# Comparative review of image processing and computer vision textbooks

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**ABSTRACT**

This paper gives a comparative overview of ten of the currently available computer vision and image processing textbooks. These texts differ significantly in their coverage, scope, approach, and target audience. Because of the multi-disciplinary nature of this field, it is important to select a textbook that takes advantage of students' backgrounds and gives them the foundation necessary to integrate diverse concepts. This comparative review provides computer vision and image processing educators with a starting point from which they can select a textbook appropriate for their students' needs.

**Keywords**: computer vision, image processing, textbook review, education, teaching

## 1 INTRODUCTION

Computer vision and image processing (CVIP), the study of enabling computers to modify, enhance, and understand images, is a broad-based field of computer science and electrical engineering that requires students to understand and integrate knowledge from numerous disciplines. Until recently, choosing a textbook for a CVIP course was a simple process. If you were teaching an undergraduate computer vision course you could choose from B. K. P. Horn's *Robot Vision* or V. Nalwa's *A Guided Tour of Computer Vision*; if you were teaching a graduate computer vision course, you used *Computer and Robot Vision* by R. Haralick and L. Shapiro. If you taught an undergraduate image processing course, you had slightly more choice, but might select *Digital Image Processing* by Gonzalez & Woods. Since 1994, however, at least six new, or revised, CVIP textbooks have become available, and at least one other will appear in 1998-99.

Because of its multi-disciplinary nature, a textbook that takes advantage of students' backgrounds and provides a basis for integration is essential to their success. Since the students of computer vision and image processing come from a wide variety of backgrounds, however, not every textbook will be appropriate for every student, or for every course. Therefore, it is important to know the coverage, appropriate audience, and strengths and weaknesses of the texts available in the field.

This presentation provides an overview of a number of the currently available computer vision textbooks, focusing on these aspects. The texts covered include the following.

- *Robot Vision*, B. K. P. Horn, MIT Press, 1985
- *Computer and Robot Vision*, R. Haralick and L. Shapiro, Addison-Wesley, 1992
- *Digital Image Processing*, R. Gonzalez and R. Woods, Addison-Wesley, 1992
- *A Guided Tour of Computer Vision*, V. Nalwa, Addison-Wesley, 1993
- *Digital Image Processing: Principles and Applications*, G. Baxes, J. Wiley & Sons, 1994
- *Machine Vision*, R. Jain, R. Kasturi, and B. G. Schunck, 1995
- *Digital Image Processing*, K. Castleman, Prentice-Hall, 1996
- *Machine Vision: Theory, Algorithms, Practicalities*, 2nd Ed., E. R. Davies, Academic Press, 1997
- *Image Processing, Analysis, and Machine Vision*, M. Sonka, V. Hlavac, and R. Boyle, PWS Publishers, 1998
- *Computer Vision and Image Processing: A Practical Approach Using CVIPtools*, S. Umbaugh, Prentice-Hall, 1998

These texts differ significantly in their coverage, scope, approach, and audience. To facilitate appropriate comparisons, this paper divides the texts into three categories depending upon the type of course for which they are appropriate. These categories are: computer vision texts, image processing texts, and comprehensive CVIP texts. The differentiation of these categories is based on the topics covered in a CV or IP course, and is defined as follows.

An image processing course is defined as a course that deals with low-level image processing, primarily manipulation of images for use by people. Major topics include: imaging fundamentals, image enhancement, image restoration, image compression, low level feature analysis, histogram and threshold based segmentation, and image transforms. Some image processing courses and texts also cover shape and boundary representation and low-level object recognition based on extracted features.

A computer vision course is defined as a course that covers image manipulation for understanding and analysis by a computer. Major topics would include edge and line-finding, segmentation and region-finding, texture, color, stereo, motion, object representation, object recognition using a variety of methods, physics-based vision, shape from X, content-based image retrieval. Transforms and morphological operators are also commonly included in a computer vision course, but not always, and certainly not as deeply as in an image processing course.

A comprehensive course is defined as combining elements of both areas, probably as a two-semester sequence or as a more intensive graduate course.

Based on these classifications, it is the author's hope that this comparative review will provide CVIP educators with a road map of the relative strengths, target audience, and coverage of each of these texts.

## 2 CLASSIC COMPUTER VISION TEXTBOOKS

### 2.1 Robot Vision, by B. K. P. Horn, 1986.

This is the classic computer vision text written by the pioneer of physics-based vision. As recently as spring 1996, this was the textbook for the Carnegie Mellon University undergraduate computer vision course. That said, however, the course was based not around the textbook, but around a set of lecture notes developed by the faculty. The textbook was considered to be a reference only.

Part of the reason the text was used only as a reference is that the coverage in Robot Vision, while adequate when published, has been diminished by age. With respect to coverage, the book presents fundamental concepts in most areas of computer vision. However, advances in algorithms, theory, and implementation require the instructor to present a significant amount of material not covered in the book.

The approach Horn takes in *Robot Vision* is to use continuous mathematics to describe the interaction of light, matter, and image sensors. As a reference for the physical and geometrical mathematics of light interacting with surfaces and the camera it is excellent. His apparent audience, however, is upper-level undergraduates and graduate students with a strong physics background and a working knowledge of multi-variable calculus.

One of the weaknesses of *Robot Vision* is that there is little discussion of the algorithms or data structures necessary to implement the basic tools of computer vision. Horn derives or provides the equations, as in Chapter 8 where he covers edges and edge finding, but does not discuss implementation issues. Second, many of the equations are presented in continuous form only. While this is appropriate for characterizing the physical world, the book does not make a strong connection between the discrete digital image and the continuous world. This adds to students' difficulties in translating equations into code and requires the instructor to repeatedly make the connection between continuous and discrete representations.

As a result of the problems with audience, methodology, and age, this book is not a good choice for an undergraduate computer vision course. This is especially true with the appearance of a the new generation of comprehensive texts.

### 2.2 A Guided Tour of Computer Vision, by Vishvjit S. Nalwa, 1993.

Nalwa's text, like *Robot Vision*, also does not concern itself with implementation details. Instead, the focus of this book is on the geometrical and conceptual foundations of computer vision. Unlike Horn, however, his approach is based less on continuous mathematics and physics, making the book more approachable to undergraduates with diverse backgrounds.

Nalwa's motivation for dealing only with the conceptual foundations is concern about the robustness of most vision algorithms. Other books in this review--for example, Davies' text--share the same point of view, but take a different approach. They focus on techniques that have been demonstrated to work in industrial applications. Nalwa takes the opposite approach and focuses on the fundamental concepts underlying the various sub-fields.

The coverage of *A Guided Tour of Computer Vision* is fairly broad, and touches on most of the standard computer vision topics. Nalwa includes chapters on: image formation and radiometry, edge detection and segmentation, line-drawing interpretation, shape from shading, texture analysis, stereo, motion, and shape representation. Some of these topics--in particular line-drawing interpretation and shape from shading--are not as relevant to modern computer vision applications, but they do provide students with a strong background in the physics of imaging and some fundamental concepts in image labeling and understanding. The major topic Nalwa steers away from is object recognition, because in his estimation it is too context dependent[8]. However, the text does cover the fundamentals of object representation.

Because Nalwa does not focus on implementation details, his text does not, and probably will not, suffer as much from age as some of the others. His focus on the concepts makes the book approachable to undergraduates of all backgrounds, so long as they have a basic mathematical dexterity. However, because of the lack of implementation details an instructor using this book would have to supplement the text with other readings in order for students to undertake practical assignments. Overall, this text would be appropriate for an undergraduate computer vision course or seminar aimed at students with a general technical or mathematical background.

**2.3 Machine Vision, by R. Jain, R. Kasturi, and B. G. Schunck, 1995.**

Whereas *A Guided Tour of Computer Vision* makes an excellent text for a more theoretical computer vision seminar, *Machine Vision* attempts to balance theory and implementation in a more general-purpose textbook for computer scientists and engineers.

The scope and detail of the material in *Machine Vision* is appropriate for undergraduates, and its coverage is broad, however, it is not as in-depth or mathematically rigorous as the more graduate-level *Computer and Robot Vision*, discussed below. In addition to binary operations, filtering, edge and line finding, and segmentation, the book also covers motion, object recognition, object representation, stereo, calibration, texture, and shading. In all of these areas, the authors have made an effort to present material that is fundamental to computer vision and not specific to a particular approach or school of thought. Because of this, the text should continue to be useful for some time.

The approach taken is biased towards an electrical engineering (EE) view of the material, but the authors do present a number of the basic vision tools--e.g. 2D operators, edge-finding, and stereo--in an algorithmic or procedural manner in addition to the mathematical presentation. The text also provides some explicit transitions from continuous mathematics to the discrete representations necessary for working with images. Thus, while the text is more appropriate for engineers, it is not unapproachable by computer scientists.

For computer science (CS) majors, however, the book is not without its difficulties. The presentation of filters in Chapter 4, for example, is geared more towards a sophomore electrical engineer than a CS major. EE majors using this book have no trouble grasping it, while the CS majors tend to understand the concepts only after seeing them presented algorithmically in class or as part of an assignment. Also, the presentation of stereo and calibration, which is divided into two disjoint chapters, is not coherent or well-organized. To follow the complete stereo process described in the book--calibration, imaging, registration--requires flipping between chapters which read as though written by different authors.

The other difficulty with *Machine Vision* as an undergraduate text is, in this author's opinion, that it is biased towards industrial applications of computer vision using grayscale or binary images. The chapters on optics, shading, and color constitute less than 40 pages of the 550 page text. Color, however, is central to a number of areas of computer vision: segmentation, object recognition, vision in human-computer interfaces, and vision applications in computer graphics. This is a concern if you are teaching mainly computer scientists, as the latter two topics are more closely connected to mainstream computer science. Unfortunately, this criticism can be leveled at all of the texts in this review, with the possible exception of *Image Processing, Analysis, & Machine Vision*, which incorporates extensions from grayscale to color in a number of chapters.

Thus, for a one-semester undergraduate course *Machine Vision* is a reasonable choice, particularly for students with an EE background.

## 3 IMAGE PROCESING TEXTBOOKS

**3.1 Digital Image Processing, R. Gonzalez and R. Woods, 1992**

Gonzalez & Woods' book is a standard textbook for an image processing (IP) course for engineers. Like all of the texts in this section, it covers digital image fundamentals, image transforms, image enhancement, image restoration, image compression, and image segmentation. Gonzalez & Woods (G&W) also provide a chapter on shape & region descriptors and a chapter on low-level recognition. The coverage of image transforms focuses on the Fourier transform, but also includes short sections on the Walsh, Hadamard, discrete cosine, Haar, slant, and Hotelling transforms. Because of the age of the book, however, wavelet transforms are not mentioned.

With respect to color image processing, G&W provide a 25 page section on the topic, including color plates that aid the presentation of the material. Note that Castleman's book also provides a chapter on color and multispectral images. The other two books, however, do not present color image processing in significant detail.

### 3.2 Digital Image Processing, 2nd Ed. K. Castleman, 1996

Castleman's book attempts to reach a broader audience than G&W, but is still most appropriate for an image processing course aimed at engineers or computer scientists with a strong linear systems background. Unlike G&W, who divide their book based on the major IP topics, Castleman divides the book into three parts based on complexity and overall theme. Part I presents basic IP concepts that do not rely heavily on mathematics. Part II covers IP techniques based on mathematical tools such as the Fourier and wavelet transforms, and the part III touches on computer vision topics and applications of IP.

The strength of Castleman's book is its extended coverage of both linear and discrete transforms, as well as the addition of wavelets. Part III also sets Castleman apart from G&W and the two other IP texts in this section. Part III contains chapters on segmentation, edge detection, line-finding, binary processing, texture and shape analysis, pattern matching, color image processing, and 3D imaging, including a short section on stereo. Because of this extended coverage, it could be an appropriate text for a two-semester EE course on image processing and computer vision. However, it is important to note that, when compared to any of the other computer vision or comprehensive CVIP texts reviewed herein, it does not have the same breadth of CV topics or depth within each topic.

### 3.3 Digital Image Processing: Principles and Applications, G. Baxes, 1994

Unlike G&W and Castleman's texts, Baxes' text, like the following one by Umbaugh, is not aimed at engineers and students with a strong mathematical background. Instead, Baxes' and Umbaugh's texts address the needs of application programmers and people who need to understand and apply digital image processing techniques. From an educators point of view, these texts would be appropriate for a general education course on digital image processing and visual information systems. They would also be appropriate for an IP course for computer scientists who may, or may not have an adequate background to delve into linear and discrete transforms. Given the existence of digital cameras, cheap scanners, and the explosion of digital images available on the world-wide web, such a course is going to play an important role in the future of CVIP education.

Baxes divides his book into four parts. Part I presents an introduction to the field. Part II covers image enhancement and restoration, segmentation, feature extraction, simple object classification, image compression, and image synthesis. Part III looks at image processing systems, video formats, and image data handling, and part IV is a long list of image processing examples, demonstrating most of the concepts covered in the book. As a supplement to the text, the book contains a disk with implementations of a number of the algorithms.

The strength of this text, compared to Umbaugh, is the broader coverage of system topics. Both texts cover image compression, restoration, analysis, and segmentation. Baxes, however, also includes the visual information system topics and a chapter on image synthesis. The latter is particularly relevant to applications programmers and computer science students, and is unique to this book compared to any of the others in this review.

Where an educator may have to supplement the text are topics such as segmentation, edge and line finding, and filtering, which are not covered in detail.

### 3.4 Computer Vision and Image Processing: A Practical Approach Using CVIPtools, S. Umbaugh, 1997

Umbaugh's book is the most limited in scope of the IP textbooks. The title is, unfortunately, somewhat misleading as this text is definitely focused on IP. The organization of the first section of this book is similar to G&W, with chapters on IP fundamentals, image analysis, restoration, enhancement, and compression. The second section is a reference for the CVIP code library and CVIP applications provided on a CD with the book.

The target audience for this text falls somewhere between Baxes and G&W, as it presents most concepts conceptually and algorithmically, while still providing more mathematical detail than Baxes. Like Baxes, this text would be appropriate for a computer science IP course, where not all students would be comfortable with a mathematical presentation of linear transforms.

The strength of Umbaugh's text is the CVIP library and applications provided with the book. In the author's experience it is the most extensive library of routines currently available with a textbook. It also has the most extensive documentation, which both students and educators should appreciate.

## 4 COMPREHENSIVE CVIP TEXTBOOKS

### 4.1 Computer and Robot Vision I and II, R. Haralick, and L. Shapiro, 1992.

This two-volume set is an in-depth examination of the fundamentals of 2D and 3D computer vision. Because of the extensive coverage of 2D vision (volume 1), it could be used as the basis for a 2-semester comprehensive CVIP course. the biggest drawback is that the age of the text requires the instructor needs to fill in more recent developments, particularly in object recognition, stereo, image understanding, and newer transforms such as the wavelet transform.

As noted previously, the first volume of this pair presents binary and 2D vision. This includes: thresholding and binary algorithms, region analysis, statistical pattern recognition, mathematical morphology, filtering, noise removal, edge and line finding, the facet model, 2-D texture analysis, grayscale segmentation, and arc extraction. With the addition of a module on image compression, these topics form the basis for a typical image processing course. The second volume covers 3D vision and includes: illumination and physics-based vision, perspective geometry, photogrammetry, motion analysis, image registration, 3D labeling, shape representation, and knowledge-based vision. Volume represents most of the standard topics within a computer vision course. The amount of information provided on each topic makes each volume appropriate for a full semester course.

Some of the topics an instructor may wish to augment with other readings include transforms, object recognition, motion analysis, and stereo. These topics, and several others, have expanded in new directions since 1990. Object recognition, for example, which is covered in chapter 18, is limited to a few specific representations and model-matching methods. Advances in appearance-based objection recognition and content-based image retrieval, in particular, will need to be added to a comprehensive graduate course.

The approach taken in *Computer and Robot Vision* is rigorously mathematical, although the two volumes do present numerous algorithms and discuss implementation issues and performance. Anyone using this book would be well-served by both a linear algebra and a modern algebra course. For mathematically unsophisticated students, however, this book would pose a major stumbling block simply because of the quantity of equations. An undergraduate CS major, for example, would be quickly overwhelmed and the text would become a hindrance rather than an educational aid. Furthermore, *Computer and Robot Vision* has an extensive bibliography at the end of each section and refers to it heavily. For a graduate student who is used to accessing technical literature this is quite appropriate. For an undergraduate who is learning computer vision for the first time, however, asking them to seek out, read, and understand the primary literature at this scale is inappropriate.

This combination of coverage, audience, and approach makes *Computer and Robot Vision* an appropriate choice for a two-semester comprehensive CVIP graduate seminar.

### 4.2 Image Processing, Analysis, and Machine Vision, 2nd ed., M. Sonka, V. Hlavac, and R. Boyle, to appear Spring 1998

This textbook, which should be available in 1998, fits in between Castleman's *Digital Image Processing*, Jain *et. al.*'s *Machine Vision* and Haralick & Shapiro's Computer *and Robot Vision*. In its breadth it covers more topics than any other text considered in this paper. Furthermore, its depth in some topics approaches that of *Computer and Robot Vision*, but with an algorithmic and conceptual focus rather than a rigorous mathematical one. Like many other texts, *Image Processing, Analysis, & Machine Vision* begins with filtering, edge-finding, segmentation, and 2-D shape representation. At this point, however, the text looks at various approaches to object recognition, including artificial neural networks, graph matching, and fuzzy logic. One of the strengths of this book is that it provides enough background on these topics for students to follow, although having an artificial intelligence, neural networks, or fuzzy logic course as prerequisite would improve students' ability to focus on the computer vision applications rather than the tools.

After object recognition, *Image Processing, Analysis, & Machine Vision* moves on to 3D vision including chapters on image understanding, 3D vision (calibration, stereo, and physics-based vision), and motion analysis. The book does not follow the same order as other texts, however, and later chapters also include mathematical morphology, linear discrete transforms, and image compression. These chapters are almost as comprehensive on these subjects as the texts in the IP section, which is why this book qualifies as a comprehensive CVIP text. This arrangement of topics is actually convenient for an undergraduate instructor, because these later chapters contain much of the material that is challenging for non-engineering majors. Their placement later in the book, and the resulting implication that previous chapters do not depend on them for understanding, means an instructor can more easily pick and choose which of these topics to cover. Thus, they would be covered in a course more focused on IP topics, or left out in a more CV-focused course.

The real strength of *Image Processing, Analysis, & Machine Vision* is its comprehensive, in-depth coverage of both CV and IP. The material is well-written and, while the mathematical formulation of methods is still the focus of the narrative, the text includes algorithms for many of the methods it covers. The text also seems to contain more example images and image comparisons than other texts, making it easier to obtain an intuitive understanding of the material. Its approach relies on a mixture of EE and CS concepts, and there is even a chapter on data structures for image analysis. Thus, with intelligent topic selection and adequate instruction this text is not inappropriate for CS majors.

The book is written at a higher level than *Machine Vision*, however, and instructors should carefully consider their prerequisites for a computer vision or image processing course before selecting this text. Based on its level and breadth, *Image Processing, Analysis, & Machine Vision* will be more accessible to students who have already had an artificial intelligence course, or related EE course, that introduces them to artificial neural networks, search, and fuzzy logic. Students without this background could be overwhelmed with a range of new concepts that, while they are useful in computer vision, are not specific to the field.

One final issue with *Image Processing, Analysis, & Machine Vision* is that the coverage, while broad, is uneven. Looking at the relative depth with which topics are covered, one is left with the perception that the personal research topics of the authors receive significantly more emphasis. For example, chapter 9 is a monolithic chapter on 3D vision that includes stereo, calibration, shape-from-shading, reflectance models, photometric stereo, and range-imaging. In all of the other texts these topics are divided into 2-3 separate chapters.

A second departure from other textbooks is that some methods that receive central coverage in others are de-emphasized, not mentioned, or placed in different contexts in *Image Processing, Analysis, & Machine Vision*. For example, the Hough transform is covered in the chapter on segmentation rather than within the chapter covering edge and line-finding. While line-finding is presented as an application of the Hough transform, this presentation comes after the line-finding chapter and in the middle of a discussion of segmentation. These issues are not a major drawback to the text, but an instructor should be aware of them and should structure the lectures and reading assignments appropriately.

Overall, *Image Processing, Analysis, & Machine Vision* is comprehensive text and a good compromise with respect to level and target audience. Through strategic selection of chapters, it would be appropriate for either a senior level CS or EE undergraduate computer vision course, or an advanced graduate level course.

### 4.3 Machine Vision: Theory, Algorithms, Practicalities, by E. R. Davies, 1997.

Davies' *Machine Vision* is an interesting contrast to the other CV and IP texts. Where the previous texts have tried to give broad coverage of CV & IP and provide the fundamentals in most of its subfields, Davies' text focuses on robust, general-purpose tools and algorithms. As such, it doesn’t fall squarely within either camp, but focuses on a few topics right in the middle. Hence, it is included in the comprehensive section rather than one or the other. Topics like color, stereo, object recognition, and model-based vision are either mentioned in passing or left out altogether. Likewise, it does not focus on a number of the standard image processing tasks like image compression or restoration. Thus, its coverage is more limited than the other texts reviewed herein.

The topics that are covered by Davies' *Machine Vision*, however, are covered in good detail in an accessible manner. The approach is fundamentally algorithmic, with mathematics used as a tool to supplement the conceptual presentation. Because of this, the audience for this text is fairly broad, and includes students with both computer science and EE backgrounds. Certain sections of the book, for example the section detailing the Fourier transform, are included as chapter appendices and are not required in order to understand the rest of the chapter.

Davies' book is also the only one of the five texts to include a full chapter on the use of artificial neural networks [ANN] in vision tasks. Both *Image Processing, Analysis, & Machine Vision* and *Digital Image Processing* by Castleman present ANNs, but as part of a larger chapter. Davies presents an overview of ANNs, and then discusses their use in both filtering and pattern recognition.

On a more specific note, chapter 2 of this book is one of the best introductions to the practical aspects of CV and IP algorithms this author has seen. Chapter 2 of *Image Processing, Analysis, & Machine Vision* is similar in nature, but focuses more on the data structures. Davies touches on many of the issues that students stumble across and have problems with during their first vision course. For example, it walks the reader through the reason they have to use two images in order to correctly convolve a Gaussian filter with an image. If students read nothing else of this book, reading chapter 2 will help them avoid numerous visits to the instructor’s office with questions about why their assignment won't work.

Overall, if the focus of your course is on industrial CVIP applications, Davies' Machine Vision would be an excellent choice for a textbook. If, however, your focus is more on classic IP, or classic CV, other texts in this review would be more appropriate.

## 5 THE FUTURE OF CVIP EDUCATION

Given the diversity of texts now available for CVIP education, it should be possible for educators to select a text appropriate for a wide range of topics, target audiences, and mathematical sophistication. Most of the reviewed texts are recent enough in their coverage of topics that additional materials are not required except at the preference of the instructor. It is worth looking ahead to the future of CVIP education, however, and thinking about the needs of students in the field five years from now.

Perhaps the event having the largest impact on CVIP is the explosion of digital cameras and the use of digital images on the world-wide web. As a result, digital imaging and digital imagery have become ubiquitous and the need for imaging technicians and applications programmers with knowledge of CVIP techniques will continue to grow. This group of students is not well-served by the current set of texts. While Baxes’ and Umbaugh’s books are aiming at this audience, they do not contain sufficient coverage of color, image matching, shape matching, segmentation, and texture analysis. These are the topics that make up the subfield of content-based image retrieval, which attempts to answer the question, “find me images like X”. Thus, while there is now a diversity of texts for CVIP educators, there is room for a new generation of textbooks.

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