Understanding Digital Image Processing

Book · September 2018

DOI: 10.1201/9781315123905

Vipin Tyagi
Jaypee University of Engineering and Technology

Understanding Digital Image Processing

Vipin Tyagi

Department of Computer Science and Engineering
Jaypee University of Engineering and Technology
Raghogarh, Guna (MP), India

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business
A SCIENCE PUBLISHERS BOOK

Cover photo credits: Prahlad Bubbar collection

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed on acid-free paper
Version Date: 20180730

International Standard Book Number-13: 978-1-138-56684-2 (Hardback)

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

Preface

Digital Images are an integral part of our digital life. Digital images are used in every aspect of or daily life. Digital image processing concerns with techniques to perform processing on an image, to get an enhanced image or to extract some useful information from it to make some decisions based on it. Digital image processing techniques are growing at a very fast speed. This book,*Understanding Digital Image Processing* aims on providing digital image processing concepts in a simple language with the help of examples. The major objective of this text book is to introduce the subject to the readers and motivate for further research in the area.

To explain the concepts, MATLAB® functions are used throughout the book. MATLAB® Version 9.3 (R2017b), Image Acquisition Toolbox Version 5.3 (R2017b), Image Processing Toolbox, Version 10.1 (R2017b) are used to create the book material. My thanks to MathWorks for providing support in preparation of this book.

The functions provided by Image Processing Toolbox™ are given in Appendix A. The details of these functions are available at on the website https://in.mathworks.com/help/images/index.html

For MATLAB® product information, please contact:

The MathWorks, Inc.

3 Apple Hill Drive

Natick, MA, 01760-2098 USA

Tel: 508-647-7000

Fax: 508-647-7001

E-mail: info@mathworks.com

Web: mathworks.com

How to buy: www.mathworks.com/store

'C' language is a very popular programming language. Various functions written in 'C' language are given in Appendix B. My sincere thanks to Mr. Dwayne Phillips for permitting to use the code written by him. Related sub-functions and their descriptions are available at http://homepages.inf.ed.ac.uk/rbf/BOOKS/PHILLIPS/.

A glossary of common image processing terms is provided in Appendix C.

A bibliography of the work in the area of image processing is also given at end of the book. We are thankful to all authors whose work has been used in preparation of the manu-script. We have tried to include all such work in bibliography, but if we have skipped some work by error, we will include in next version of the book, Color version of some figures have been provided at the end of the book. These figures also have corresponding black & white versions in the text.

The target audience spans the range from the undergraduate with less exposure to subject to research students interested in learning digital image processing. Many texts are available in the area of digital image processing. In this book, objective is to explain the concepts in a very simple and understandable manner. Hope this book will succeed in its aim.

This work would not have been possible without the help and mentoring from many,in particular, my teacher Prof. Vinod K. Agarwal, Meerut. Special thanks to my dear scholars Mr. K. B. Meena, Dr. Ashwani Kumat and Dr. Deepshikha Tiwari, for their help and support in preparation of the manuscript.

The research work of several researchers contributed to a substantial part of some sections of the book. I thankfully acknowledge their contributions.

It has been a pleasure working with Taylor and Francis Publishers in the development of the book. Thanks to Mr. Vijay Primlani for his kind and timely support in publishing the book and for handling the publication.

Contents

1

Introduction to Digital Image Processing

1.1 Introduction

In today's digital life, digital images are everywhere around us. An image is a visual representation of an object, a person, or a scene. A digital image is a two-dimensional function f(x, y) that is a projection of a 3-dimesional scene into a 2-dimensional projection plane, where x, y represents the location of the picture element or pixel and contains the intensity value. When values of x, y and intensity are discrete, then the image is said to be a digital image. Mathematically, a digital image is a matrix representation of a two-dimensional image using a finite number of points cell elements, usually referred to as pixels (picture elements, or pels). Each pixel is represented by numerical values: for grayscale images, a single value representing the intensity of the pixel (usually in a [0, 255] range) is enough; for color images, three values (representing the amount of red (R), green (G), and blue (B)) are stored. If an image has only two intensities, then the image is known as a binary image. Figure 1.1 shows a color image and its red, green and blue components. The color image is a combination of these three images. Figure 1.1e shows the 8-bit grayscale image corresponding to color image shown in Fig. 1.1a. Figure 1.1 also shows the matrix representation of a small part of these images.

MATLAB® supports the following image types:

1. **Grayscale:** A grayscale image, having M×N pixels is represented as a matrix of double datatype of M×N size in MATLAB. Element values denote the pixel grayscale intensities in the range [0,1] with 1 = white and 0 = black.
2. **True-color RGB:** A true-color red-green-blue (RGB) image is represented as a three-dimensional M×N×3 double matrix in MATLAB. Each pixel has

(a)

(b)

(c)

(d)

(e)

(f)

103	105	102	99	97	97	96	95
139	144	144	143	142	133	125	111
174	181	184	189	193	193	187	179
174	179	185	187	189	193	194	192
183	185	184	187	187	187	188	196
184	182	180	184	183	185	186	191
184	182	182	182	181	181	180	184
194	184	182	180	178	177	175	179
199	189	184	178	175	173	172	171
190	186	185	178	174	169	168	167

(g)

76	82	82	83	83	85	85	88
83	83	82	80	81	82	83	84
80	80	78	73	75	80	80	75
78	80	76	76	78	78	75	73
74	79	74	74	77	79	80	80
73	78	77	74	75	78	78	75
76	72	75	75	73	73	75	75
73	74	74	70	71	74	76	78
75	76	78	79	79	75	76	80
78	78	80	83	82	80	78	78
81	78	82	81	81	84	82	83

(h)

67	71	72	72	73	74	70	66
70	72	73	73	71	73	72	68
72	72	71	71	71	68	70	70
74	73	66	66	69	68	71	71
70	67	66	69	71	70	70	68
69	64	69	71	68	68	72	70
67	67	71	70	63	66	70	72
71	69	68	68	66	69	68	71
68	69	67	67	73	69	62	70
63	65	62	61	68	68	61	66

(i)

51	54	53	52	53	54	53	51
52	53	55	54	52	54	54	51
52	53	53	52	51	52	53	53
55	53	51	52	53	52	53	53
53	50	49	50	52	51	52	50
52	48	49	49	49	51	52	51
51	50	52	51	48	51	52	53
52	52	52	52	52	53	52	54
50	53	52	51	52	53	50	52
48	48	49	48	51	51	48	49

Fig. 1.1 contd. ...

red, green and blue components. The color components of a pixel (m,n) are denoted as (m,n,1) = red, (m,n,2) = green, (m,n,3) = blue.

3. **Indexed:** In MATLAB, Indexed (paletted) images are represented with an index matrix of size M×N and a colormap matrix of size K×3. The colormap matrix holds all colors used in the image and the index matrix represents the pixels by referring to colors in the colormap.
4. **Binary:** In MATLAB, a binary image having two values, 1 (white) or 0 (black), is represented by an M×N logical matrix.
5. **uint8:** In MATLAB, this type uses less memory and some operations compute faster than with double types.

In image processing operations, most of the operations are performed in grayscale images. For color image processing applications, a color image can be decomposed into Red, Green and Blue components and each component is processed independently as a grayscale image. For processing, an indexed image is converted to grayscale image or RGB color image for most operations.

MATLAB commands imread and imwrite are used for reading and writing image files as:

I = imread(filename);
imwrite(I, filename) writes image data I to the file specified by filename, inferring the file format from the extension. The bit depth of the output image depends on the data type of I and the file format. For most formats:

- If I is of data type uint8, then imwrite outputs 8-bit values.
- If I is of data type uint16 and the output file format supports 16-bit data (JPEG, PNG and TIFF), then imwrite outputs 16-bit values. If the output file format does not support 16-bit data, then imwrite returns an error.
- If I is a grayscale or RGB color image of double or single data type, then imwrite assumes that the dynamic range is [0,1] and automatically scales the data by 255 before writing it to the file as 8-bit values. If the data in I is single, convert I to double before writing to a GIF or TIFF file.
- If I is of logical data type, then imwrite assumes that the data is a binary image and writes it to the file with a bit depth of 1, if the format allows it. BMP, PNG, or TIFF formats accept binary images as input arrays.

...Fig. 1.1 contd.

Fig. 1.1. (a) A color image; (b) Red Component of color image (a); (c) Green Component of color image (a); (d) Blue Component of color image (a); e) Color image (a) converted into 8-bit grayscale image; (f) Matrix representation of upper left corner of image (b); (g) Matrix representation of upper left corner of image (c); (h) Matrix representation of upper left corner of image (d); (i) Matrix representation of upper left corner of image (e).

Original image reprinted with permission of The MathWorks, Inc.

(For color images of Fig. 1.1(a), (b), (c), (d) see Color Figures Section at the end of the book)

In literature, the following three levels of image processing operations are defined:

- Low-Level image processing: Primitive operations on images (e.g., contrast enhancement, noise reduction, etc.) are under this category, where both the input and the output are images.
- Mid-Level image processing: In this category, operations involving extraction of attributes (e.g., edges, contours, regions, etc.), from images are included.
- High-Level image processing: This category involves complex image processing operations related to analysis and interpretation of the contents of a scene for some decision making.

Image processing involves many disciplines, mainly computer science, mathematics, psychology and physics. Other areas, such as artificial intelligence, pattern recognition, machine learning, and human vision, are also involved in image processing.

1.2 Typical Image Processing Operations

Image processing involves a number of techniques and algorithms. The most representative image processing operations are:

- **Binarization:** Many image processing tasks can be performed by converting a color image or a grayscale image into binary in order to simplify and speed up processing. Conversion of a color or grayscale image to a binary image having only two levels of gray (black and white) is known as binarization.
- **Smoothing:** A technique that is used to blur or smoothen the details of objects in an image.
- **Sharpening:** Image processing techniques, by which the edges and fine details of objects in an image are enhanced for human viewing, are known as sharpening techniques.
- **Noise Removal and De-blurring:** Before processing, the amount of noise in images is reduced using noise removal filters. Image removal technique can sometimes be used, depending on the type of noise or blur in the image.
- **Edge Extraction:** To find various objects before analyzing image contents, edge extraction is performed.
- **Segmentation:** The process of dividing an image into various parts is known as segmentation. For object recognition and classification segmentation is a pre-processing step.

1.3 History of Digital Image Processing

Earlier digital image processing was mainly used in the newspaper industry to make images look better or for simply converting black and white images into color images. In the 1920s, digital images were transmitted electronically between London and New York. Initial Bartlane cable picture systems were capable of coding an image using five gray levels; this was later enhanced to 15 gray levels in 1929. Actual digital image processing started after the invention of digital computers and related technologies, including image storage, display and transmission. In the 1960s, powerful computers gave birth to meaningful digital image processing. Satellite Images of the moon, taken by Ranger 7 U.S. spacecraft, were processed at the Jet Propulsion laboratory at California. At the same time, use of digital image processing began in various activities relating to astronomy, medical image processing, remote sensing, etc. From 1960 onwards, the use of digital image processing techniques has grown tremendously. These techniques are now used in almost every part of our life. They have applications in the fields of defence, astronomy, medicine, law, etc.

Some common examples of digital image processing are fingerprint recognition, processing of satellite images, weather prediction, character recognition, face recognition, product inspection and assembly.

1.4 Human Visual System

The human visual system consists of two parts: eye and brain. The human eye acts as a receptor of images by capturing light and converting it into signals. These signals are then transmitted to the brain for further analysis. Eyes and brain work in combination to form a picture.

The human eye is analogous to a camera. The structure of human eye is shown in Fig. 1.2:

Various parts of the human eye are identified:

- Primary Lens: Cornea and aqueous humour, used to focus incoming light signal.
- Iris: The iris dynamically controls the amount of light entering the eye, so that the eye can function in various lighting conditions, from dim light to very bright light. The portion of the lens not covered by the iris is called the pupil.
- Zonula: This is a muscle that controls the shape and positioning (forward and backward) of the eye's lens.

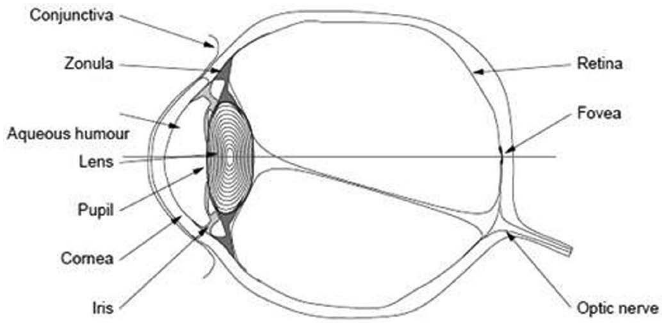

Fig. 1.2. Human eye.

- Retina: provides a photo-sensitive screen at the back of the eye; it converts the light hitting the retina into nerve signals.
- Fovea: A small central region of the retina that contains a large number of photo-sensitive cells and provides very good resolution.
- Optic nerve: These nerves carry the signals generated by the retina to the brain.

Human vision has a "blind spot" in the area of the retina where the optic nerves are attached. This blind spot does not have any photosensitive cells.

Light sensitive cells in the brain are of two types: rods and cones. There are about 120 million rod cells and 6 million cone cells. Rod cells provide visual capability at very low light levels and are very sensitive. Cone cells provide our daytime visual facilities and perform best at normal light levels.

Rods and cones are not uniformly distributed across the retina. The cones are concentrated in the center, while the rods are away from the center (Fig. 1.3). A yellow spot (macula), of size 2.5 to 3 mm in diameter, is found in the middle of the retina. Cones are very tightly packed together and the blood vessels within the fovea and other cells are pulled aside in order to expose them directly to the light.

In dim light, such as moonlight, rods in our eyes are activated and the fovea effectively acts as a second blindspot. To see small objects at night, one must shift the vision slightly to one side, around 4 to 12 degrees, so that the light falls on some rods.

Although there are about 120 million rods and 6 million cone cells in the retina, there are less than a million optic nerve fibres which connect them to the brain. This means that there cannot be a single one-to-one connection between the photoreceptors and the nerve fibres. The number of receptors connecting to each fibre is location dependent.

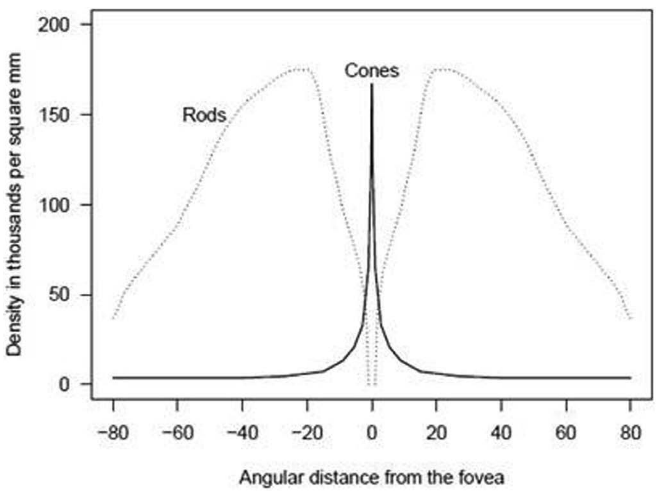

Fig. 1.3. Rods and Cones cells distribution in the retina.

In the fovea, cones have a one-to-one interaction, while in the outer part of the retina, about 600 rods are connected to each nerve fibre.

1.5 Classification of Digital Images

With regard to the manner in which they are stored, digital images can be classified into two categories: (1) Raster or Bitmap image, (2) Vector image.

A bitmap or raster image is a rectangular array of sampled values or pixels. These images have a fixed number of pixels. In the zooming of a raster image, mathematical interpolation is applied. The quality of a zoomed image degrades after a particular value of zooming factor, as shown in Fig. 1.4.

The resolution of a bitmap image is determined by the sensing device. BMP, GIF, PNG, TIFF and JPEG common image formats are bitmap or raster image formats.

On the other hand, vector images are stored in the form of mathematical lines and curves. Information like length, color, thickness, etc., is stored in the form of a vector. These images can be displayed in any size, any resolution and on any output

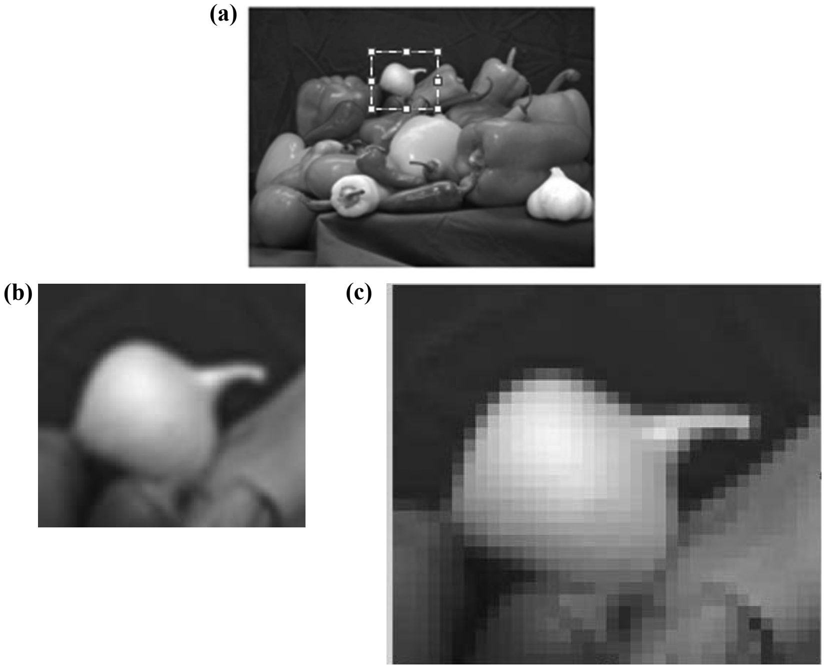

Fig. 1.4. Zooming of a Bitmap image (a) Original image (b) Part of image zoomed 4 times (c) Same part of the image zoomed 8 times.
Original image reprinted with permission of The MathWorks, Inc.
(For color image of Fig. 1.4(a), see Color Figures Section at the end of the book)

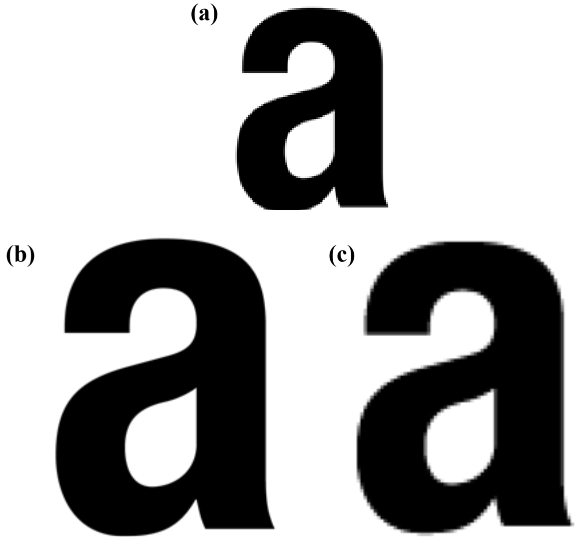

Fig. 1.5. (a) An image (b) Image in (a) zoomed in vector format (c) Image in (a) zoomed in Raster format.

device. Vector images are suitable in illustrations, line art, font, etc. The difference in zooming of a vector image and raster image can be observed in Fig. 1.5. The degradation in the quality due to zooming is clearly visible on the boundaries of the character stored in raster format.

1.6 Digital Image File Types

There are a number of digital image file types available these days. The most commonly used image file types are: JPEG, GIF, TIFF, PNG and BMP. Image file types are based on the compression technique used for reducing the size of the image file. Images in various file types may differ in color, if color has been used. An image in its simplest form may contain only two intensities, i.e., black and white, and needs only 1 bit to represent intensity at each pixel.

- **TIFF** (Tagged Image File Format): This format is a very flexible and may be based on a lossy or lossless compression technique. The details of the compression technique are stored in the image itself. Generally, TIFF files use a lossless image storage format and, hence, are quite large in size.
- **Portable Network Graphics** (PNG): This format is a lossless storage format and uses patterns in the image to compress the image. The compression in PNG files is exactly reversible, meaning the uncompressed image is identical to the original image.
- **Graphical Interchange Format** (GIF): This format creates a table of upto 256 colors from 16 million colors. If the image to be compressed has less

than 256 colors, then the GIF image has exactly the same color. But if the number of colors is greater than 256, then the GIF approximates the colors in the image using a table of the 256 colors that are available.

- **Joint Picture Experts Group** (JPG or JPEG): This format is an optimized format for photographs and continuous tone images that contain a large number of colors. JPEG files can achieve high compression ratios while maintaining clear image quality.
- **RAW:** This is a lossless image format available on some digital cameras. These files are very small but the format is manufacturer dependent, therefore, the manufacturer's software is required in order to view the images.
- **Bitmapped Image** (BMP) is an uncompressed proprietary format invented by Microsoft.

Some other common image file formats are PSD, PSP, etc., which are proprietary formats used by graphics programs. Photoshop's files have the PSD extension, while Paintshop Pro files use the PSP extension.

MATLAB supports a number of image file formats, e.g., Windows Bitmap, Windows Cursor resources, Flexible Image Transport, Graphics Interchange Format, Windows Icon resources, JPEG, Portable Bitmap, Windows Paintbrush, Tagged Image File Format.

The details can be obtained using MATLAB function imformats. The imformats function can be used if the file format exists in the registry as:

```
formatStruct = imformats ('bmp'), then the output will look like:
format Struct = struct with fields:
  ext: {'bmp'}
  isa: @isbmp
  info: @imbmpinfo
  read: @readbmp
  write: @writebmp
  alpha: 0
  description: 'Windows Bitmap'
```

1.7 Components of an Image Processing System

A complete digital image processing system comprises of various elements, such as image acquisition, storage, image processing, displays, etc. (Fig. 1.6).

Sensing devices are used to capture the image. The sensing device senses the energy radiated by the object and converts it into digital form. For example, a digital camera senses the light intensity and converts into the digital image form. Image processing elements are used to perform various operations on a digital image. It requires a combination of hardware and software. Storage is a very important part of an image processing system. The size of an image or video file is very large. For instance, an 8-bit image having 1024 x 1024 pixels requires 1 megabyte of storage space. Therefore, mass storage devices are required in image processing systems.

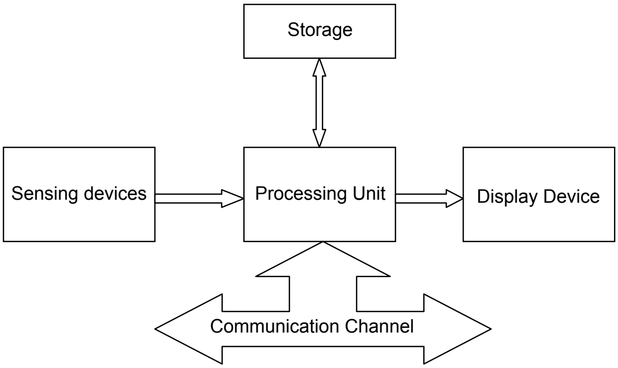

Fig. 1.6. A digital image processing system.

Display devices are required to display the images. These can be a computer monitor, mobile screen, projector for display or hardcopy devices, such as printers. A communication channel is also essential for sending and receiving images.

1.8 Applications of Digital Image Processing

Digital image processing techniques are now used in a number of applications; some common applications are given below.

In medicine: Several medical tools use image processing for various purposes, such as image enhancement, image compression, object recognition, etc. X-radiation (X-rays), computed tomography scan (CT scan), positron-emission tomography (PET), Single-photon emission computed tomography (SPECT), nuclear magnetic resonance (NMR) spectroscopy and Ultra-Sonography are some popular pieces of medical equipment based on image processing.

In agriculture: Image processing plays a vital role in the field of agriculture. Various paramount tasks such as weed detection, food grading, harvest control and fruit picking are done automatically with the help of image processing. Irrigated land mapping, determination of vegetation indices, canopy measurement, etc., are possible with good accuracy through the use of imaging techniques in various spectrums, such as hyper spectral imaging, infrared, etc.

In weather forecasting: Image processing also plays a crucial role in weather forecasting, such as prediction of rainfall, hailstorms, flooding. Meteorological radars are widely used to detect rainfall clouds and, based on this information, systems predict immediate rainfall intensity.

In photography and film: Retouched and spliced photos are extensively used in newspapers and magazines for the purpose of picture quality enhancement. In movies, many complex scenes are created with image and video editing tools which are based on image and video processing operations. Image processing-based methods are used to predict the success of upcoming movies. For a global media and entertainment company, Latent View extracted over 6000 movie posters from IMDB along with their metadata (genre, cast, production, ratings, etc.), in order to predict the movies' success using image analytics. The colour schemes and objects in the movie posters were analyzed using Machine Learning (ML) algorithms and image processing techniques.

In entertainment and social media: Face detection and recognition are widely used in social networking sites where, as soon as a user uploads the photograph, the system automatically identifies and gives suggestion to tag the person by name.

In security: Biometric verification systems provide a high level of authenticity and confidentiality. Biometric verification techniques are used for recognition of humans based on their behaviours or characteristics. To create alerts for particularly undesirable behaviour, video surveillance systems are being employed in order to analyze peoples' movements and activities. Several banks and other departments are using these image processing-based video surveillance systems in order to detect undesired activities.

In banking and finance: The use of image processing-based techniques is rapidly increasing in the field of financial services and banking. 'Remote deposit capture' is a banking facility that allows customers to deposit checks electronically using mobile devices or scanners. The data from the check image is extracted and used in place of a physical check. Face detection is also being used in the bank customer authentication process. Some banks use 'facial-biometric' to protect sensitive information. Signature verification and recognition also plays a significant role in authenticating the signature of the customers. However, a robust system used to verify handwritten signatures is still in need of development. This process has many challenges because handwritten signatures are imprecise in nature, as their corners are not always sharp, lines are not perfectly straight, and curves are not necessarily smooth.

In marketing and advertisement: Some companies are using image-sharing through social media in order to track the influence of the company's latest products/advertisement. The tourist department uses images to advertise tourist destinations.

In defence: Image processing, along with artificial intelligence, is contributing to defence based on two fundamental needs of the military: one is autonomous operation and the other is the use of outputs from a diverse range of sophisticated sensors for predicting danger/threats. In the Iran-Iraq war, remote sensing technologies were employed for the reconnaissance of enemy territory. Satellite images are analyzed in order to detect, locate and destroy weapons and defence systems used by enemy forces.

In industrial automation: An unprecedented use of image processing has been seen in industrial automation. The 'Automation of assembly lines' system detects the position and orientation of the components. Bolting robots are used to detect the moving bolts. Automation of inspection of surface imperfection is possible due to image processing. The main objectives are to determine object quality and detect any abnormality in the products. Many industries also use classification of products by shape automation.

In forensics: Tampered documents are widely used in criminal and civil cases, such as contested wills, financial paper work and professional business documentation. Documents like passports and driving licenses are frequently tampered with in order to be used illegally as identification proof. Forensic departments have to identify the authenticity of such suspicious documents. Identifying document forgery becomes increasingly challenging due to the availability of advanced document-editing tools. The forger uses the latest technology to perfect his art. Computer scan documents are copied from one document to another to make them genuine. Forgery is not only confined to documents, it is also gaining popularity in images. Imagery has a remarkable role in various areas, such as forensic investigation, criminal investigation, surveillance systems, intelligence systems, sports, legal services, medical imaging, insurance claims and journalism. Almost a decade ago, Iran was accused of doctoring an image from its missile tests; the image was released on the official website, Iran's Revolutionary Guard, which claimed that four missiles were heading skyward simultaneously. Almost all the newspaper and news magazine published this photo including, The Los Angeles Times, The Chicago Tribune and BBC News. Later on, it was revealed that only three missiles were launched successfully, one missile failed. The image was doctored in order to exaggerate Iran's military capabilities.

In underwater image restoration and enhancement: Underwater images are often not clear. These images have various problems, such as noise, low contrast, blurring, non-uniform lighting, etc. In order to restore visual clarity, image enhancement techniques are utilized.

Summary

- Digital images are very important in today's digital life.
- An image may be a grayscale image or a color image. A grayscale image, having only two intensities, is termed as a binary image.
- Digital images can be classified as Raster image or Vector image, with regard to the manner in which the image is stored.
- Some common image file types which are used in our daily life are JPEG, GIF, TIFF, PNG and BMP.
- The main components of an image processing system are (1) Sensing device, (2) Image processing elements, (3) Storage device and (4) Display device.

Bibliography

Abbasi, S., Mokhtarian, F. and Kittler, J. 2000. Enhancing CSS-based shape retrieval for objects with shallow concavities. Image and Vision Computing 18(3): 199–211.

Aggarwal, C. C., Hinneburg, A. and Keim, D.A. 2001. On the surprising behavior of distance metrics in high dimensional space. Lecture Notes in Computer Science, pp. 420–434.

Ahmed, H. A., El Gayar, N. and Onsi, H. 2008. A New Approach in Content-Based Image Retrieval Using Fuzzy Logic" Proceedings of INFOS'2008.

Alajlan, N., Kamel, M. S. and Freeman, G. 2006. Multi-object image retrieval based on shape and topology. Signal Processing: Image Communication 21: 904–918.

Alajlan, N., Rube, I. E., Kamel, M. S. and Freeman, G. 2007. Shape retrieval using triangle-area representation and dynamic space warping. Pattern Recognition 40(7): 1911–1920.

Arbter, K., Snyder, W. E., Burkhardt, H. and Hirzinger. G. 1990. Application of affine-invariant Fourier descriptors to recognition of 3D objects. IEEE Trans. Pattern Analysis and Machine Intelligence 12: 640–647.

Arbter, K., Snyder, W., Burkhardt, H. and Hirzinger, G. 1990. Applications of affine-invariant Fourier descriptors to recognition of 3-D objects. IEEE Trans. Pattern Analysis and Machine Intelligence 12(7): 640–646.

Arica, N. and Vural, F. 2003. BAS: a perceptual shape descriptor based on the beam angle statistics. Pattern Recognition Letters 24(9-10).

Arkin, E. M., Chew, L. P., Huttenlocher, D. P., Kedem, K. and Mitchell, J. S. B. 1991. An efficiently computable metric for comparing polygonal shapes. IEEE Trans. Pattern Analysis and Machine Intelligence 13(3): 209–226.

Aslandogan, Y. A. and Yu, C. T. 1999. Techniques and Systems for Image and Video Retrieval. IEEE Transactions on Knowledge and Data Engineering 11(1): 56–63.

Assfalg, J., Bimbo, A. D. and Pala. P. 2000. Using multiple examples for content-based retrieval," Proc. Int'l Conf. Multimedia and Expo.

Badawy, O. E. and Kamel, M. 2004. Shape Retrieval using Concavity Trees. pp. 111–114. In: Proceedings of the 17th International Conference on Pattern Recognition.

Ballard, D. H. and Brown, C. M. 1982. Computer Vision, New, Jersey: Prentice Hall.

Banon, G. J. F. et al. 2007. Mathematical morphology and its applications to signal and image processing: 8th International Symposium on Mathematical Morphology. Rio de Janeiro, RJ, Brazil, October 10–13.

Bauckhage, C. and Tsotsos, J. K. 2005. Bounding box splitting for robust shape classification. pp. 478–481. In: Proc. IEEE International Conference on Image Processing.

Beckmann, N. et al. 1990. The R*-tree: An efficient robust access method for points and rectangles. ACM SIGMOD Int. Conf. on Management of Data, Atlantic City, May 1990.

Belongie, S., Malik, J. and Puzicha, J. 2002. Shape Matching and Object Recognition Using Shape Context. IEEE Trans. Pattern Analysis and Machine Intelligence 24(4): 509– 522.

Benson, K. B. 1992. Television Engineering Handbook. McGraw-Hill, London, U.K. 1992.

Berretti, S., Bimbo, A. D. and Pala, P. 2000. Retrieval by shape similarity with perceptual distance and effective indexing. IEEE Trans. on Multimedia 2(4): 225–239.

Bhattacharyya, A. 1943. On a measure of divergence between two statistical populations defined by their probability distributions. Bulletin of the Calcutta Mathematical Society 35: 99–109.

Birren, F. 1969. Munsell: A Grammar of Color. Van Nostrand Reinhold, New York, N.Y..

Blaser, A.1979. Database Techniques for Pictorial Applications, Lecture Notes in Computer Science, Vo1.81, Springer Verlag GmbH.

Borgefors, G. 1986. Distance transformations in digital images. Computer Vision, Graphics, And Image Processing 34(3): 344–371.

Borgefors, G.1986. Distance Transformations in Digital Images. Computer Vision, Graphics, and Image Processing, 344–371.

Bovik, A. C. (ed.). 2005. Handbook of Image and Video Processing, second edition, Academic Press, NY.

Boxer, L. and Miller, R. 2000. Efficient computation of the Euclidean distance transform. Computer Vision and Image Understanding 80: 379–383.

Boynton, R. M. 1990. Human Color Vision. Halt, Rinehart and Winston.

Burger, W. and Burge, M. J. 2005. Principles of Digital Image Processing, Springer, London, UK.

Burkhardt, H. and Siggelkow, S. 2000. Invariant features for discriminating between equivalence classes. Nonlinear Model-based Image Video Processing and Analysis, John Wiley and Sons.

Carson, C., Thomas, M., Belongie, S., Hellerstein, J. M. and Malik, J. 1999. Blobworld: A system for region-based image indexing and retrieval," Proceedings of the Third International Conference VISUAL'99, Amsterdam, The Netherlands, Lecture Notes in Computer Science 1614. Springer.

Catalan, J. A. and Jin, J. S. 2000. Dimension reduction of texture features for image retrieval using hybrid associative neural networks. IEEE International Conference on Multimedia and Expo 2: 1211–1214.

Celebi, M. E. and Aslandogan, Y. A. 2005. A Comparative Study of Three Moment-Based Shape Descriptors. pp. 788–793. In: Proc. of the International Conference of Information Technology: Codingand Computing.

Celenk, M. 1990. A color clustering technique for image segmentation. Computer Vision, Graphics, and Image Processing 52: 145–170.

Chakrabarti, K., Binderberger, M., Porkaew, K. and Mehrotra, S. 2009. Similar shape retrieval in MARS. In: Proc. IEEE International Conference on Multimedia and Expo.

Chang, N. S. and Fu, K. S. 1980. Query by pictorial example. IEEE Trans. on Software Engineering, 6(6): 519–524, Nov.

Chang, S. K. and Kunii, T. L. 1981. Pictorial database systems," IEEE Computer Magazine, Vol. 14(11):13–21, Nov. 1981.

Chang, S. K. and Liu, S. H. 1984. Picture indexing and abstraction techniques for pictorial databases, IEEE Trans. Pattern Anal. Mach. Intell. 6(4): 475–483.

Chang, S. K., Shi, Q. Y. and Yan, C. Y. 1987. Iconic indexing by 2-D strings. IEEE Trans. on Pattern Anal. Machine Intell. 9(3): 413–428, May 1987.

Chang, S. K., Yan, C. W., Dimitroff, D. C. and Arndt, T. 1988. An intelligent image database system," IEEE Trans. on Software Engineering 14(5): 681–688, May 1988.

Chang, S. K. and Hsu, A. 1992. Image information systems: where do we go from here? IEEE Trans. On Knowledge and Data Engineering 5(5): 431–442, Oct.1992.

Chang, T. and Kuo, C.C.1. 1993. Texture analysis and classification with tree-structured wavelet transform. IEEE Trans. on Image Processing 2(4): 429–441, October 1993.

Chen, G. and Bui, T. D. 1999. Invariant Fourier-wavelet descriptor for pattern recognition. Pattern Recognition 32: 1083–1088.

Chen, Y., Wang, J. Z. and Krovetz, R. 2003. An unsupervised learning approach to content-based image retrieval, IEEE Proceedings of the International Symposium on Signal Processing and its Applications, pp. 197–200.

Chuang, C.-H. and Kuo, C.-C. 1996. Wavelet Descriptor of Planar Curves: Theory and Applications. IEEE Trans. Image Processing 5(1): 56–70.

Coggins, J. M. 1983. A framework for texture analysis based on spatial filtering. Ph.D. thesis.

Conrad, S. (ed.). 2000. Petkovic, M. and Riedel, H. (eds.). Content-based Video Retrieval, 74–77.

Costa, L. F. and Cesar, R.M., Jr. 2001. Shape Analysis and Classification: Theory and Practice. CRC Press, Boca Raton, FL, USA.
Danielsson, P. 1980. Euclidean distance mapping. Computer Graphics and Image Processing 14: 227–248.
Datta, R., Joshi, D., Li, J. and Wang, J. Z. 2008. Image retrieval: Ideas, influences, and trends of the new age. ACM Comput. Surv. 40, 2, Article 5.
Davies, E. 1997. Machine Vision: Theory, Algorithms, Practicalities. Academic Press, New York.
Davies, E. R. 2005. Machine Vision: Theory, Algorithms, Practicalities, Morgan Kaufmann, San Francisco.
de Valois, R. L. and De Valois, K. K. 1975. Neural coding of color. pp. 117–166. In: Carterette, E.C., Friedman, M.P. (eds.). Handbook of Perception. Volume 5, Chapter 5, Academic Press, New York, N.Y..
de Valois, R. L. and De Valois, K. K. 1993. A multistage color model. Vision Research 33(8): 1053–1065.
di Baja, G.S. and Thiel, E. 1996. Skeletonization algorithm running on path-based distance maps. Image Vision Computer 14: 47–57.
Dubinskiy, A. and Zhu, S. C. 2003. A Multi-scale Generative Model for Animate Shapes and Parts. In: Proc. Ninth IEEE International Conference on Computer Vision, ICCV.
Dubuisson, M.P. and Jain, A.K. 1994. A modified Hausdorff distance for object matching. Proceedings of the 12th IAPR International Conference on Pattern Recognition, Conference A: Computer Vision & Image Processing (ICPR ‘94) 1: 566–568.
Duda, R. O., Hart, P. E. and Stork, D. G. 2001. Pattern Classification, second edition, John Wiley & Sons, NY.
Fairchild, M. D. 1998. Color Appearance Models. Addison-Wesley, Readings, MA.
Faloutsos, C. et al. 1994. Efficient and effective querying by image content,” Journal of intelligent information systems 3: 231–262.
Fasano, G. and Franceschini, A. 1987. A multidimensional version of the Kolmogorov Smirnov test. Mon. Not. Roy. Astron. Soc. 225: 155–170.
Finlayson, G. D. 1996. Color in perspective. IEEE Trans on Pattern Analysis and Machine Intelligence 8(10): l034–1038, Oct. 1996.
Flusser, J., Suk, T. and Zitová, B. 2009. Moments and Moment Invariants in Pattern Recognition, John Wiley & Sons, Ltd.
Flusser, J.1992. Invariant Shape Description and Measure of Object Similarity. In: Proc. 4th International Conference on Image Processing and its Applications, pp. 139–142.
Foley, J.D., van Dam, A., Feiner, S.K. and Hughes, J.F. 1990. Fundamentals of Interactive Computer Graphics. Addison Wesley, Reading, MA.
Francos, J. M., Meiri, A. A. and Porat, B. 1993. A unified texture model based on a 2d Wold like decomposition,” IEEE Trans on Signal Processing pp. 2665–2678, Aug. 1993.
Francos, J. M., Narasimhan, A. and Woods. J. W. 1995. Maximum likelihood parameter estimation of textures using a Wold-decomposition based model. IEEE Trans. on Image Processing, pp. 1655–1666, Dec. 1995.
Franti, P. 2001. Digital Image Processing, Univ. of Joensuu, Dept. of Computer Science, Lecture notes.
Furht, B., Smoliar, S. W. and Zhang, H. J. 1995. Video and Image Processing in Multimedia Systems, Kluwer Academic Publishers.
Gary, J. E. and Mehrotra, R. 1992. Shape similarity-based retrieval in image database systems. Proc. of SPIE, Image Storage and Retrieval Systems 1662: 2–8.
Gevers, T. and Smeulders, A. W. M. 1999. Content-based image retrieval by viewpoint-invariant image indexing. Image and Vision Computing 17(7): 475–488.
Gong, Y., Zhang, H. 1. and Chua, T. C. 1994. An image database system with content capturing and fast image indexing abilities. Proc. IEEE International Conference on Multimedia Computing and Systems, Boston, pp. l21–130, 14–19 May 1994.
Gonzalez, R. C. and Woods, R. E. 2018. Digital Image Processing, fourth edition, Pearson, NY.
Goutsias, J, Vincent, L. and Bloomberg, D. S. (eds.). 2000. Mathematical Morphology and Its Applications to Image and Signal Processing, Kluwer Academic Publishers, Boston, MA.

Grosky, W. I. and Mehrotra, R. 1990. Index based object recognition in pictorial data management," CVGIP 52(3): 416–436.
Gudivada, V. N. and Raghavan, V. V. 1995. Design and evaluation of algorithms for image retrieval by spatial similarity. ACM Trans. on Information Systems 13(2): 115–144, April 1995.
Guo, F., lin, J. and Feng, D. 1998. Measuring image similarity using the geometrical distribution of image contents. Proc. of ICSP, pp. 1108–1112.
Gupta, A. and Jain, R. 1997. Visual information retrieval. Communication of the ACM 40(5): 71–79, May, 1997.
Guru, D. and Nagendraswam, H. 2007. Symbolic representation of two-dimensional shapes. Pattern Recognition Letters 28: 144–155.
Hafner, J. et al. 1995. Efficient color histogram indexing for quadratic form distance functions. IEEE Trans. on Pattern Analysis and Machine Intelligence 17(7): 729–736, July 1995.
Hafner, J., Sawhney, H. S., Equitz, W., Flickner, M. and Niblack, W. 1995. Efficient color histogram indexing for quadratic form distance functions. IEEE Transactions on Pattern Analysis and Machine Intelligence 17(7): 729–735.
Hague, G. E., Weeks, A. R. and Myler, H.R. 1995. Histogram equalization of 24 bit color images in the color difference color space. Journal of Electronic Imaging 4(1): 15–23.
Hall, R. A. 1981. Illumination and Color in Computer Generated Imagery. Springer Verlag, New York, N.Y.
Han, S.and Yang, S. 2005. An Invariant Feature Representation for shape Retrieval. In: Proc. Sixth International Conference on Parallel and Distributed Computing, Applications and Technologies.
Haralick, R. M. 1979. Statistical and structural approaches to texture. Proceedings of the IEEE 67: 786–804.
Haralick, R. M. and Shapiro, L. G. 1992. Computer and Robot vision, Vols. 1 and 2, Addison Wesley, Reading, MA.
Hawkins, J. K. 1970. Textural properties for pattern recognition. Picture Processing and Psychopictorics, pp. 347–370.
Higham Desmond J. and Higham Nicholas, J. 2016. MATLAB Guide, Third Edition, SIAM publications.
Hill, B., Roer, T. and Vorhayen, F.W. 1997. Comparative analysis of the quantization of color spaces on the basis of the CIE-Lab color difference formula. ACM Transaction of Graphics 16(1): 110–154.
Hitchcock, F. L. 1941. The distribution of a product from several sources to numerous localities. Journal of Math. Phys. 20: 224–230.
Holla, K. 1982. Opponent colors as a 2-dimensional feature within a model of the first stages of the human visual system. Proceedings of the 6th Int. Conf. on Pattern Recognition 1: 161–163.
Hollink, L., Schreiber, G., Wielinga, B. and Worring, M. 2004.Classification of user image descriptions", International Journal of Human Computer Studies 61: 601–626.
http://homepages.inf.ed.ac.uk/rbf/BOOKS/PHILLIPS/.
http://mpeg7.org/visual-descriptors/.
https://en.wikipedia.org/wiki/Digital_image_processing.
https://www.mathworks.com/discovery/digital-image-processing.html.
Hu, K. 1977. Visual pattern recognition by moment invariants. In: Aggarwal, J. K., Duda, R. O. and Rosenfeld, A. (eds.). Computer Methods in Image Analysis. IEEE computer Society, Los Angeles, CA.
Hu, M. K.1962. Visual Pattern Recognition by Moment Invariants. IRE Trans. Information Theory IT-8: 179–187.
Huang, J. et al. 1997. Image indexing using color correlogram. IEEE Int. Conf. on Computer Vision and Pattern Recognition, pp. 762–768, Puerto Rico.
Huang, J., Kumar, S. R. and Metra, M. 1997. Combining supervised learning with color correlograms for content-based image retrieval. Proc. of ACM Multimedia 95: 325–334.
Huang, J., Kumar, S. R., Mitra, M., Zhu, W.-J. and Zabih, R. 1997. Image indexing using color correlograms. Proceedings of Computer Vision and Pattern Recognition, pp. 762–768.
Huang, J., Kumar, S.R. Metra, M., Zhu, W. J. and Zabith, R. 1999. Spatial color indexing and applications," Int'l J Computer Vision 35(3): 245–268.

Hurvich, Leo M. 1981. Color Vision. Sinauer Associates, Sunderland MA.
Huttenlocher, D.P., Klanderman, G.A. and Rucklidge, W.J. 1993. Comparing images using the Hausdorff distance. IEEE Transactions on Pattern Analysis and Machine Intelligence 15(9): 850–863.
Iivarinen, J. and Visa, A. 1996. Shape recognition of irregular objects. In: Proc. SPIE, Intelligent Robots and Computer Vision XV: Algorithms, Techniques, Active Vision, and Materials Handling, pp. 25–32.
ISO/IEC JTC1/SC29/WG11, MPEG-7 Overview (version 10), Technical report (2004).
Jagadish, H. V. 1991. A retrieval technique for similar shapes. Proc. of Int. Conf on Management of Data, SIGMOID'9i, Denver, CO, pp. 208–217.
Jahne, B. 2004. Practical Handbook on Image Processing for Scientific and Technical Applications, Second Edition, CRC Press.
Jain, A. K. 1989. Fundamentals of Digital Image Processing, Prentice-Hall.
Jain, A. K. and F. Farroknia. 1991. Unsupervised texture segmentation using Gabor filters. Pattern Recognition 24(l2): 1167–1186.
Jain, P. and Tyagi, V. 2016. A survey of edge-preserving image denoising methods. Inf Syst Front 18(1): 159–170.
Jain, R. 1992. Proc. US NSF Workshop Visual Information Management Systems.
Jain, R., Pentland, A. and Petkovic, D. 1995. Workshop Report: NSF-ARPA Workshop on Visual information Management Systems, Cambridge, Mass, USA.
Jalba, A., Wilkinson, M. and Roerdink, J. 2006. Shape representation and recognition through morphological curvature scale spaces. IEEE Trans. Image Processing 15(2): 331–341.
Jameson, D. and Hurvich, L.M. 1968. Opponent-response functions related to measured cone photo pigments. Journal of the Optical Society of America 58: 429–430.
Jayaraman, S., Esakirajan, S. and Veerakumar, T. 2015. Digital Image Processing, McGraw Hill.
Jin, K., Cao, M., Kong, S. and Lu, Y. 2006. Homocentric Polar-Radius Moment for Shape Classification. In: The 8th International Conference on Proc. Signal Processing.
Johnson, G. M. and Fairchild, M. D. 1999. Full spectral color calculations in realistic image synthesis. IEEE Computer Graphics and Applications 19(4): 47–53.
Judd, D. B. and Wyszecki, G. 1975. Color in Business, Science and Industry. John Wiley, New York, N.Y.
Julesz, B. 1965. Texture and visual perception. Scientific American 212: 38–49.
Jurman, G., Riccadonna, S., Visintainer, R. and Furlanello, C. 2009. Canberra Distance on Ranked Lists. In Proceedings, Advances in Ranking – NIPS 09 Workshop, pp. 22–27.
Kailath, T. 1967. The divergence and Bhattacharyya distance measures in signal selection. IEEE Trans. Comm. Techn., pp. 52–60.
Kan, C. and Srinath, M. D. 2002. Invariant character recognition with Zernike and orthogonal Fourier-Mellin moments. Pattern Recognition 35: 143–154.
Kasson, M.J. and Ploaffe, W. 1992. An analysis of selected computer interchange color spaces. ACM Transaction of Graphics 11(4): 373–405.
Kauppinen, H., Seppanen, T. and Pietikainen, M. 1995. An Experimental Comparison of Auto-regressive and Fourier-Based Descriptors in 2-D Shape Classification. IEEE Trans. Pattern Analysis and Machine Intelligence 17(2): 201–207.
Kauppinen, H., Seppnaen, T. and Pietikainen, M. 1995. An experimental comparison of autoregressive and Fourier-based descriptors in 20 shape classification. IEEE Trans. Pattern Anal. and Machine intell. 17(2): 201–207.
Khalil, M. and Bayoumi, M. 2001. A Dyadic Wavelet Affine Invariant Function for 2D Shape Recognition. IEEE Trans. Pattern Analysis and Machine Intelligence 25(10): 1152–1164.
Kolesnikov, A. 2003. Efficient algorithms for vectorization and polygonal approximation, Ph.D thesis, University of Joensu, Finland.
Kpalma, K. and Ronsin, J. 2006. Multiscale contour description for pattern recognition. Pattern Recognition Letters 27: 1545–1559.
Krzanowski. 1995. Recent Advances in Descriptive Multivariate Analysis, Chapter 2, Oxford science publications.
Kullback, S. and Leibler, R. A. 1951. On information and sufficiency. Annals of Mathematical Statistics 22(1): 79–86.

Kullback, S. 1968. Information Theory and Statistics. Dover Publications, New York.
Kumar, A., Ghrera, S.P. and Tyagi, V. 2015. A Comparison of Buyer-Seller Watermarking Protocol (BSWP) Based on Discrete Cosine Transform (DCT) and Discrete Wavelet Transform (DWT), Advances in Intelligent Systems and Computing, vol 337. Springer.
Lance, G. N. and Williams, W. T. 1966. Computer programs for hierarchical polythetic classification ("similarity analysis"). Computer Journal, Vol. 9(1): 60–64.
Latecki, L. J. and Lakamper, R. 1999. Convexity rule for shape decomposition based on discrete Contour Evolution. Computer Vision and Image Understanding 73(3): 441–454.
Latecki, L. J. and Lakamper, R. 2000. Shape Similarity Measure Based on Correspondence of Visual Parts. IEEE Trans. Pattern Analysis and Machine Intelligence 22(10): 1185– 1190.
Lee, S.-M., Abbott, A. L., Clark, N. A. and Araman, P. A. 2006. A Shape Representation for Planar Curves by Shape Signature Harmonic Embedding. In: Proc. IEEE Computer Society Conference on Computer Vision and Pattern Recognition.
Lee, S. Y. and Hsu, F. H. 1990. 2D C-string: a new spatial knowledge representation for image database systems. Pattern Recognition 23: 1077–1087.
Lee, S. Y., Yang, M.C. and Chen, J. W. 1992. 2D B-string: a spatial knowledge representation for image database system. Proc. ICSC'92 Second into computer Sci. Conf., pp. 609–615.
Levine, M. D. 1985. Vision in man and machine, McGraw-Hill College.
Levkowitz, H. and Herman, G. T. 1993. GLHS: a generalized lightness, hue and saturation color model. Graphical Models and Image Processing, CVGIP 55(4): 271–285.
Li, J., Wang, J. Z. and Wiederhold, G. 2000. IRM: integrated region matching for image retrieval. In Proceedings of the eighth ACM international conference on multimedia, pp. 147–156.
Lin, J. 1991. Divergence measures based on the Shannon entropy. TIT.
Liu, F. and Picard, R. W.1996. Periodicity, directionality, and randomness: Wold features for image modeling and retrieval. IEEE Trans. on Pattern Analysis and Machine Learning 18(7).
Liu, H., Song, D., Rüger, S., Hu, R. and Uren, V. 2008. Comparing Dissimilarity Measures for Content-Based Image Retrieval, Information Retrieval Technology. AIRS 2008. Lecture Notes in Computer Science, vol. 4993. Springer, pp. 44–50.
Liu, Y. et al. 2007. A survey of content-based image retrieval with high-level semantics, Pattern Recognition 40: 262–282.
Liu, Y., Zhang, D. and Lu, G. 2007. A survey of content-based image retrieval with high-level semantics. Pattern Recognition 40: 262–282.
Liu, Y. K., Wei, W., Wang, P. J. and Zalik, B. 2007. Compressed vertex chain codes. Pattern Recognition 40(11): 2908–2913.
Long, F., Zhang, H. and Feng D. D. 2003. Fundamentals of Content-Based Image Retrieval. In: Feng, D. D., Siu, W. C. and Zhang, H. J. (eds.). Multimedia Information Retrieval and Management. Signals and Communication Technology. Springer, Berlin, Heidelberg
Lotufo, R. A., Falcao, A. A. and Zampirolli, F. A. 2000. Fast Euclidean distance transform using a graph-search algorithm. In Proceeding of SIBGRAPI, pp. 269–275.
Lu, Guoyun. 1996. Communication and Computing for Distributed Multimedia Systems. Artech House Publishers, Boston, MA.
Lu, G. and Sajjanhar, A. 1999. Region-based shape representation and similarity measure suit-able for content based image retrieval. ACM Multimedia System Journal 7(2): 165–174.
Lu, K.-J. and Kota, S. 2002. Compliant Mechanism Synthesis for Shape-Change Applications: Preliminary Results. pp. 161–172. In: Proceedings of SPIE Modelling, Signal Processing, and Control Conference.
Luo, J., Joshi, D., Yu, J. and Gallagher, A. 2011. Geotagging in multimedia and computer vision-a survey, Multimedia Tools and Applications 51(1): 187–211.
Luong, Q. T. 1993. Color in computer vision. Handbook of Pattern Recognition and Computer Vision, Word Scientific Publishing Company 311–368.
Ma, W. Y. and Manjunath, B. S. 1995. A comparison of wavelet features for texture annotation. Proc. of IEEE Int. Conf. on Image Processing, Vol. II, pp. 256–259, Washington D.C.

Ma, W. Y. and Manjunath, B. S. 1995. Image indexing using a texture dictionary. Proc. of SPIE Conf. on image Storage and Archiving System, Vol. 2606, pp. 288–298, Philadelphia, Pennsylvania.

Ma, W. Y. and Manjunath, B. S. 1997. Edge flow: a framework of boundary detection and image segmentation. IEEE into Conf. on Computer Vision and Pattern Recognition, pp. 744–749, Puerto Rico.

MacDonald, L. W. 1999. Using color effectively in computer graphics. IEEE Computer Graphics and Applications 19(4): 20–35.

Mahalanobis, P. C.1936. On the generalised distance in statistics. Proceedings of the National Institute of Sciences of India 2(1): 49–55.

Mallat, S. G. 1989. A theory for multiresolution signal decomposition: the wavelet representation. IEEE Trans. Pattern Analysis and Machine Intelligence, Vol. 11, pp. 674–693.

Manjunath, B. S. and Ma, W. Y. 1996. Texture features for browsing and retrieval of image data. IEEE Trans. on Pattern Analysis and Machine intelligence 18(8): 837–842.

Manning, C. D. 2009. Prabhakar Raghavan & Hinrich Schütze, An introduction to information retrieval, Cambridge University press.

Mao, J. and Jain, A. K. 1992. Texture classification and segmentation using multiresolution simultaneous autoregressive models. Pattern Recognition 25(2): 173–188.

Marques, Oge. 2011. Practical Image and Video Processing Using MATLAB, Wiley IEEE press.

Mathias, E. 1998. Comparing the influence of color spaces and metrics in content-based image retrieval. Proceedings of International Symposium on Computer Graphics, Image Processing, and Vision, pp. 371–378.

Maxwell, J. C. 1890. On the theory of three primary colors. Science Papers Cambridge University Press: 445–450.

McLaren, K. 1976. The development of the CIE L*a*b* uniform color space. J. Soc. Dyers Color, 338–341.

Mehtre, B. M., Kankanhalli, M. S. and Lee, W. F. 1997. Shape Measures for Content Based Image Retrieval: A Comparison. Pattern Recognition 33(3): 319–337.

Meijster, A., Roerdink, J. and Hesselink, W. 2000. A general algorithm for computing distance transforms in linear time. In Math. Morph. and Its Appls. to Image and Signal Proc., pp. 331–340.

Miano, J. 1999. Compressed Image File Formats: JPEG, PNG, GIF, XBM, BMP, ACM Press/Addison-Wesley Publ. Co., New York, NY, USA.

Miguel, Arevalillo-Herráez, Juan Domingo, Francesc J. Ferri. 2008. Combining similarity measures in content-based image retrieval, Pattern Recognition Letters 29(16): 2174–2181.

Mingqiang Yang, Kidiyo Kpalma, Joseph Ronsin. 2012. Shape-based invariant features extraction for object recognition. Advances in reasoning-based image processing, analysis and intelligent systems: Conventional and intelligent paradigms, Springer.

Mokhtarian, F. and Mackworth, A. K. 1992. A Theory of Multiscale, Curvature-Based Shape Representation for Planar Curves. IEEE Trans. Pattern Analysis and Machine Intelligence 14(8): 789–805.

Mori, G. and Malik, J. 2002. Estimating Human Body Configurations Using Shape Context Matching. pp. 666–680. In: Heyden, A., Sparr, G., Nielsen, M. and Johansen, P. (eds.). ECCV 2002. LNCS, vol. 2352. Springer, Heidelberg.

MPEG Video Group, Description of core experiments for MPEG-7 color/texture descriptors, ISO/MPEGJTC1/SC29/WGll/MPEG98/M2819, July 1999.

Mukundan, R. 2004. A new class of rotational invariants using discrete orthogonal moments. pp. 80–84. In: Sixth IASTED International Conference on Signal and Image Processing.

Muller, H. and Muller, W. et al. 2001. Performance evaluation in Content based image retrieval: overview and proposals, Pattern Recognition Letters 22: 593–601.

Myler, H. R. and Arthur R. Weeks. 2009. The pocket handbook of image processing algorithms in C, Prentice Hall Press, NJ.

Niblack, W., Barber, R., Equitz, W., Flickner, M.D., Glasman, E.H., Petkovic, D., Yanker, P., Faloutsos, C., Taubin, G. and Heights, Y. 1993. Querying images by content, using color, texture, and shape. In SPIE Conference on Storage and Retrieval for Image and Video Databases 1908: 173–187.

Nixon, M.S. and Aguado, A.S. 2002. Feature Extraction and Image Processing, Newnes Publishers.
Ohta, Y., Kanade, T. and Sakai, T. 1980. Color information for region segmentation. Computer Graphics and Image Processing 13: 222–241.
Ojala, T., Pietikainen, M. and Harwood, D. 1996. A comparative study of texture measures with classification based feature distributions. Pattern Recognition 29(1): 51–59.
Osterreicher, F. and Vajda, I. 2003. A new class of metric divergences on probability spaces and its statistical applications. AISM.
Paglieroni, D. W. 1992. Distance transforms: properties and machine vision applications. CVGIP: Graphical Models and Image Processing 54(1): 56–74.
Palus, H. 1998. Color spaces. pp. 67–89. In: Sangwine, S.J. and Horne, R.E.N. (eds.) The Color Image Processing Handbook, Chapman & Hall, Cambridge, Great Britain.
Pass, G. and Zabith, R. 1996. Histogram refinement for content-based image retrieval. IEEE Workshop on Applications of Computer Vision, pp. 96–102.
Pass, G. and Zabith, R. 1999. Comparing images using joint histograms. Multimedia Systems 7: 234–240.
Pele, O. and Werman, M. 2010. The Quadratic-Chi Histogram Distance Family, in Lecture Notes of Computer Science 6312: 749–762.
Peng, J., Yang, W. and Cao, Z. 2006. A Symbolic Representation for Shape Retrieval in Curvature Scale Space. In: Proc. International Conference on Computational Intelligence for Modelling Control and Automation and International Conference on Intelligent Agents Web Technologies and International Commerce.
Persoon, E. and Fu, K. 1977. Shape discrimination using Fourier descriptors. IEEE Trans. Syst. Man and Cybern. 7: 170–179.
Petrou, M. and Petrou, C. 2010. Image Processing: The Fundamentals, John Wiley & Sons, NY.
Picard, R. W., Kabir, T. and Liu, F. 1993. Real-time recognition with the entire Brodatz texture database. Proc. IEEE Int. Conf. on Computer Vision and Pattern Recognition, pp. 638–639, New York.
Plataniotis, K. N. and Venetsanopoulos, A. N. 2000. Color Spaces. In: Color Image Processing and Applications, Digital Signal Processing, Springer, Berlin, Heidelbergm.
Poynton, C. A. A Technical Introduction to Digital Video. Prentice Hall, Toronto.
Pratt, W. K. 2014. Introduction to Digital Image Processing, CRC Press, Boca Raton, FL.
Rangayyan, R. M. 2005. Biomedical Image Analysis, CRC Press, Boca Raton, FL.
Rhodes, P.A. 1998. Color management for the textile industry. Sangwine, S.J., Horne, R.E.N. (eds.). The Color Image Processing Handbook, 307–328, Chapman & Hall, Cambridge, Great Britain.
Ricard, J., Coeurjolly, D. and Baskurt, A. 2005. Generalizations of angular radial transform for 2D and 3D shape retrieval. Pattern Recognition Letters 26(14).
Richards, W. and Polit, A. 1974. Texture matching. Kybernetik 16:155–162.
Robertson, P. and Schonhut, J. 1999. Color in computer graphics. IEEE Computer Graphics and Applications 19(4): 18–19.
Robinson, J. T. 1981. The k-d-B-tree: a search structure for large multidimensional dynamic indexes. Proc. of SIGMOD Conference, Ann Arbor.
Rosenfield, A. and Kak, A. C. 1982. Digital picture processing, second edition, vols. 1 & 2, Academic press, New York.
Rubner, Y. 1999. Perceptual Metrics for Image Database Navigation. PhD Thesis, Stanford University, May 1999.
Rui, Hu, Stefan, Ruger, Dawei, Song, Haiming, Liu and Zi Huang. 2008. Dissimilarity Measures for Content-Based Image Retrieval. IEEE International Conference on Multimedia and Expo, pp. 1365–1368.
Rui, Y., Huang, T. S., Ortega, M. and Mehrotra, S. 1998. Relevance feedback: a power tool for interactive content-based image retrieval. IEEE Trans. on Circuits and Systems for Video Technology.
Rui, Y., Huang, T.S. and Mehrotra, S. 1997. Content-based image retrieval with relevance feedback in MARS. Proceedings of International Conference on Image Processing 2: 815–818.
Russ, J. C. 2011. The Image Processing Handbook, 6th edition, CRC Press, Boca Raton, FL.
Safar, M., Shahabi, C. and Sun, X. 2000. Image Retrieval by Shape: A Comparative Study. In IEEE International Conference on Multimedia and Expo (I), pp. 141–144.

Saito, T. and Toriwaki, J. I. 1994. New algorithms for Euclidean distance transformation of an n dimensional digitized picture with application. Pattern Recognition 27(11): 1551–1565.
Salton, G. and McGill, M. 1983. Introduction to Modern Information Retrieval. McGraw-Hill, New York, NY.
Sclaroff, S., Taycher, L. and Cascia, M. L. 1997. ImageRover: a content-based image browser for the World Wide Web. Boston University CS Dept. Technical Report 97-005.
Sebastian, T., Klein, P. and Kimia, B. 2004. Recognition of Shapes by Editing Their Shock Graphs. IEEE Trans. Pattern Analysis and Machine Intelligence 26(5): 550–571.
Shapiro, L. G. and Stockman, G. C. 2001. Computer Vision, Prentice-Hall, Upper Saddle River, NJ.
Sharma, G. and Trussel, H. J. 1997. Digital color processing. IEEE Trans. on Image Processing, 6(7): 901–932.
Sharma, G., Yrzel, M. J. and Trussel, H. J. 1998. Color imaging for multimedia. Proceedings of the IEEE 86(6): 1088–1108.
Shashank, J., Kowshik, P., Srinathan, K. and Jawahar, C. V. 2008. Private Content Based Image Retrieval. 2008 IEEE Conference on Computer Vision and Pattern Recognition, Anchorage, AK, pp. 1–8.
Shih, Tian-Yuan. 1995. The reversibility of six geometric color spaces. Photogrammetric Engineering and Remote Sensing 61(10): 1223–1232.
Siddiqi, K. and Kimia, B. 1996. A Shock Grammar for Recognition. In: Proceedings of the IEEE Conference Computer Vision and Pattern Recognition, pp. 507–513.
Sklansky, J. 1978. Image Segmentation and Feature Extraction," {IEEE} Trans. Systems, Man, and Cybernetics 8: 237–247.
Smith, A. R. 1978. Color gamut transform pairs. Computer Graphics (SIGGRAPH'78 Proceedings) 12(3): 12–19.
Smith, S. P. and Jain, A. K. 1982. Chord distribution for shape matching. Computer Graphics and Image Processing 20: 259–271.
Soile, P. 2003. Morphological image analysis: Principles and applications, second edition, Springer-Verlag, New York.
Soille, P. 2003. Morphological Image Analysis: Principles and Applications, second edition, Springer-Verlag, NY.
Sonka, M., Hlavac, V. and Boyle, R. 2008. Image Processing, Analysis and Machine Vision, Third edition, Thomson Learning.
Stricker, M. and Orengo, M. 1995. Similarity of color images. In SPIE Conference on Storage and Retrieval for Image and Video Databases III 2420: 381–392.
Sundararajan, D. 2017. Digital Image Processing: A Signal Processing and Algorithmic Approach, Springer Singapore.
Swain, M. J. and Ballard, D. H. 1991. Color indexing. International Journal of Computer Vision 7(1): 11–32.
Tamura, H., Mori, S. and Yamawaki, T. 1978. Textural features corresponding to visual perception. IEEE Transactions on Systems, Man, and Cybernetics 8: 460–473.
Taubin, G. and Cooper, D. 1991. Recognition and positioning of rigid objects using algebraic moment invariants. In: SPIE Conference on Geometric Methods in Computer Vision, pp. 175–186.
Taza, A. and Suen, C. 1989. Discrimination of planar shapes using shape matrices. IEEE Trans. System, Man, and Cybernetics 19(5): 1281–1289.
Tegolo, D. 1994. Shape analysis for image retrieval. Proc. of SPIE. Storage and Retrieval for Image and Video Databases-II, no. 2185, San Jose, CA, pp. 59–69, February 1994.
Tektronix, TekColor Color Management System: System Implementers Manual. Tektronix Inc., 1990.
Thayananthan, A., Stenger, B., Torr, P. H. S. and Cipolla, R. 2003. Shape Context and Chamfer Matching in Cluttered Scenes. In: Proc. IEEE Computer Society Conference on Computer Vision and Pattern Recognition.
Tieng, Q. M. and Boles, W. W. 1997. Wavelet-Based Affine Invariant Representation: A Tool for Recognizing Planar Objects in 3D Space. IEEE Trans. Pattern Analysis and Machine Intelligence 19(8): 846–857.
Tiwari, D. and Tyagi, V. 2017. Digital Image Compression, Indian Science Cruiser, Vol. 31 (6): 44–50.

Tominaga, S. 1986. Color image segmentation using three perceptual attributes. Proceedings of CVPR'86, 1: 628–630.

Torres, R. S. and Falcão, A. X. 2006. Content-Based Image Retrieval: Theory and Applications. RITA, Vol. XIII (2), DOI: 10.1.1.89.34.

Trussell, H. J and Vrhel, M. J. 2008. Fundamentals of Digital Imaging, Cambridge University Press, UK.

Tsai, C.-F. and Hung, C. 2008. Automatically annotating images with keywords: A Review of Image Annotation Systems. Recent Patents on Computer Science 1: 55–68.

Tyagi, Vipin. 2017. Content-Based Image Retrieval: Ideas, Influences, and Current Trends, Springer Singapore Publisher.

Umbaugh, S. E. 2005. Computer Imaging: Digital Image Analysis and Processing, CRC Press, Boca Raton, FL.

Umbaugh, S. E. 2010. Digital Image Processing and Analysis, second edition, CRC Press, Boca Raton, FL.

Veltkamp, R. C. and Hagedoorn, M. 1999. State-of-the-art in shape matching. Technical Report UU-CS-1999-27, Utrecht University, Department of Computer Science, Sept.

Vendrig, J., Worring, M. and Smeulders, A. W. M. 1999. Filter image browsing: exploiting interaction in retrieval. Proc. Viusl'99: Information and Information System.

von Stein, H.D. and Reimers, W. 1983. Segmentation of color pictures with the aid of color information and spatial neighborhoods. Signal Processing II: Theories and Applications 1: 271–273.

Voorhees, H. and Poggio, T. 1988. Computing texture boundaries from images. Nature 333: 364–367.

Wang, B., Zhang, X., Wang, M. and Zhao, P. 2010. Saliency distinguishing and applications to semantics extraction and retrieval of natural image. International Conference on Machine Learning and Cybernetics (ICMLC) 2: 802–807.

Wang, H., Guo, F., Feng, D. and Jin, J.1998. A signature for content-based image retrieval using a geometrical transform. Proc. of ACM MM'98, Bristol, UK.

Wang, J. Z. 2001. Integrated Region-Based Image Retrieval, Kluwer Academic Publishers.

Wang, Y. P. and Lee, K. T. 1999. Multiscale curvature-based shape representation using B-spline wavelets. IEEE Trans. Image Process 8(10): 1586–1592.

Weeks, A. R. 1996. Fundamentals of Electronic Image Processing. SPIE Press, Piscataway, New Jersey.

Weng, L., Amsaleg, L., Morton, A. and Marchand-Maillet, S. 2015. A Privacy-Preserving Framework for Large-Scale Content-Based Information Retrieval. In IEEE Transactions on Information Forensics and Security 10(1): 152–167. doi: 10.1109/TIFS.2014.2365998.

Wong, W. H., Siu, W. C. and Lam, K. M. 1995. Generation of moment invariants and their uses for character recognition. Pattern Recognition Letters 16: 115–123.

www.mathworks.com.

Wyszecki, G. and Stiles, W. S. 1996. Color Science, Concepts and Methods, Quantitative Data and Formulas. John Wiley, N.Y., 2nd Edition.

Yang, L. and Aigregtsen, F. 1994. Fast computation of invariant geometric moments: A new method giving correct results. Proc. IEEE Int. Conf. on Image Processing.

Yang, M., Kpalma, K. and Ronsin, J. 2007. Scale-controlled area difference shape descriptor. In: Proc. SPIE, Electronic Imaging science and Technology.

Young, T. 1802. On the theory of light and colors. Philosophical Transactions of the Royal Society of London 92: 20–71.

Zahn, C. T. and Roskies, R. Z. 1972. Fourier Descriptors for Plane closed Curves. IEEE Trans. Computer c-21(3): 269–281.

Zhang, D. and Lu, G. 2002. A Comparative Study of Fourier Descriptors for Shape Representation and Retrieval. In: Proc. 5th Asian Conference on Computer Vision.

Zhang, D. and Lu, G. 2003. A comparative study of curvature scale space and Fourier descriptors for shape-based image retrieval. Visual Communication and Image Representation 14(1).

Zhang, D. and Lu, G. 2004. Review of shape representation and description techniques. Pattern Recognition 37: 1–19

Zhang, D. S. and Lu, G. 2001. A Comparative Study on Shape Retrieval Using Fourier Descriptors with Different Shape Signatures. In: Proc. International Conference on Intelligent Multimedia and Distance Education (ICIMADE 2001).

Zhang, H. and Malik, J. 2003. Learning a discriminative classifier using shape context distances. In: Proc. IEEE Computer Society Conference on Computer Vision and Pattern Recognition.

Zhang, H. J. and Zhong, D. 1995. A scheme for visual feature-based image indexing. Proc. of SPIE conf. on Storage and Retrieval for Image and Video Databases III, pp. 36–46, San Jose.

Zhang, H. J. et al. 1995. Image retrieval based on color features: An evaluation study. SPIE Conf. on Digital Storage and Archival, Pennsylvania.

Zhou, X. S. and Huang, T. S. 2000. CBIR: from low-level features to high- level semantics, Proceedings of the SPIE, Image and Video Communication and Processing, San Jose, CA 3974: 426–431.