COLLEGE OF **ENGINEERING** &
APPLIED SCIENCE
UNIVERSITY OF WYOMING

Digital Image Processing

EE 5620 Course Syllabus for Fall 2018

Abstract

This course will introduce the student to fundamental aspects of *practical* digital image processing, using specific applications to demonstrate these principles. The use of modern engineering tools (specifically MATLAB®) to solve image processing problems is emphasized.

Contents

1   Instructor

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2   Course Goals and Objectives

Goal: The goal of this course is for the students to understand the characteristics of digital images and be able to implement various algorithms which manipulate or extract information from such images.

Objectives: Students will be able to

- Understand how images are formed, acquired, and stored, along with an appreciation for the limitations of images in terms of characteristics such as resolution, object visibility, contrast, and so on.

- Understand how to manipulate digital images in the spatial domain and in the frequency domain to achieve a desired result, such as image enhancement or image restoration.

- Demonstrate the ability to critically assess image processing results and to apply judgment as to how well a particular image processing algorithm worked.

- Demonstrate the basic software engineering skills to choose and implement the appropriate algorithm in MATLAB; correctly interpret and write up the results.

- Demonstrate the ability to communicate technical topics clearly, concisely, and with proper grammar, formatting, and style for technical writing and presentations.

3   Course Prerequisites

Each student must have earned a C or better in EE 3220 or verify having an equivalent background.[1] While some limited review will be given in class at the appropriate time, if the student feels particularly "rusty" in any of the background areas, it is highly recommended to review such material early in the semester.

If you are in this course without the appropriate prerequisites, you will be administratively dropped. This may happen immediately, but it can occur at any time during the semester if you are found to not have the prerequisites. This is a College-wide policy regarding prerequisites.

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[1]The student is expected to be comfortable with topics such as basic linear algebra, Fourier transforms, linear signals and systems (i.e., convolution, correlation, FIR and IIR digital filters, etc.), the sampling theorem, quantization, basic probability and random processes, and simple programming in MATLAB.

4   Course Grading

4.1   Breakdown of Graded Events

Graded material is given the following weights. **Note the Final Exam is scheduled to be given from 10:15 AM to 12:15 PM on Friday, December 14, 2018.**

Graded event	Note	Weight
Exam 1	Chap 1–3	25%
Final Exam	Chap 1–5 +	30%
Quizzes, Exercises	no notice	5%
Computer Projects	at least 5, see rubric	25%
Final Project	current industry topic	15%
Total		100%

Unless arranged for *ahead of time* by the student with the instructor, it is not possible to make up a missed exam without an Authorized Absence (available only from the Dean of Students Office). This policy, in accordance with University Regulation 2-108, is strictly observed. See `http://www.uwyo.edu/dos/absences/`.

4.2   Grading Scale

The course will be graded on the following scale, where the student's overall average in the course, as a percentage, is represented by x. No "curving" for grades is used.

Grade	Average (%)
A	$90 \leq x \leq 100$
B	$80 \leq x < 90$
C	$70 \leq x < 80$
D	$60 \leq x < 70$
F	$0 \leq x < 60$

4.3   Turn-In Policy

Computer projects are due NLT 1600L (for civilians, that means "no later than 4:00 PM local time" ☺) on their respective due dates.[2] The format for project reports is given on the course website (in the Admin section); the specified format is strictly enforced.[3]

Computer projects must be submitted as e-mail attachments, and should include both your report (in PDF format only) and your original software (i.e., MATLAB m-files) for the project. Pay close attention to the project assignment instructions, including the required naming conventions for your files.

Computer project code must be original; no pre-written MATLAB software is allowed. Past students would agree that writing the code yourself is the best way to understand the IP algorithms.

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[2]Late turn-ins will not be accepted unless an extraordinary situation exists. Unforeseen computer, e-mail, or printer problems do *not* constitute an extraordinary situation.

[3]There is an example formatted report on the course web page; it would be foolish not to look it over before writing your first project report.

4.4 Computer Project Grading Rubric

The following rubric will be used to score computer projects and the final project. Students who read the rubric *before* starting on the first project consistently score better than their peers who don't bother to read the rubric. Note that a typical "pretty good" project turn-in will only score about 70% according to this rubric. It will take real effort to get into the "A" range on the projects.

		Score	10 - Excellent	7 – Average	4 - Minimal	0 - Unsatisfactory
Results	Correctness		The project results are completely correct.	The project results are mostly correct.	The project results are incorrect in a few areas.	The project results are incorrect in multiple areas.
	Completeness		All parts of the results are present and well presented.	All parts of the results are present but are not well presented (e.g., poor or missing figures or tables).	Minor parts of results are missing.	Major parts of results are missing.
	Interpretation		Interpretation of results is excellent and provides an approriate level of critical insight.	Interpretation of results is adequate and provides a moderate level of critical insight.	Interpretation of results is minimal or lacking critical insight.	Little or no interpretation of results.
Method	Algorithms		Application of algorithms shows originality and thoughtful application, with no coding errors.	Application of algorithms is appropriate, with no coding errors.	Application of algorithms is basic, and may have minor coding errors.	Incorrect algorithms or errors in code.
	Efficiency		Code shows sophisticated and/or original techniques to maximize efficiency.	Code shows a significant attempt to use efficient techniques.	Code shows a moderate attempt to use efficient techniques.	Code shows little or no attempt to use efficient techniques.
	Clarity		Code includes very helpful comments and is logically organized.	Code is adequately commented and is logically organized.	Code is poorly commented and is disorganized.	Use of obfuscated, poorly designed code.
Report	Content		The content is very well formulated, shows impressive insight or originality, and is very well organized.	The content is well formulated, somewhat insightful, and is well organized.	The content is only moderately insightful and not well organized.	The content is minimal, missing information, and/or is poorly organized.
	Style		The paper is clear, concise, and consistent. It is easily understandable and a pleasure to read.	The paper is understandable, but could be improved.	Multiple sections of the paper are difficult to read/understand.	The entire paper is difficult to read/understand.
	Mechanics		The writing is near perfect with almost no grammar or spelling errors.	Minor grammar or spelling errors are present, but are not too distracting. Content is clear.	Some grammar or spelling errors are significant and detract from the meaning. Requires closer editing.	Pervasive grammar or spelling errors distort meaning and make reading difficult.
	Formatting		Required formatting guidelines are correctly followed.	There are minor formatting errors present in the paper	There are major formatting errors present in the paper.	Required formatting guidelines are not being followed.

Total: 0.00 out of a possible 100 points maximum

Qualitiatve points (max of 10)

0.00 Final score

5 Course Materials and Resources

5.1 Textbook

The primary textbook used for EE 5620, by R. C. Gonzalez and R. E. Woods, is listed as [1] in the reference section of this syllabus. This is by far the most popular image processing text in the world, and for good reason. You will use the book extensively in this course. For some topics, handouts may also be used.

5.2 Online Resources

In this course, we will make frequent use of the course website hosted under the WyoCourses system. It is a secure web host for UW students, and you will need to log in with your normal UW student account details. **We will mainly use just the "Files" area of the website.** A copy of this syllabus, assignments, data files, the textbook, and other supplemental material will be posted to this website, and it will be updated regularly. **You are responsible for checking it often.** Files will be organized using easy-to-understand subdirectory and file names.

Some course materials may also be available on the ECE Department network drive that can be found at `\\warehouse\ece\EE5620`. Another website you may find helpful is the textbook publisher's companion web site. See:

> `http://www.imageprocessingplace.com/`

This is a richly populated website with all the figures in the book, tutorials, links to many other sites, etc. You are encouraged to take advantage of it!

5.3 Software and Other Resources

Each student must demonstrate proficiency with the following software:

- MATLAB, version 7 (or higher), The MathWorks, Inc.

This software is available in the ESIG Labs (EN 1034, 1039 and 1041) and in the ECE Department Student Computing Lab (EN 5038). There are also *significant* price reductions on MATLAB and its Toolboxes for student purchasers if you wish to work at home.

6 Miscellaneous Course Policies

6.1 Collaboration, Attendance, and Student Behavior Policy

For all computer projects and the final project, you will work as *a team* of two students.[4] You may also consult with other students currently enrolled in EE 5620 who are on other teams, but you must document *any* such help you receive (e.g., as comments directly in

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[4]If there is an odd number of students in the class, one and only one "team" will have just a single member. This team approach is a reflection of the team-oriented nature of essentially *every* engineering (and computer science) type of job in today's workforce.

the source code of your program *and* in the References or Acknowledgment section of your project report). No comments mean you are submitting the project as *totally* your own team's work; my assumption will always be that each one of you is an honorable person unless you cause me to believe otherwise. Simply copying all or part of another team's assignment is absolutely not allowed—the actual item you turn in must ultimately be your own team's work. You may be called upon to explain to me *in person and in detail* how certain answers were obtained or how your software works. Exams and quizzes must always be the *student's own work*.

Attendance for class lectures is left to the student's own (hopefully mature) judgment. While the lesson slides and textbook provide the main concepts, lectures provide considerable amplification, explanation, MATLAB demonstrations, and the overall context of the concepts, and therefore should not be missed. And if you miss class, you'll miss my corny jokes!

Student behavior is expected to always be professional and respectful of others. An enduring goal is to foster a positive learning environment for all. Side conversations, and the use of cell phones or other mobile devices in such a way that it distracts others, is strictly forbidden during class.

6.2   Academic Honesty

"The University of Wyoming is built upon a strong foundation of integrity, respect and trust. All members of the University community have a responsibility to be honest and have the right to expect honesty from others. Any form of academic dishonesty is unacceptable to our community and will not be tolerated." [excerpted from the UW General Bulletin] All persons should report suspected violations of standards of academic honesty to the instructor, department head, or dean. See UW Regulation 2-114, "Procedures and Authorized University Actions in Cases of Student Academic Dishonesty." You can read this and all other University regulations at: `http://www.uwyo.edu/regs-policies/`

6.3   Disability and Diversity Statements

If you have a physical, learning, sensory, or psychological disability and require accommodations, please let the instructor know as soon as possible. You must register with, and provide documentation of your disability to, Disability Support Services (DSS) located in room 128 of Knight Hall. You may also contact DSS at (307) 766-3073 or `udss@uwyo.edu`. Visit their website for more information: `www.uwyo.edu/udss`.

From UW Regulation 2-117: "The University of Wyoming values an educational environment that is diverse, equitable, and inclusive. The diversity that students and faculty bring to class, including age, country of origin, culture, disability, economic class, ethnicity, gender identity, immigration status, linguistic, political affiliation, race, religion, sexual orientation, veteran status, worldview, and other social and cultural diversity is valued, respected, and considered a resource for learning."

7 Course Overview

Welcome to Digital Image Processing! This course will prepare you to deal competently with various image processing challenges that may confront you in the future. The subject is usually found to be fun and enjoyable by most students, but don't think this course is just playing with pictures! There is a considerable need for quantitative, mathematical descriptions and manipulations of images—so be prepared for that. However, the emphasis in this course is on fundamental principles and practical applications, rather than esoteric theory or arcane derivations.

Warning: *the computer projects are not easy and will take a lot of time.* Just like with anything worthwhile in life, if you aren't willing to put in the time and effort, you won't ever become good at it. Be prepared to devote *considerable* time to this class—***especially* the computer projects!** The time needed to do well on the computer projects catches many students by surprise, so work that into your time planning. Too many students, underestimating what the projects will take, destroy any hope for a good grade by not turning in good work on the projects. While I promise to be sensitive to the time requirements of every assignment I give you, it's you who must put forth sufficient effort. As Robert E. Heinlein was known to say, "TANSTAFL."

8 Course Topic Outline

The following outline lists the basic sequence of course topics. The speed and depth of coverage will depend to some degree upon student comprehension, but remember: this is NOT a lower-level class; I won't "hold your hand." That also means an appropriate amount of independent reading and work outside of class is expected of you. More specific lesson-by-lesson guidance will be given when needed as the semester progresses.

- Introduction to Digital Image Processing **(Chap. 1–2)**
  - What is it, why do we do it? Origins and examples of image processing (IP)
  - Fundamental steps in IP, components of an IP system
  - Perception, image formation and optics, pixelization, quantization
  - Basic pixel descriptions, measures, and operators
- Image enhancement in the spatial domain **(Chap. 3)**
  - Gray level transformations and histograms
  - Using arithmetic and logic operations on images
  - Spatial filters: smoothing, sharpening, other
- Image enhancement in the frequency domain **(Chap. 4)**
  - The 1-D Fourier transform, the DFT and FFT, in time and in space
  - The 2-D Fourier transform in space and its inverse
  - Filtering in the frequency domain: smoothing, sharpening, other

- Image restoration **(Chap. 5, up to Sec. 5.10)**

  – Types of image degradation

  – Spatial domain and frequency domain noise reduction

  – Reducing other forms of degradation: inverse filtering, Wiener filtering, other

  – Introduction to image reconstruction from projections (computed tomography)

- Final Project: current industry problem

9   Final Project

The final project (one per team) consists of finding a practical solution to a current industry problem using image processing techniques. A final project report, similar to regular project reports, will be required. If time permits, a brief presentation of the team's solution will be made to the class.

Lecture time will be reserved to introduce the students to the problem, and to provide any additional image processing concepts that may apply to solving the problem. Time will be allotted for student questions, and for in-class brainstorming.

References

[1] R. C. Gonzalez and R. E. Woods, *Digital Image Processing*, Pearson, 4th ed., 2018. ANNOTATION: This is the number one image processing text in the world, with an amazingly complete companion website.

[2] J. C. Russ, *The Image Processing Handbook*, CRC Press, 5th ed., 2006. ANNOTATION: A fairly useful book, long on breadth but short on depth.

[3] R. C. Gonzalez, R. E. Woods, and S. L. Eddins, *Digital Image Processing Using MAT-LAB*, Gatesmark Publishing, 2nd ed., 2009. ANNOTATION: Written by the authors of your textbook and a person from The Mathworks (creators of MATLAB), this book is much lighter on theory but heavy on specific MATLAB examples. There is an excellent companion web site.

[4] A. Rosenfeld and A. C. Kak, *Digital Picture Processing*, vol. 1 and 2. Academic Press, 2nd ed., 1982. ANNOTATION: While a bit dated in some respects and hard to find, these volumes are still considered by many to be *required* books to have in your personal IP library. An excellent treatment of computed tomography in Volume 1.

[5] K. R. Castleman, *Digital Image Processing*, Prentice Hall, 1979. ANNOTATION: A good introductory text, similar in scope to your textbook.

[6] A. C. Kak and M. Slaney, *Principles of Computerized Tomographic Imaging*. SIAM Press, 2001. ANNOTATION: A somewhat newer and expanded treatment of the material found in Chapter 8 (volume 1) of the Rosenfeld and Kak classic, "Digital Picture Processing."

[7] W. K. Pratt, *Digital Image Processing*, John Wiley & Sons, 3rd ed., 2001. ANNOTATION: Another comprehensive introductory IP book, similar in scope to your textbook. The ISO standard PIKS software for IP (written in C) and an image database is included on a CD-ROM.

[8] M. A. Sid-Ahmed, *Image Processing: Theory, Algorthms, & Architectures*, McGraw-Hill, 1995. ANNOTATION: Another introductory IP text, not as well organized as your textbook, which includes many examples coded in C and a good discussion of TV video.

[9] M. Sonka, V. Hlavac, and R. Boyle, *Image Processing, Analysis, and Machine Vision*. Thomson Learning, 3rd ed., 2008. ANNOTATION: A mathematically rigorous IP book that skims over some of the basics to make room for some very interesting advanced topics. Good for graduate students.

[10] D. A. Forsyth and J. Ponce, *Computer Vision: A Modern Approach*, Prentice Hall, 2003. ANNOTATION: Contains introductory material on both lower-level image processing and higher-level computer vision.

[11] R. M. Haralick and L. G. Shapiro, *Computer and Robot Vision*, vol. 1 and 2. Addison-Wesley, 1992. ANNOTATION: A *very* complete two volume set, but a bit hard to read as an introduction. After the divorce, Shapiro's later book with Stockman is less complete but more approachable.

[12] L. G. Shapiro and G. C. Stockman, *Computer Vision*, Prentice Hall, 2001. ANNOTATION: More advanced than your textbook, but covers some good foundation for object recognition.

[13] E. R. Davies, *Machine Vision: Theory, Algorithms, Practicalities*. Morgan Kaufmann (Elsevier), 3rd ed., 2005. ANNOTATION: A huge (nearly 1,000 pages!), comprehensive book by the well-known British author.

[14] S. E. Umbaugh, *Computer Imaging: Digital Image Analysis and Processing*, CRC Press, 2005. ANNOTATION: An introductory text that is light on the math but heavy on examples, the book includes the ANSI-C library and GUI skeleton software called CVIPtools on a CD-ROM.

[15] D. Marr, *Vision*, W. H. Freeman and Company, 1982. ANNOTATION: While Marr died soon after this book was published, it is still revered as one of the best references on the entire phenomonon of vision and imaging.

[16] E. R. Dougherty and R. A. Lotufo, *Hands-On Morphological Image Processing*, SPIE Press, 2003. ANNOTATION: The best tutorial on morphological IP I've found so far!

[17] B. Jähne, *Digital Image Processing: Concepts, Algorithms, and Scientific Applications*. Springer-Verlag, 3rd ed., 1995.

[18] I. Pitas, *Digital Image Processing Algorithms*, Prentice Hall UK, 1993.

[19] R. H. Vollmerhausen, D. A. Reago, Jr., and R. G. Driggers, *Analysis and Evaluation of Sampled Imaging Systems*, SPIE Press, 2010. Annotation: An updated excellent treatment of aliasing and other image degradations.

[20] M. Rabbani and P. W. Jones, *Digital Image Compression Techniques*, SPIE Press, 1991. Annotation: A rigorous treatment of this very mathematical subject, but surprisingly readable.

[21] G. C. Holst, *Electro-Optical Imaging System Performance*, SPIE Press, 3rd ed., 2003. Annotation: A non-rigorous but practical treatment of imaging *system* performance, going beyond just the sensors. A very readable discussion of radiometry.

[22] G. C. Holst, *Sampling, Aliasing, and Data Fidelity for Electronic Imaging Systems, Communications, and Data Acquisition*, SPIE Press, 1998. Annotation: Not particularly rigorous mathematically, but it provides a good "seat of the pants" intuitive approach to the subject.

[23] G. C. Holst, *CCD Arrays, Cameras, and Displays*, SPIE Press, 1996. Annotation: Similar in some respects to the author's 2003 text, this book discusses mainly CCD sensors and cameras.

[24] J. Nakamura, ed., *Image Sensors and Signal Processing for Digital Still Cameras*, CRC Press, 2006.

[25] K. B. Benson and J. Whitaker, *Television Engineering Handbook*, McGraw-Hill, revised ed., 1992. Annotation: An excellent resource with regard to video standards and related technology.

[26] T. Fukinuki, "Television: Past, present, and future," *Proceedings of the IEEE*, vol. 86, pp. 998–1004, May 1998. Annotation: A very readable combinaton of TV history and the HDTV future.

[27] S. Inoué and K. R. Spring, *Video Microscopy: The Fundamentals*, Plenum Press, 2nd ed., 1997. Annotation: It may not be evident from the title, but this book contains one of the best treatments of video I've ever come across.

[28] T. S. Rzeszewski, ed., *Digital Video*. IEEE Press, 1995. Annotation: A good collection of seminal papers on all types of video.

[29] A. F. Inglis and A. C. Luther, *Video Engineering*, McGraw-Hill, 2nd ed., 1996. Annotation: An excellent video reference, fewer topics but more rigor than Benson's handbook.

[30] R. S. Prabhakara, C. H. G. Wright, and S. F. Barrett, "Motion detection: a biomimetic vision sensor versus a CCD camera sensor," *IEEE Sensors J.*, vol. 12, pp. 298–307, Feb. 2012.

[31] D. T. Riley, W. M. Harmann, S. F. Barrett, and C. H. G. Wright, "Musca domestica inspired machine vision sensor with hyperacuity," *IOP Bioinsp. Biomim.*, vol. 3, no. 2, pp. 026003(+13), 2008.

[32] C. H. G. Wright, S. F. Barrett, D. J. Pack, T. R. Schei, J. R. Anderson, and M. J. Wilcox, "Computational image processing for a computer vision system using biomimetic sensors and eigenspace object models," in *Proceedings of the SPIE 16th International Symposium on Electronic Imaging (SPIE 5299)*, pp. 327–336, Jan. 2004.

[33] S. F. Barrett, C. H. G. Wright, H. Zwick, M. Wilcox, B. A. Rockwell, and E. Naess, "Efficiently tracking a moving object in two-dimensional image space," *SPIE Journal of Electronic Imaging*, vol. 10, pp. 785–793, July 2001.

[34] D. Sage and M. Unser, "Teaching image-processing programming in Java," *IEEE Signal Processing Magazine*, vol. 20, pp. 43–52, Nov. 2003. ANNOTATION: A well written article, but the software advocated tends to hide a lot of the low level details of image processing. Still, it's a worthwhile article with links to some good, free software with which you can learn some things.

[35] B. G. Batchelor and P. F. Whelan, eds., *Selected Papers on Industrial Machine Vision*, vol. MS-97 of *SPIE Milestone Series*, SPIE Press, 1994. ANNOTATION: A broad collection of seminal papers in the machine vision field.

[36] C. H. G. Wright, "Technical writing tools for engineers and scientists," *IEEE/AIP Computing in Science and Engineering*, vol. 12, pp. 98–103, Sep/Oct 2010.

[37] C. H. G. Wright, T. B. Welch, and M. G. Morrow, "Leveraging student knowledge of DSP for optical engineering," in *Proceedings of the 2015 IEEE Signal Processing and Signal Processing Education Workshop*, pp. 148–153, Aug. 2015.

[38] B. K. Dean, C. H. G. Wright, and S. F. Barrett, "Biomimetic signal conditioning and light adaptation for compound vision sensors," *IEEE Sensors J.*, vol. 15, pp. 269–278, Jan. 2015.

[39] C. H. G. Wright and S. F. Barrett, "Biomimetic vision sensors," in *Engineered Biomimicry: Bioinspiration, Biomimetics, and Bioreplication* (A. Lakhtakia and R. Martín-Palma, eds.), ch. 1, pp. 1–36, Elsevier, 2013.

[40] M. Aghajarian, J. E. McInroy, and C. H. G. Wright, "Salt-and-pepper noise removal using modified mean filter and total variation minimization," *SPIE Journal of Electronic Imaging*, vol. 27, no. 1, pp. 1–8, 2018.

Finally...

Congratulations on reading this far! Lesser mortals gave up several pages earlier. As a reward, perhaps these quotes will inspire you in a positive manner...

Whoever controls the media—the images—controls the culture.
—ALLEN GINSBERG

Scientists investigate that which already is;
engineers create that which has never been.
—ALBERT EINSTEIN

It is change, continuing change, inevitable change, that is the dominant factor in society today. No sensible decision can be made any longer without taking into account not only the world as it is, but the world as it will be ...
—ISAAC ASIMOV

The trouble with quotes from the Internet is that you can never tell if they're genuine.
—ABRAHAM LINCOLN

That which does not kill us makes us stronger.
—FRIEDRICH NIETZSCHE

The WISPR Laboratory
Wyoming Image and Signal Processing Research