PART I

IMAGE PROCESSING

CHAPTER 1

INTRODUCTION AND OVERVIEW

WHAT WILL WE LEARN?

- What is image processing?
- What are the main applications of image processing?
- What is an image?
- What is a digital image?
- What are the goals of image processing algorithms?
- What are the most common image processing operations?
- Which hardware and software components are typically needed to build an image processing system?
- What is a machine vision system (MVS) and what are its main components?
- Why is it so hard to emulate the performance of the human visual system (HVS) using cameras and computers?

1.1 MOTIVATION

Humans have historically relied on their vision for tasks ranging from basic instinctive survival skills to detailed and elaborate analysis of works of art. Our ability to guide our actions and engage our cognitive abilities based on visual input is a remarkable trait of the human species, and much of how exactly we do what we do—and seem to do it so well—remains to be discovered.

Practical Image and Video Processing Using MATLAB®. By Oge Marques.

The need to extract information from images and interpret their contents has been one of the driving factors in the development of image processing[1] and computer vision during the past decades.

Image processing applications cover a wide range of human activities, such as the following:

- *Medical Applications*: Diagnostic imaging modalities such as digital radiography, PET (positron emission tomography), CAT (computerized axial tomography), MRI (magnetic resonance imaging), and fMRI (functional magnetic resonance imaging), among others, have been adopted by the medical community on a large scale.
- *Industrial Applications*: Image processing systems have been successfully used in manufacturing systems for many tasks, such as safety systems, quality control, and control of automated guided vehicles (AGVs).
- *Military Applications*: Some of the most challenging and performance-critical scenarios for image processing solutions have been developed for military needs, ranging from detection of soldiers or vehicles to missile guidance and object recognition and reconnaissance tasks using unmanned aerial vehicles (UAVs). In addition, military applications often require the use of different imaging sensors, such as range cameras and thermographic forward-looking infrared (FLIR) cameras.
- *Law Enforcement and Security*: Surveillance applications have become one of the most intensely researched areas within the video processing community. Biometric techniques (e.g., fingerprint, face, iris, and hand recognition), which have been the subject of image processing research for more than a decade, have recently become commercially available.
- *Consumer Electronics*: Digital cameras and camcorders, with sophisticated built-in processing capabilities, have rendered film and analog tape technologies obsolete. Software packages to enhance, edit, organize, and publish images and videos have grown in sophistication while keeping a user-friendly interface. High-definition TVs, monitors, DVD players, and personal video recorders (PVRs) are becoming increasingly popular and affordable. Image and video have also successfully made the leap to other devices, such as personal digital assistants (PDAs), cell phones, and portable music (MP3) players.
- *The Internet, Particularly the World Wide Web*: There is a huge amount of visual information available on the Web. Collaborative image and video uploading, sharing, and annotation (tagging) have become increasingly popular. Finding and retrieving images and videos on the Web based on their contents remains an open research challenge.

[1]From this point on, the use of the phrase *image processing* should be interpreted as *digital image processing*. We shall only use the *digital* qualifier when it becomes relevant (e.g., after an analog image has been converted to a digital representation).

1.2 BASIC CONCEPTS AND TERMINOLOGY

In this section, we define the most frequently used terms in Part I of this book. Although there is no universal agreement on the terminology used in this field, the definitions presented here are consistently used throughout the book. This section is structured in a question-and-answer format.

What Is an Image?

An *image* is a visual representation of an object, a person, or a scene produced by an optical device such as a mirror, a lens, or a camera. This representation is two dimensional (2D), although it corresponds to one of the infinitely many projections of a real-world, three-dimensional (3D) object or scene.

What Is a Digital Image?

A digital image is a representation of a two-dimensional image using a finite number of points, usually referred to as *picture elements*, *pels*, or *pixels*. Each pixel is represented by one or more numerical values: for monochrome (grayscale) images, a single value representing the intensity of the pixel (usually in a [0, 255] range) is enough; for color images, three values (e.g., representing the amount of red (R), green (G), and blue (B)) are usually required. Alternative ways of representing color images, such as the *indexed color image* representation, are described in Chapter 2.

What Is Digital Image Processing?

Digital image processing can be defined as the science of modifying digital images by means of a digital computer. Since both the images and the computers that process them are digital in nature, we will focus exclusively on *digital* image processing in this book. The changes that take place in the images are usually performed *automatically* and rely on carefully designed algorithms. This is in clear contrast with another scenario, such as touching up a photo using an airbrush tool in a photo editing software, in which images are processed *manually* and the success of the task depends on human ability and dexterity. We refer to the latter as *image manipulation* to make this distinction more explicit.

What Is the Scope of Image Processing?

In this book, we adopt the terminology used in [GW08] (among others) and employ the term *image processing* to refer to all the techniques and applications described in Part I of this book, whether the output is a modified (i.e., processed) version of the input image, an encoded version of its main attributes, or a nonpictorial description of its contents.

Moreover, we distinguish among three levels of image processing operations [GW08]:

- *Low Level*: Primitive operations (e.g., noise reduction, contrast enhancement, etc.) where both the input and the output are images.
- *Mid Level*: Extraction of attributes (e.g., edges, contours, regions, etc.) from images.
- *High Level*: Analysis and interpretation of the contents of a scene.

This book does not cover the area of computer graphics or *image synthesis*, the process by which a 2D or 3D image is rendered from numerical data. In fact, we are often interested in the opposite process (sometimes referred to as *image analysis*), by which textual and numerical data can be extracted from an array of pixels.

Image processing is a multidisciplinary field, with contributions from different branches of science (particularly mathematics, physics, and computer science) and computer, optical, and electrical engineering. Moreover, it overlaps other areas such as pattern recognition, machine learning, artificial intelligence, and human vision research. This combination of cross-disciplinary research and intersecting fields can be seen in the list of magazines and journals presented in Section 1.6.

1.3 EXAMPLES OF TYPICAL IMAGE PROCESSING OPERATIONS

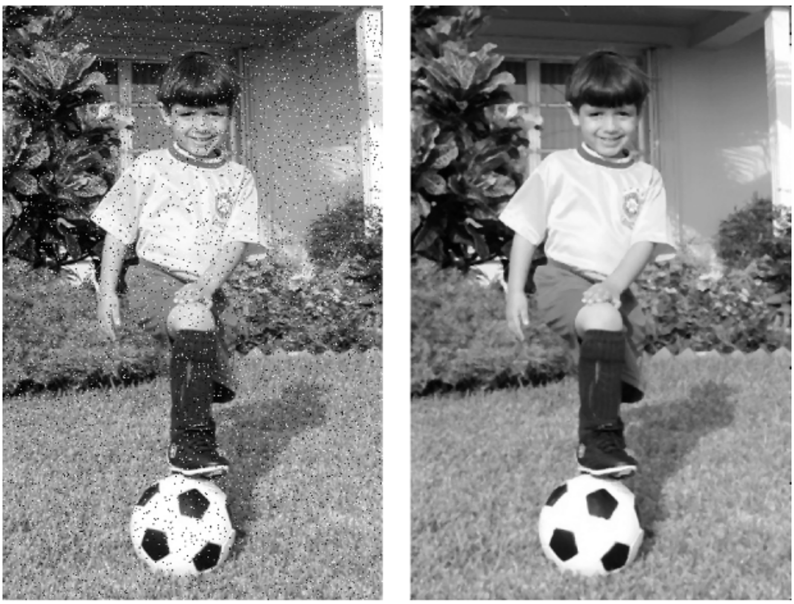
Image processing covers a wide and diverse array of techniques and algorithms, which will be described in detail in the remainder of Part I of this book. In this section, we provide a preview of the most representative image processing operations that you will learn about in forthcoming chapters.

1. *Sharpening (Figure 1.1)*: A technique by which the edges and fine details of an image are enhanced for human viewing. Chapters 8–10 will discuss how this is done in the spatial domain, whereas Chapter 11 will extend the discussion to frequency-domain techniques.
2. *Noise Removal (Figure 1.2)*: Image processing filters can be used to reduce the amount of noise in an image before processing it any further. Depending on the type of noise, different noise removal techniques are used, as we will learn in Chapter 12.
3. *Deblurring (Figure 1.3)*: An image may appear blurred for many reasons, ranging from improper focusing of the lens to an insufficient shutter speed for a fast-moving object. In Chapter 12, we will look at image deblurring algorithms.
4. *Edge Extraction (Figure 1.4)*: Extracting edges from an image is a fundamental preprocessing step used to separate objects from one another before identifying their contents. Edge detection algorithms and techniques are discussed in Chapter 14.

(a) (b)

FIGURE 1.1 Image sharpening: (a) original image; (b) after sharpening.

5. *Binarization (Figure 1.5)*: In many image analysis applications, it is often necessary to reduce the number of gray levels in a monochrome image to simplify and speed up its interpretation. Reducing a grayscale image to only two levels of gray (black and white) is usually referred to as *binarization*, a process that will be discussed in more detail in Chapter 15.



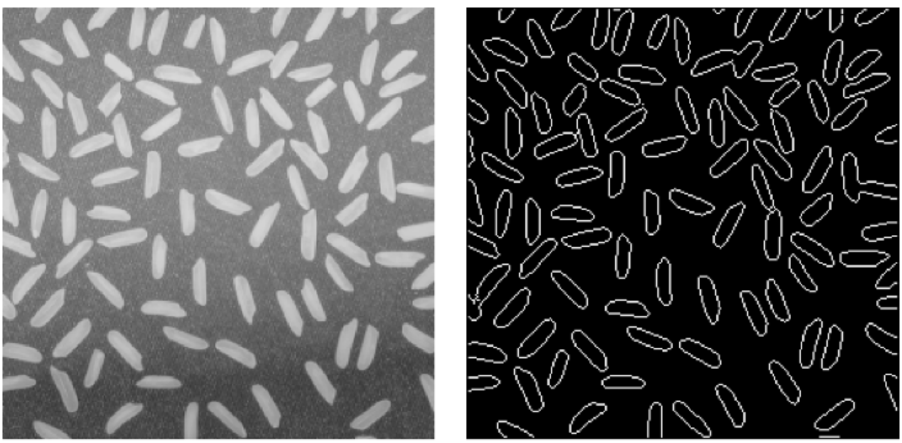
(a) (b)

FIGURE 1.2 Noise removal: (a) original (noisy) image; (b) after removing noise.

(a) (b)

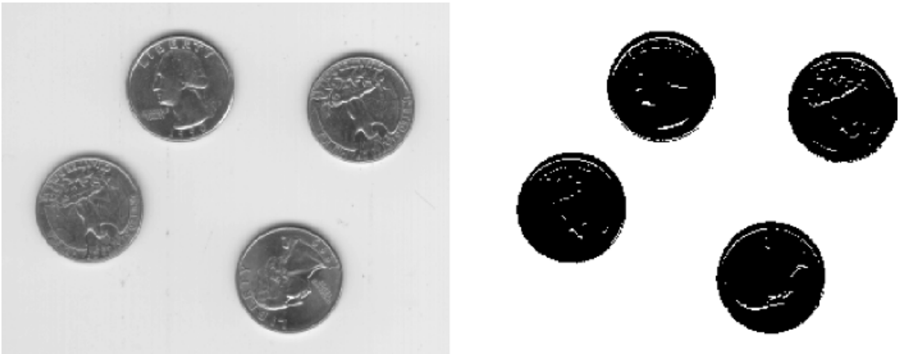
FIGURE 1.3 Deblurring: (a) original (blurry) image; (b) after removing the (motion) blur. Original image: courtesy of MathWorks.

6. *Blurring (Figure 1.6)*: It is sometimes necessary to blur an image in order to minimize the importance of texture and fine detail in a scene, for instance, in cases where objects can be better recognized by their shape. Blurring techniques in spatial and frequency domain will be discussed in Chapters 10 and 11, respectively.
7. *Contrast Enhancement (Figure 1.7)*: In order to improve an image for human viewing as well as make other image processing tasks (e.g., edge extraction)



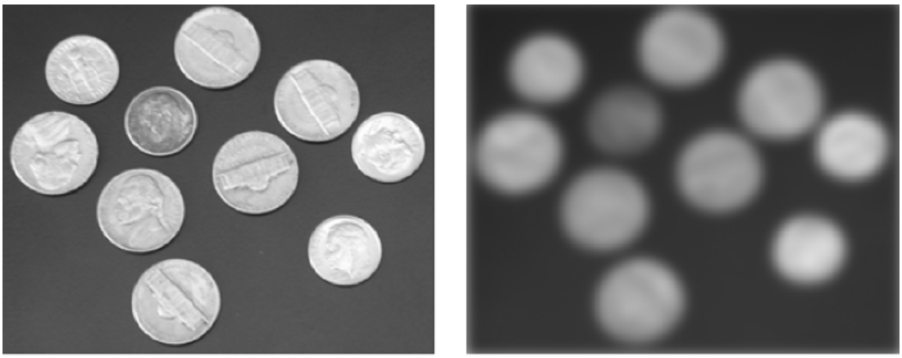
(a) (b)

FIGURE 1.4 Edge extraction: (a) original image; (b) after extracting its most relevant edges. Original image: courtesy of MathWorks.



(a) (b)

FIGURE 1.5 Binarization: (a) original grayscale image; (b) after conversion to a black-and-white version. Original image: courtesy of MathWorks.



(a) (b)

FIGURE 1.6 Blurring: (a) original image; (b) after blurring to remove unnecessary details. Original image: courtesy of MathWorks.

(a) (b)

FIGURE 1.7 Contrast enhancement: (a) original image; (b) after histogram equalization to improve contrast.

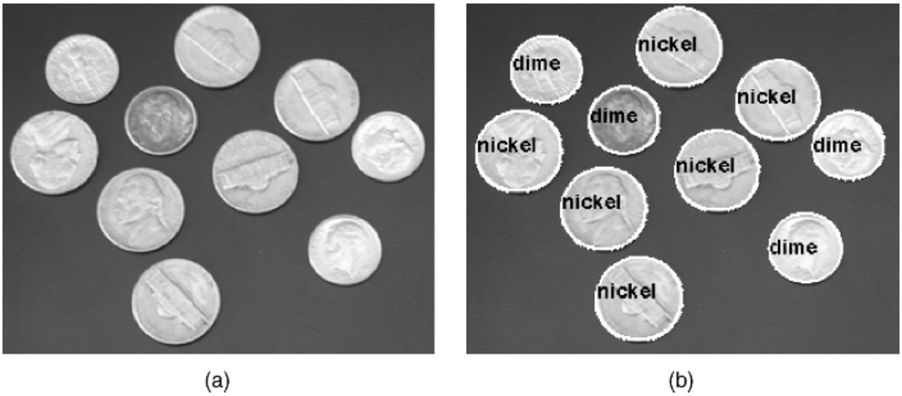


FIGURE 1.8 Object segmentation and labeling: (a) original image; (b) after segmenting and labeling individual objects. Original image: courtesy of MathWorks.

easier, it is often necessary to enhance the contrast of an image. Contrast enhancement techniques using transformation functions and histogram processing will be discussed in Chapters 8 and 9, respectively.

8. *Object Segmentation and Labeling (Figure 1.8)*: The task of segmenting and labeling objects within a scene is a prerequisite for most object recognition and classification systems. Once the relevant objects have been segmented and labeled, their relevant features can be extracted and used to classify, compare, cluster, or recognize the objects in question. Segmentation and labeling of connected components from an image will be discussed in Chapters 13 and 15. Feature extraction and representation, and pattern recognition will be covered in Chapters 18 and 19, respectively.

1.4 COMPONENTS OF A DIGITAL IMAGE PROCESSING SYSTEM

In this section, we present a generic digital image processing system and discuss its main building blocks (Figure 1.9). The system is built around a computer in which most image processing tasks are carried out, but also includes hardware and software for image acquisition, storage, and display. The actual hardware associated with each block in Figure 1.9 changes as technology evolves. In fact, even contemporary digital still cameras can be modeled according to that diagram: the CCD sensor corresponds to the *Acquisition* block, flash memory is used for *storage*, a small LCD monitor for *display*, and the digital signal processor (DSP) chip becomes the '*Computer*', where certain image processing operations (e.g., conversion from RAW format to JPEG[2]) take place.

[2]See Section 2.2 for information on image file formats.

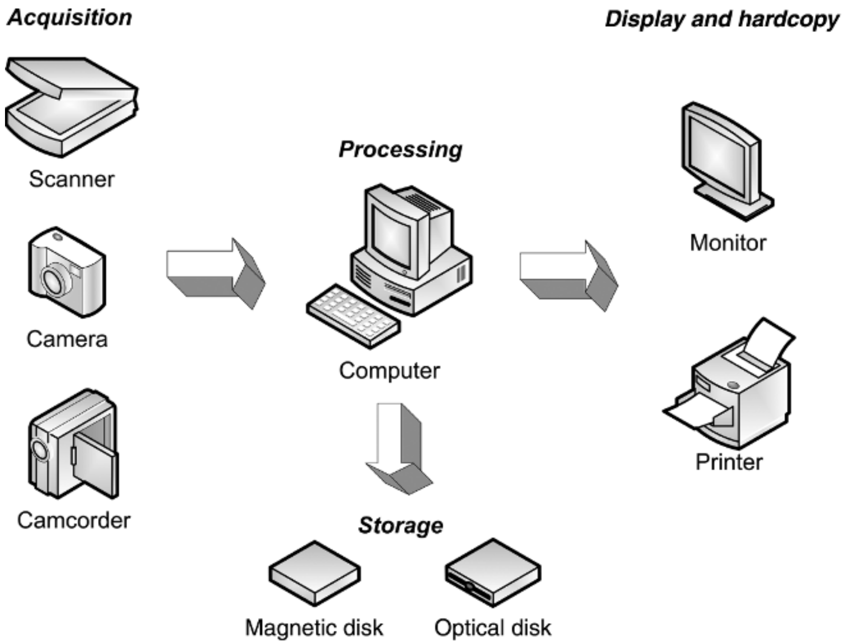


FIGURE 1.9 Components of a digital image processing system. Adapted and redrawn from [Umb05].

Hardware

The hardware components of a digital image processing system typically include the following:

- *Acquisition Devices*: Responsible for capturing and digitizing images or video sequences. Examples of general-purpose acquisition devices include scanners, cameras, and camcorders. Acquisition devices can be interfaced with the main computer in a number of ways, for example, USB, FireWire, Camera Link, or Ethernet. In cases where the cameras produce analog video output, an image digitizer—usually known as *frame grabber*—is used to convert it to digital format.
- *Processing Equipment*: The main computer itself, in whatever size, shape, or configuration. Responsible for running software that allows the processing and analysis of acquired images.
- *Display and Hardcopy Devices*: Responsible for showing the image contents for human viewing. Examples include color monitors and printers.
- *Storage Devices*: Magnetic or optical disks responsible for long-term storage of the images.

Software

The software portion of a digital image processing system usually consists of modules that perform specialized tasks. The development and fine-tuning of software for image processing solutions is iterative in nature. Consequently, image processing researchers and practitioners rely on programming languages and development environments that support modular, agile, and iterative software development.

In this book, the software of choice is MATLAB® (MATrix LABoratory), a multiplatform, data analysis, prototyping, and visualization tool with built-in support for matrices and matrix operations, rich graphics capabilities, and a friendly programming language and development environment. MATLAB offers programmers the ability to edit and interact with the main functions and their parameters, which leads to valuable time savings in the software development cycle.

MATLAB has become very popular with engineers, scientists, and researchers in both industry and academia, due to many factors, such as the availability of *toolboxes* containing specialized functions for many application areas, ranging from data acquisition to image processing (which is the main focus of our interest and will be discussed in Chapter 4).

1.5 MACHINE VISION SYSTEMS

In this section, we introduce the main components of a machine vision system (Figure 1.10) using a practical example application: recognizing license plates at a highway toll booth. Image processing is not a one-step process: most solutions follow a sequential processing scheme whose main steps are described next.

The *problem domain*, in this case, is the automatic recognition of license plates. The goal is to be able to extract the alphanumeric contents of the license plate of a vehicle passing through the toll booth in an automated and unsupervised way, that is, without need for human intervention. Additional requirements could include 24/7 operation (under artificial lighting), all-weather operation, minimal acceptable success rate, and minimum and maximum vehicle speed.

The *acquisition* block is in charge of acquiring one or more images containing a front or rear view of the vehicle that includes its license plate. This can be implemented using a CCD camera and controlling the lighting conditions so as to ensure that the image will be suitable for further processing. The output of this block is a digital image that contains a (partial) view of the vehicle. Several factors should be considered in the design of this block and will likely impact the quality of the resulting image as well as the performance of the whole system, such as the maximum speed allowed for the vehicle without risk of blurring the picture, illumination aspects (e.g., number, type, and positioning of light sources), choice of lenses, and the specification (resolution and speed) of the image digitizer hardware.

The goal of the *preprocessing* stage is to improve the quality of the acquired image. Possible algorithms to be employed during this stage include contrast improvement, brightness correction, and noise removal.

The *segmentation* block is responsible for partitioning an image into its main components: relevant foreground objects and background. It produces at its output a number of labeled regions or "subimages." It is possible that in this particular case segmentation will be performed at two levels: (1) extracting the license plate from the rest of the original image; and (2) segmenting characters within the plate area. Automatic image segmentation is one of the most challenging tasks in a machine vision system.

The *feature extraction* block (also known as *representation and description*) consists of algorithms responsible for encoding the image contents in a concise and descriptive way. Typical features include measures of color (or intensity) distribution, texture, and shape of the most relevant (previously segmented) objects within the image. These features are usually grouped into a *feature vector* that can then be used as a numerical indicator of the image (object) contents for the subsequent stage, where such contents will be recognized (classified).

Once the most relevant features of the image (or its relevant objects, in this case individual characters) have been extracted and encoded into a feature vector, the next step is to use this K-dimensional numerical representation as an input to the *pattern classification* (also known as *recognition and interpretation*) stage. At this point, image processing meets classical pattern recognition and benefits from many of its tried-and-true techniques, such as minimum distance classifiers, probabilistic classifiers, neural networks, and many more. The ultimate goal of this block is to classify (i.e., assign a label to) each individual character, producing a string (or ASCII file) at the output, containing the license plate contents.

In Figure 1.10, all modules are connected to a large block called *knowledge base*. These connections—inspired by a similar figure in [GW08]—are meant to indicate that the successful solution to the license plate recognition problem will depend on how much knowledge about the problem domain has been encoded and stored in the MVS. The role of such knowledge base in the last stages is quite evident (e.g., the

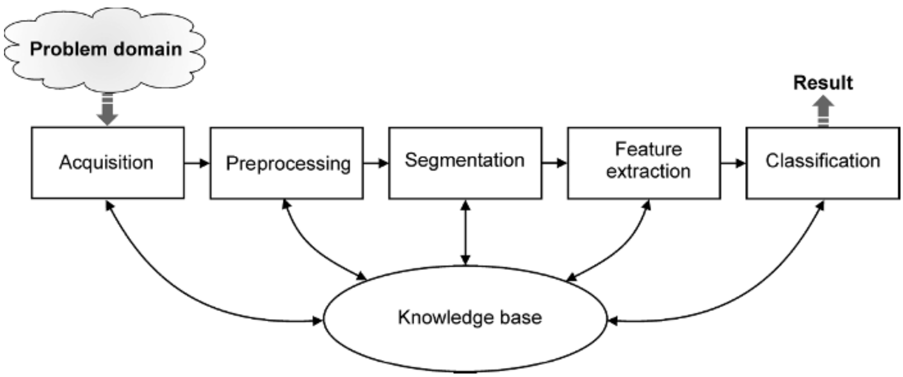


FIGURE 1.10 Diagram of a machine vision system. Adapted and redrawn from [GW08].

knowledge that the first character must be a digit may help disambiguate between a "0" and an "O" in the *pattern classification* stage). In a less obvious way, the knowledge base should (ideally) help with all tasks within the MVS. For example, the *segmentation* block could benefit from rules specifying known facts about the license plates, such as shape and aspect ratio, most likely location within the original image, number of characters expected to appear within the plate, size and position information about the characters, and relevant background patterns that may appear in the plate area.

The human visual system and a machine vision system have different strengths and limitations and the designer of an MVS must be aware of them. A careful analysis of these differences provides insight into why it is so hard to emulate the performance of the human visual system using cameras and computers. Three of the biggest challenges stand out:

- The HVS can rely on a very large database of images and associated concepts that have been captured, processed, and recorded during a lifetime. Although the storage of the images themselves is no longer an expensive task, mapping them to high-level semantic concepts and putting them all in context is a very hard task for an MVS, for which there is no solution available.
- The very high speed at which the HVS makes decisions based on visual input. Although several image processing and machine vision tasks can be implemented at increasingly higher speeds (often using dedicated hardware or fast supercomputers), many implementations of useful algorithms still cannot match the speed of their human counterpart and cannot, therefore, meet the demands of real-time systems.
- The remarkable ability of the HVS to work under a wide range of conditions, from deficient lighting to less-than-ideal perspectives for viewing a 3D object. This is perhaps the biggest obstacle in the design of machine vision systems, widely acknowledged by everyone in the field. In order to circumvent this limitation, most MVS must impose numerous constraints on the operating conditions of the scene, from carefully controlled lighting to removing irrelevant distractors that may mislead the system to careful placing of objects in order to minimize the problems of shades and occlusion.

Appendix A explores selected aspects of the HVS in more detail.

1.6 RESOURCES

In this section, we have compiled a list of useful resources for readers who want to deepen their knowledge and tackle more advanced concepts, algorithms, and mathematical constructs. A similar section on video processing resources appears in Chapter 20.

Books

The following is a list of selected books on image processing and related fields:

- Burger, W. and Burge, M. J., *Digital Image Processing: An Algorithmic Introduction Using Java*, New York: Springer, 2008.
- Gonzalez, R. C. and Woods, R. E., *Digital Image Processing*, 3rd ed., Upper Saddle River, NJ: Prentice Hall, 2008.
- Sonka, M, Hlavac, V., and Boyle, R., *Image Processing, Analysis, and Computer Vision*, 3rd ed., Toronto, Ontario: Thomson Learning, 2008.
- Pratt, W. K., *Digital Image Processing*, 4th ed., New York: Wiley–Interscience, 2007.
- Jahne, B., *Digital Image Processing: Concepts, Algorithms, and Scientific Applications*, 6th ed., Berlin: Springer, 2005.
- Davies, E. R., *Machine Vision: Theory, Algorithms, Practicalities*, 3rd ed., San Francisco, CA: Morgan Kaufmann, 2005.
- Umbaugh, S. E., *Computer Imaging: Digital Image Analysis and Processing*, Boca Raton, FL: CRC Press, 2005.
- Gonzalez, R. C., Woods, R. E., and Eddins, S. L., *Digital Image Processing Using MATLAB*, Upper Saddle River, NJ: Prentice Hall, 2004.
- McAndrew, A., *Introduction to Digital Image Processing with MATLAB*, Boston, MA: Thomson, 2004.
- Forsyth, D. F. and Ponce, J., *Computer Vision: A Modern Approach*, Upper Saddle River, NJ: Prentice Hall, 2002.
- Duda, R. O., Hart, P. E., and Stork, D. G., *Pattern Classification*, 2nd ed., New York: Wiley, 2001.
- Shapiro, L. G. and Stockman, G. C., *Computer Vision*, Upper Saddle River, NJ: Prentice Hall, 2001.
- Bovik, A. (Ed.), *Handbook of Image and Video Processing*, San Diego, CA: Academic Press, 2000.
- Efford, N., *Digital Image Processing: A Practical Introduction Using Java*, Harlow, UK: Addison-Wesley, 2000.
- Seul, M., O'Gorman, L., and Sammon, M. J., *Practical Algorithms for Image Analysis*, Cambridge, UK: Cambridge University Press, 2000.
- Schalkoff, R. J., *Digital Image Processing and Computer Vision*, New York: Wiley, 1989.

Magazines and Journals

The following are some of the magazines and journals that publish research results in image and video processing and related areas (in alphabetical order): *Artificial Intelligence*, *Computer Vision and Image Understanding*, *EURASIP Journal on Advances in Signal Processing*, *EURASIP Journal on Image and Video Processing*, *IEEE Multimedia Magazine*, *IEEE Transactions on Circuits and Systems for Video Technology*, *IEEE Transactions on Image Processing*, *IEEE Transactions on Medical Imaging*, *IEEE Transactions on Multimedia*, *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *Image and Vision Computing*, *International Journal of Computer Vision*, *Journal of Electronic Imaging (SPIE and IS&T)*, *Journal of Mathematical Imaging and Vision*, *Journal of Visual Communication and Image Representation*, *Machine Vision and Applications*, *Pattern Recognition*, and *Signal Processing: Image Communication*.

In addition, there are a number of useful trade magazines, such as *Advanced Imaging Magazine*, *Imaging and Machine Vision Europe Magazine*, *Studio Monthly*, and *Vision Systems Design Magazine*.

Web Sites

This section contains a selected number of useful web sites. Some of them are portals to image processing and computer vision information (e.g., conferences, research groups, and publicly available databases) and contain many links to other relevant sites.

Since web pages often move and change URLs (and some disappear altogether), the current URL for the web sites suggested in the book will be available (and maintained up-to-date) in the book's companion web site (http://www.ogemarques.com). The book's companion web site will also add relevant sites that were not available at the time of this writing.

- *CVonline*: This ever-growing Compendium of Computer Vision, edited and maintained by Professor Robert B. Fisher, School of Informatics, University of Edinburgh, UK, includes a collection of hypertext summaries on more than 1400 topics in computer vision and related subjects.
  http://homepages.inf.ed.ac.uk/rbf/CVonline
- *Computer Vision Home Page*: Arguably the best-known portal for image processing research. Excellent starting point when searching for publications, test images, research groups, and much more.
  http://www.cs.cmu.edu/ cil/vision.html
- *USC Annotated Computer Vision Bibliography*: An extensive and structured compilation of relevant bibliography in the fields of computer vision and image processing.
  http://iris.usc.edu/Vision-Notes/bibliography/contents.html
- *USC Computer Vision Conference Listing*: A structured list of computer vision and image processing conferences and pertinent details.
  http://iris.usc.edu/Information/Iris-Conferences.html
- *Vision-Related Books*: A list of more than 500 books—including online books and book support sites—edited and maintained by Bob Fisher.
  http://homepages.inf.ed.ac.uk/rbf/CVonline/books.htm

- *Mathtools.net*: A technical computing portal containing links to thousands of relevant code for MATLAB (among others).
  http://www.mathtools.net/
- *The MathWorks Central File Exchange*: User-contributed MATLAB code for image processing and many other fields.
  http://www.mathworks.com/matlabcentral/fileexchange/

WHAT HAVE WE LEARNED?

- Digital image processing is the science of modifying digital images using a digital computer.
- Digital image processing is closely related to other areas such as *computer vision* and *pattern recognition*.
- Digital image processing algorithms, techniques, and applications usually take an image as input and produce one of the following outputs: a modified (i.e., processed) image, an encoded version of the main attributes present in the input image, or a nonpictorial description of the input image's contents.
- Digital image processing has found applications in almost every area of modern life, from medical imaging devices to quality control in manufacturing systems, and from consumer electronics to law enforcement and security.
- An *image* is a visual representation of an object, a person, or a scene produced by an optical device such as a mirror, a lens, or a camera. This representation is two dimensional, although it corresponds to one of the infinitely many projections of a real-world, three-dimensional object or scene.
- A digital image is a representation of a two-dimensional image using a finite number of pixels, each of which indicates the gray level or color contents of the image at that point.
- Image manipulation techniques consist of manually modifying the contents of an image using preexisting tools (e.g., airbrush).
- Representative image processing operations include image sharpening, noise removal, edge extraction, contrast enhancement, and object segmentation and labeling.
- A digital image processing system is usually built around a general-purpose computer equipped with hardware for image and video acquisition, storage, and display. The software portion of the system usually consists of modules that perform specialized tasks. In this book, we shall use MATLAB (and its Image Processing Toolbox) as the software of choice.
- A machine vision system is a combination of hardware and software designed to solve problems involving the analysis of visual scenes using intelligent algorithms. Its main components are acquisition, preprocessing, segmentation, feature extraction, and classification.

- It is extremely difficult to emulate the performance of the human visual system—in terms of processing speed, previously acquired knowledge, and the ability to resolve visual scenes under a wide range of conditions—using machine vision systems.

LEARN MORE ABOUT IT

- Chapter 1 of [GW08] contains a detailed account of the history of image processing and its most representative applications.
- Another good overview of image processing applications is provided by Baxes [Bax94].
- Chapter 16 of [SHB08] contains insightful information on design decisions involved in the development of a few selected case studies in machine vision.

1.7 PROBLEMS

1.1 Use the block diagram from Figure 1.10 as a starting point to design a machine vision system to read the label of the main integrated circuit (IC) on a printed circuit board (PCB) (see Figure 1.11 for an example). Explain what each block will do, their input and output, what are the most challenging requirements, and how they will be met by the designed solution.

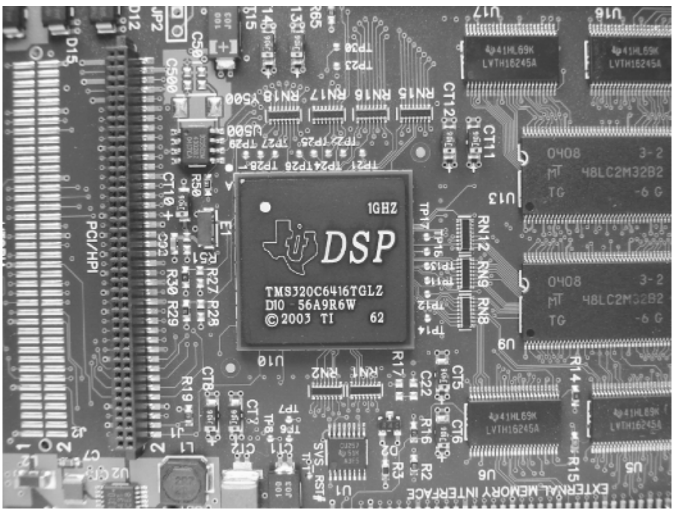


FIGURE 1.11 Test image for the design of a machine vision system to read the label of the main integrated circuit on a printed circuit board.

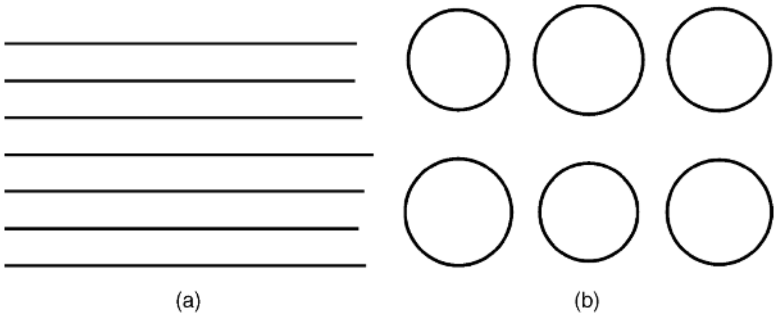


FIGURE 1.12 (a) Test image for distance estimation: parallel lines with up to 5% difference in length. (b) Test image for area estimation: circles with up to 10% difference in radius. Both images are adapted and redrawn from [Jah05].

1.2 In our discussion on machine vision systems, we indicated that the following are the three biggest difficulties in emulating the human visual system: its huge database (images and concepts captured, processed, and recorded during a lifetime), its high speed for processing visual data and making decisions upon them, and the ability to perform under a wide range of work conditions. Explain each of these challenges in your own words, and comment on which ones are more likely to be minimized, thanks to advances in image processing hardware and software.

1.3 Who do you think would perform better at the following tasks: man (HVS) or computer (MVS)? Please explain why.

(a) Determining which line is the shortest in Figure 1.12a.

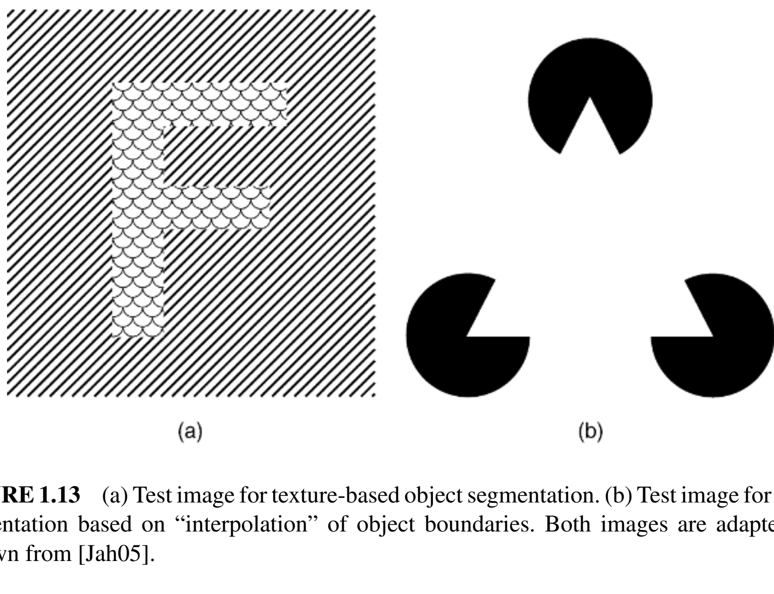


FIGURE 1.13 (a) Test image for texture-based object segmentation. (b) Test image for object segmentation based on "interpolation" of object boundaries. Both images are adapted and redrawn from [Jah05].

(b) Determining which circle is the smallest in Figure 1.12b.

(c) Segmenting the image containing the letter “F” from the background in Figure 1.13a.

(d) Segmenting the white triangle (this triangle—known as “Kanizsa’s triangle”—is a well-known optical illusion) in Figure 1.13b.