficient processing of sensor data in embedded environments. Dan is a Life Fellow of the IEEE.

Course Outcomes and Learning Goals, EmbV1

- An understanding of the OpenCV library, how to call and use it on an embedded platform
- Understand the basic data structures for still and video image representations
- Understand how to use basic Image Processing operations such as filtering and transforms
- Basic object recognition, features to contours to objects
- Motion detection and tracking
- Understand the fundamental principles of Machine Learning
- Be able to apply simple Machine Learning techniques to a simple Computer Vision application
- Be able to combine Image Processing and Machine Learning operations into Computer Vision applications such as face and object recognition
- Port a simple Computer Vision application and demonstrate real time operation on an SBC connected to a video camera
- Practice writing good technical documentation and well-structured and organized source code
- Practice writing and debugging embedded system applications and drivers
- Work as part of a team to build and debug an computer vision application

Who Should Take This Class?

You should take this course if:

- You want to learn the basics of image processing and machine learning
- You want to learn how to implement Computer Vision applications on embedded platforms
- You want to learn OpenCV
- You like project-oriented learning
- You want to learn/improve your C++, C, or Python programming
- You like to learn new tools and techniques.

You should not take this course if:

- You are looking for an easy class
- You cannot dedicate at least 10 hours/week (outside of the lectures) to this course
- You do not like to read lots of documentation
- You do not like the frustration of learning new, leading edge, tools
- You are unable and/or unwilling to attend this class regularly

Recommended Text

- *Learning OpenCV: Computer Vision with the OpenCV Library*, by Gary Bradski and Adrian Kaehler, Publisher: O'Reilly Media; 1st edition (October 4, 2008), ISBN-10: 0596516134, ISBN-13: 978-0596516130

There is a newer book, you can use it, it has most of the information in the first book and even more detail in some places. However, we are not using Version 3 of OpenCV and this book has remained incomplete for a while:

- *Learning OpenCV 3 - Computer Vision in C++ with the OpenCV Library*, By Adrian Kaehler, Gary Bradski, O'Reilly

The course will follow the basic outline in the first book. However, we will use the Version 2.4 C++ format for data types and function calls, consequently, for function format and reference you will need to go directly to the OpenCV 2.4 online documentation: <http://docs.opencv.org/2.4/index.html>.

Two useful and important web pages are:

- <http://opencv.org>
- <http://www.embedded-vision.com>

Other Readings – Relevant, But Not Required

These first two books are particularly good and I have found them to be a very nice complement to the Bradski and Kaehler book.

- *Learning Image Processing with OpenCV*, G.B. Garcia, et al., <http://shop.oreilly.com/product/9781783287659.do>
- *OpenCV 2 Computer Vision Application Programming Cookbook*, Laganiere, <https://www.packtpub.com/application-development/opencv-2-computer-vision-application-programming-cookbook>

The Szeliski book is the book that most graduate level computer vision courses use. It is loaded with useful information, but goes into significantly more depth and in more topics than we will have time for in the Embedded Vision sequence. It is also available for free download.

- *Computer Vision: Algorithms and Applications*, R. Szeliski, Springer, ISBN-13: 978-1848829343, <http://szeliski.org/Book>.

- *Exploring BeagleBone: Tools and Techniques for Building with Embedded Linux 1st Edition*, by Derek Molloy, Publisher: Wiley; 1 edition (December 31, 2014), ISBN-10: 1118935128, ISBN-13: 978-1118935125, <http://beagleboard.org>

Required Hardware

- A small portable Linux capable embedded computing board will be used for building embedded computer vision functions. There will be one class project in Embedded Vision 1 and several class projects in Embedded Vision 2 that will use the BeagleBone Black board. The class focus will be on the BeagleBone Black board connected to a Webcam. Students are free to use any Linux capable small board, but support for other boards will be minimal.
- Students may find it convenient to purchase the required hardware, but are not required to do so.
- The FAB Capstone lab will have BeagleBone boards and webcams available for student use. However, the boards are available on a first-come, first-served.
- This first course in the sequence will make minimal use of the hardware, so you may want to consider using the ECE provided boards in the first course for the final project. If you decide to continue on to the second course, buying a board and camera then makes more sense.

Software Tools

The course will use the OpenCV library, which can be called from C, C++, or Python. The library can be obtained from opencv.org. This library is large and complex and we will focus exclusively on it for the first course. Even then we will only be looking at a subset of OpenCV functionality. However, you should learn enough to be able to expand your knowledge and expertise in OpenCV on your own.

Course Website

The course website will be maintained on D2L, PSU's online learning environment. The website will have news, the class calendar, lecture notes, readings, assignments and solutions, project assignments, links to the video recordings, links to websites and other documentation. The discussion forums will be enabled to provide a platform for asking and answering questions related to the course. Students will submit assignments electronically to D2L and will receive feedback and grades on D2L. **You are expected to check D2L for announcements, discussion forum additions, etc. every day; "Oh, I forgot to check..." is not a valid excuse.**

Course Organization

There will be a midterm exam and a final exam based on the lecture material. The labs will constitute most homework and will provide "practice" to the material covered in the lectures.

Late labs will be accepted with a valid excuse, but that excuse must be given before the due date. Late labs with no valid excuse will not be accepted after midnight on the due date.

There may be occasional "pop quizzes" so it is highly recommended that students do the reading assignments in a timely fashion. It will be difficult to perform the labs without have done the reading and attended the lectures. I will try to accommodate students who cannot take the exams when scheduled if they have a valid excuse and make arrangements in advance.

You will need to work primarily with OpenCV via C, C++ or Python. The particular environment you use for the early assignments is up to you. The GNU tool chain and Eclipse development environments work well, but you can also use Visual Studio with Windows, and XCode with Mac OS X. Another option is Qt Creator which is available free to students on Windows, Mac OSX, and Linux.

During the final two weeks of the course you will work in teams of two to propose and demonstrate a final computer vision project. You will need to write a proposal for your project, which will allow me to assess the level of complexity, generally keeping them simple and straightforward. The final projects will be demonstrated in class at the end of the term.

Lectures will cover the basic operations of OpenCV, image processing, machine learning and computer vision. Students will be tested on this material with in-class exams.

Lecture Recordings

For a number of reasons the lectures will not be recorded.

Attendance Policy

- **You are strongly encouraged to attend every class meeting in person.** You will not be able to get a good grade in this class without attending the lectures and participating in the discussion. We will be learning from each other and your voice is important.

In order to encourage your participation I will keep track of class meeting attendance this term. Good attendance may, in a small way, affect your final grade.

- You are required to be in-class for all exams and for your final project progress report and demo night. Please let me know ahead of time when you know you will not be able to one of these required class meetings so that we can work out a way for you to complete the assignment.

Project Demos

Projects will be demonstrated to the instructor or TA. I will try to have a Demo class where people show off their projects.

Grading and Assignments

The course grade will be based on the projects and exams. In fairness to everyone, I will not accept late assignments or reschedule exams. If you have an emergency, please notify me as soon as possible. This helps to ensure that everyone has the same amount of time to complete assignments and prepare for exams and allows us to post solutions to the course web site.

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| • Projects | 50% |
| • Exams, Midterm and Final 15% each | 30% |
| • Final project | 20% |

IMPORTANT NOTE: SUCCESSFULLY COMPLETING THIS COURSE REQUIRES A STRONG COMMITMENT, HIGH MOTIVATION AND SUFFICIENT TIME TO COMPLETE THE COURSE WORK. THE COURSE WILL MOVE AT A FAST PACE WITH OVERLAPPING ASSIGNMENTS.

Grading Scale

Portland State University utilizes a grading system that recognizes A=excellent, B=good, C=satisfactory, D=inferior and F=failure. All assignments will be graded on a 100 point scale. In general the points to letter grade conversion is as follows, but the instructor may make changes (usually favorable to the students) based on how the class performs.

| Points | Letter grade |
|---------|--------------|
| ≥ 94 | A |
| 90 – 93 | A- |
| 87 – 89 | B+ |
| 84 – 86 | B |
| 80 – 83 | B- |
| 77 – 79 | C+ |
| 74 – 76 | C |
| 70 – 73 | C- |
| 67 – 69 | D+ |
| 64 – 67 | D |
| 60 – 63 | D- |
| < 60 | F |

Letters of Recommendation

I am happy to write letters of recommendation for students who do well in the class and who I know. It is difficult for the instructors and TA to spend one-on-time with every student so make yourself known by participating in the class meetings and being active in the discussion forums. I can write a strong letter if you show me you care, stand out in a positive way, show impeccable behavior, act as a role model for others, and show leadership skills. If I do not know who you are and what you are capable of I may decline to provide a strong recommendation, and a weak recommendation does not help you. Please give me advanced notice and provide a resume and information about the reason for seeking the recommendation (job description, PhD program you are applying for, etc.).

Disability Resources

If you have a disability and are in need of academic accommodations, please notify me immediately to arrange needed support. I will make reasonable accommodations to meet your needs. For more information about the Disability Resource Center, see <http://www.pdx.edu/drc/>

Center for Student Health & Counseling (SHAC)

- Main SHAC website: <http://www.shac.pdx.edu>
- Suicide prevention: <http://www.pdx.edu/shac/suicide-prevention>

Student Conduct and Plagiarism:

Students are expected to handle themselves in a professional manner, respecting property and treating fellow students and the instructors with respect. If you use any of the equipment in the labs please take care of it and report any problems to an instructor or TA. You are welcome to collaborate with your fellow students, **but all of the work you submit must be your own.** Plagiarism of any type will not be tolerated and the consequences will be severe. The PSU code of conduct and information about plagiarism can be found at the following links:

- Code of Conduct: <http://www.pdx.edu/dos/codeofconduct>
- Acknowledgements and Citations: <http://library.pdx.edu/research/citing-sources/>

Work resulting from plagiarism or cheating will receive no credit on that entire assignment or exam. If work is copied from another member of the class (either team or individual) with or without permission, the person or team doing the copying and the person or team providing the work will both receive no credit for the assignment without regard to who is at fault.

Practically speaking, as soon as you decide to submit work that is not your own, you destroy not only your chance of earning an A in the course, but also that of your partner(s) and the person(s) who you copied from.

It is ECE department policy that any cases of plagiarism or cheating are reported to PSU administration for further action. You really do not want to go there...and neither do I.

Homework and Project:

There will be two kinds of out of class exercises:

- Individual homework and small projects involving using OpenCV on any platform
- Mapping a simple computer vision application to the BeagleBone board with connected webcam – depending on enrollments and the availability of the BeagleBone boards, we may divide into groups of 2 for the final project

A two person submission will be treated as a single entity. It is each team member's responsibility to review the work of his/her colleagues and ensure the quality of the final submission.

[Note: the reading assignments are tentative. Not all parts of all chapters will be covered in this first course. When the course is running I will fine-tune the readings to be more specific for what is covered in lectures and homework assignments.]