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Image Processing: Opportunities and Challenges in Research

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Abstract

Interest in digital image processing methods stems from two principal application areas: improvement of pictorial information for human interpretation; and processing of image data for storage, transmission, and representation for autonomous machine perception. The objectives of this article are to define the meaning and scope of image processing, discuss the various steps and methodologies involved in a typical image processing, and applications of image processing tools and processes in the frontier areas of research.

Key Words: Image Processing, Image analysis, applications, research.

1. Introduction

Image processing is a powerful tool for increasing the reliability and reproducibility of disease diagnostics. In the hands of pathologists, image processing provides quantitative data from histological images which supplement the qualitative data currently used by specialists. Image processing is clinically relevant in its application to microscopic tissue images. Patients and medical professionals alike have great interest in the development of methods which are reliable and reproducible. The field of digital image processing refers to processing digital images by means of a digital computer. Note that a digital image is composed of a finite number of elements, each of which has a particular location and value.

These elements are referred to as picture elements, image elements, pels, and pixels. Pixel is the term most widely used to denote the elements of a digital image. Vision is the most advanced of our senses, so it is not surprising that images play the single most important role in human perception. However, unlike humans, who are limited to the visual band of the electromagnetic (EM) spectrum, imaging machines cover almost the entire EM spectrum, ranging from gamma to radio waves. They can operate on images generated by sources that humans are not accustomed to associating with images. These include ultrasound, electron microscopy, and computer-generated images. Thus, digital image processing encompasses a wide and varied field of applications [1].

2. Fundamental steps in digital image

The digital image processing steps can be categorized into two broad areas as the methods whose input and output are images, and methods whose inputs may be images, but whose outputs are attributes extracted from those images.

Image acquisition is the first process in the digital image processing. Note that acquisition could be as simple as being given an image that is already in digital form. Generally, the image acquisition stage involves preprocessing, such as scaling. The next step is image enhancement, which is one among the simplest and most appealing areas of digital image processing. Basically, the idea behind enhancement techniques is to bring out detail that is obscured, or simply to highlight certain features of interest in an image.

A familiar example of enhancement is when we increase the contrast of an image because “it looks better.” It is important to keep in mind that enhancement is a very subjective area of image processing. Image restoration is an area that also deals with improving the appearance of an image. However, unlike enhancement, which is subjective, image restoration is objective, in the sense that restoration techniques tend to be based on mathematical or probabilistic models of image degradation. Enhancement, on the other hand, is based on human subjective preferences regarding what constitutes a “good” enhancement result.

Color image processing is an area that has been gaining in importance because of the significant increase in the use of digital images over the Internet. Color image processing involves the study of fundamental concepts in color models and basic color processing in a digital domain. Image color can be used as the basis for extracting features of interest in an image. Wavelets are the foundation for representing images in various degrees of resolution. In particular, wavelets can be used for image data compression and for pyramidal representation, in which images are subdivided successively into smaller regions.

Compression, as the name implies, deals with techniques for reducing the storage required to save an image, or the bandwidth required to transmit it. Although storage technology has improved significantly over the past decade, the same cannot be said for transmission capacity. This is true particularly in uses of the Internet, which are characterized by significant pictorial content. Image compression is familiar (perhaps inadvertently) to most users of computers in the form of image file extensions, such as the jpg file extension used in the JPEG (Joint Photographic Experts Group) image compression standard. Morphological processing deals with tools for extracting image components that are useful in the representation and description of shape.

The morphological image processing is the beginning of transition from processes that output images to processes that output image attributes. Segmentation procedures partition an image into its constituent parts or objects. In general, autonomous segmentation is one of the most difficult tasks in digital image processing. A rugged segmentation procedure brings the process a long way toward successful solution of imaging problems that require objects to be identified individually.

On the other hand, weak or erratic segmentation algorithms almost always guarantee eventual failure. In general, the more accurate the segmentation, the more likely recognition is to succeed. Representation and description almost always follow the output of a segmentation stage, which usually is raw pixel data, constituting either the boundary of a region (i.e., the set of pixels separating one image region from another) or all the points in the region itself.

In either case, converting the data to a form suitable for computer processing is necessary. The first decision that must be made is whether the data should be represented as a boundary or as a complete region. Boundary representation is appropriate when the focus is on external shape characteristics, such as corners and inflections. Regional representation is appropriate when the focus is on internal properties, such as texture or skeletal shape. In some applications, these representations complement each other. Choosing a representation is only part of the solution for transforming raw data into a form suitable for subsequent computer processing. A method must also be specified for describing the data so that features of interest are highlighted. Description, also called feature selection, deals with extracting attributes that result in some quantitative information of interest or are basic for differentiating one class of objects from another. Recognition is the process that assigns a label (e.g., “vehicle”) to an object based on its descriptors. Recognition topic deals with the methods for recognition of individual objects in an image.

Applications of image processing - There are a large number of applications of image processing in diverse spectrum of human activities-from remotely sensed scene interpretation to biomedical image interpretation. In this section we provide only a cursory glance in some of these applications.

2.1. Automatic Visual Inspection System

Computer vision and human vision appear to have the same function and goal. Both systems interpret multidimensional spatial data for the purpose of information gathering and visual recognition. Due to the complexity of the human visual system and the lack of total understanding of the neural aspects of human perception, even the best computer vision system cannot replicate the human eye. The development of computer vision techniques is focused, then, on improving upon the human vision model rather than replicating it. This section explains basic computer vision systems and how they operate in comparison to the human vision system. Automated visual inspection systems are essential to improve the productivity and the quality of the product in manufacturing and allied industries [2].

We briefly present few visual inspection systems here.

• Automatic inspection of incandescent lamp filaments: An interesting application of automatic visual inspection involves inspection of the bulb manufacturing process. Often the filament of the bulbs get fused after short duration due to erroneous geometry of the filament, e.g., no uniformity in the pitch of the wiring in the lamp. Manual inspection is not efficient to detect such aberrations.

In an automated vision-based inspection system, a binary image slice of the filament is generated, from which the silhouette of the filament is produced. This silhouette is analyzed to identify the non-uniformities in the pitch of the filament geometry inside the bulb.

Such a system has been designed and installed by the General Electric Corporation.

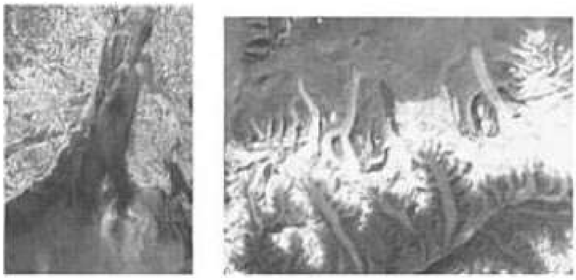
• Faulty component identification: Automated visual inspection may also be used to identify faulty components in an electronic or electromechanical systems.

• Automatic surface inspection systems: Detection of flaws on the surfaces is important requirement in many metal industries. For example, in the hot or cold rolling mills in a steel plant, it is required to detect any aberration on the rolled metal surface. This can be accomplished by using image processing techniques like edge detection, texture identification, fractal analysis, and so on.

3.2. Remotely Sensed Scene Interpretation

Information regarding the natural resources, such as agricultural, hydrological & mineral, forest, geological resources, etc., can be extracted based on remotely sensed image analysis. For remotely sensed scene analysis, images of the earth's surface arc captured by sensors in remote sensing satellites or by a multi-Spectra) scanner housed in an aircraft and then transmitted to the Earth Station for further processing. We show examples of two remotely sensed images in Figure 1 whose color version has been presented in the color figure pages. Figure 1(a) shows the delta of river Ganges in India. The light blue segment represents the sediments in the delta region of the river, the deep blue segment represents the water body, and the deep red regions are mangrove swamps of the adjacent islands.

Figure 1.1(b) is the glacier flow in Bhutan Himalayas. The white region shows the stagnated ice with lower basal velocity.



(a) (b)

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Fig. 1: Example of a remotely sensed image of (a) delta of river Ganges, (b) Glacier flow in Bhutan Himalayas

Techniques of interpreting the regions and objects in satellite images are used in city planning, resource mobilization, flood control, agricultural production monitoring, etc.

2.2. Biomedical Imaging Techniques

The dental diseases are generally classified into two primary groups. The first one includes those diseases of the teeth like the development of cavities and tooth decay. The tooth decay takes place when plaque is allowed to linger on the tooth's surface for a long period. The plaque pertains to a gluey substance, which contains bacteria that feed on the sugars consumed by a person. These bacteria created acid and absorbed through the tooth's surface, which creates the formation of cavities. Segmentation and detection methods are specifically valuable in the area of computer‐aided medical diagnosis applications where visualization of the parts which are difficult to identify by human vision is the critical component (Rad *et al.* 2013).

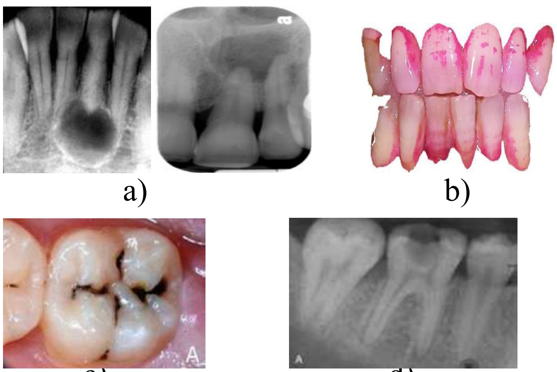

Figure 1 Dental Diseases
(a) Dental Cysts x-ray images
(b) Photograph of Dental Plaque
(c) Photograph of occlusal caries
(d) Caries in Periapical x-ray image

Various types of imaging devices like X-ray, computer aided tomographic (CT) images, ultrasound, etc., are used extensively for the purpose of medical diagnosis [5]-[7]. Examples of biomedical images captured by different image formation modalities such as CT-scan, X-ray, and MRI are shown in Figure 2.

(a) (b) (c)

Fig. 2: Examples of (a) CT Scan image of brain, (b) X-ray image of wrist and (c) MRI image of brain

(i) Localizing the objects of interest, i.e. different organs
(ii) Taking the measurements of the extracted objects, e.g. tumors in the image
(iii) Interpreting the objects for diagnosis.

Some of the biomedical imaging applications are presented below.

(A) Lung disease identification: In chest X-rays, the structures containing air appear as dark, while the solid tissues appear lighter. Bones are more radio opaque than soft, tissue. The anatomical structures clearly visible on a normal chest X-ray film are the ribs, the thoracic spine, the heart, and the diaphragm separating the chest cavity from the abdominal cavity. These regions in the chest radiographs are examined for abnormality by analyzing the corresponding segments.

(B) Heart disease identification: Quantitative measurements such as heart size and shape are important diagnostic features to classify heart diseases. Image analysis techniques may be employed to radiographic images for improved diagnosis of heart diseases.

(C) Digital mammograms: Digital mammograms are very useful in detect-ing features (such as micro- calcification) in order to diagnose breast tumor. Image processing techniques such as contrast enhancement, segmentation, feature extraction, shape analysis, etc. are used to analyze mammograms. The regularity of the shape of the tumor determines whether the tumor is benign or malignant.

3.4. Defense Surveillance

Application of image processing techniques in defense surveillance is an important area of study. There is a continuous need for monitoring the land and oceans using aerial surveillance techniques. Suppose we are interested in locating the types and formation of naval vessels in an aerial image of ocean surface.The primary task here is to segment different objects in the water body part of the image. After extracting the segments, the parameters like area, location, perimeter, compactness, shape, length, breadth, and aspect ratio are found, to classify each of the segmented objects. These objects may range from small boats to massive naval ships.

Using the above features it is possible to recognize and localize these objects. To describe all possible formations of the vessels, it is required that we should be able to identify the distribution of these objects in the eight possible directions, namely, north, south, east, west, northeast, northwest, southeast and southwest. From the spatial distribution of these objects it is possible to interpret the entire oceanic scene, which is important for ocean surveillance.

3.5. Content-Based Image Retrieval

Retrieval of a query image from a large image archive is an important application in image processing. The advent of large multimedia collection and digital libraries has led to an important requirement for development of search tools for indexing and retrieving information from them. A number of good search engines are available today for retrieving the text in machine readable form, but there are not many fast tools to retrieve intensity and color images. The traditional approaches to searching and indexing images are slow and expensive. Thus there is urgent need for development of algorithms for retrieving the image using the embedded content in them.

The features of a digital image (such as shape, texture, color, topology of the objects, etc.) can be used as index keys for search and retrieval of pictorial information from large image database. Retrieval of images based on such image contents is popularly called the content-based image retrieval.

3.6. Moving-Object Tracking

Tracking of moving objects, for measuring motion parameters and obtaining a visual record of the moving object, is an important area of application in image processing (13, 14). In general there are two different approaches to object tracking:
(i) Recognition-based tracking
(ii) Motion-based tracking.

A system for tracking fast targets (e.g., a military aircraft, missile, etc.) is developed based on motion-based predictive techniques such as Kalman filtering, extended Kalman filtering, particle filtering, etc. In automated image processing based object tracking systems, the target objects entering the sensor field of view are acquired automatically without human intervention. In recognition-based tracking, the object pattern is recognized in successive image-frames and tracking is carried-out using its positional information.

4. Conclusion

Image processing has wide verity of applications leaving option to the researcher to choose one of the areas of his interest. Lots of research findings are published but lots of research areas are still untouched. Moreover, with the fast computers and signal processors available in the 2000s, digital image processing has become the most common form of image processing and generally, is used because it is not only the most versatile method, but also the cheapest.

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