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Digital Image Processing: Methods and Applications

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ABSTRACT

In electrical engineering and computer science, image processing is any form of signal processing that converts the raw form of an input image into a usable and often meaningful output image. There are several standard techniques available for image processing and these techniques are broadly classified as image enhancement and image analyzing techniques. This paper discusses some of the most frequently used methods under this category.

1. Introduction

In the modern world, almost all leading fields like the medical industry, astronomy, physics, chemistry, forensics, remote sensing, manufacturing, defense, etc., rely upon images to store, display, and provide information about the world. The challenge to scientists, engineers and business people is to quickly extract valuable information from image and to converting images to meaningful information. Digital image processing allows one to enhance image features of interest while attenuating detail irrelevant to a given application, and then extract useful information about the scene from the enhanced image. It is defined as a vision that allows humans to perceive and understand the world surrounding them [1].

The development of electronic physical devices, like still and video cameras, x-ray devices, electron microscopes, radar, ultrasound, etc., has resulted in huge number of images [4]. These images are used for various purposes which include entertainment, healthcare, government, military, civil, business, industry, security and scientific. The images produced are in "raw" form and cannot be directly used with processing them in some manner. These processing techniques are Image processing techniques and are classified under two main categories, namely, "Image enhancement" or "Image Analysis". Image enhancement deals with the improvement of pictorial information for human interpretation and image analysis deals with the processing of image data for storage, transmission and representation of autonomous machine perception.

1.1. Applications

Image processing has an enormous range of applications; almost every area of science and technology can make use of image processing methods. This section provides a short list just to give some indication of the range of image processing applications.

1. Medicine

- Inspection and interpretation of images obtained from X-rays, MRI or CAT scans,
- Analysis of cell images, of chromosome karyotypes.

2. Agriculture

- Satellite/aerial views of land, for example to determine how much land is being used for different purposes, or to investigate the suitability of different regions for different crops,
- Inspection of fruit and vegetables, for example, distinguishing good and fresh produce from old.

3. Industry

- Automatic inspection of items on a production line
- Inspection of paper samples.

4. Law enforcement

- Fingerprint analysis,
- Sharpening or de-blurring of speed-camera images.

1.2. Challenges in Image Processing

An image is a complex interface of several features such as intensity, distribution of illuminating radiation, geometry of projection of the reflected or transmitted radiation from 3-dimensional to 2-dimension image plane, electronic characteristics of the capturing devices, etc. There is no comparable theory for extracting scene information of interest, such as position or quality of an article of manufacture, from an image. Human vision is enormously more sophisticated and it is very difficult to duplicate it in computers. Image processing requires lot of numeric computations and therefore using computers for image processing is a good choice. The main challenge lies in the manner it is processed. In the modern world, the requirement is triple curse, that is the market needs a system which uses minimum resources, fast and economic, all in the same image processing system. Until recently the computational burden of digital image processing for the most part had to be handled by dedicated hardware. The last few years has seen a move away from dedicated hardware towards pure software solutions.

2. Image Processing Algorithms

As mentioned previously the image processing algorithms are generally categorized into image enhancement algorithms and image analysis algorithms (Figure 1). This section discusses some algorithms under both these categories.

2.1. Image Enhancement

Image enhancement algorithms are broadly divided into two classes, point transforms and neighbourhood operations. Point transforms produce output images where each pixel is some function of a corresponding input pixel. The function is the same for every pixel, and is often derived from global statistics of the image.

With neighbourhood operations, each output pixel is a function of a set of corresponding input pixels. This set is called a neighbourhood because it considers the surrounding region corresponding a pixel, for example a 3x3 neighbourhood. Point transforms generally execute rapidly but are limited to global transformations such as adjusting overall image contrast. Neighbourhood operations can implement frequency and shape filtering and other sophisticated enhancements, but execute more slowly because the neighbourhood must be recomputed for each output pixel [2].

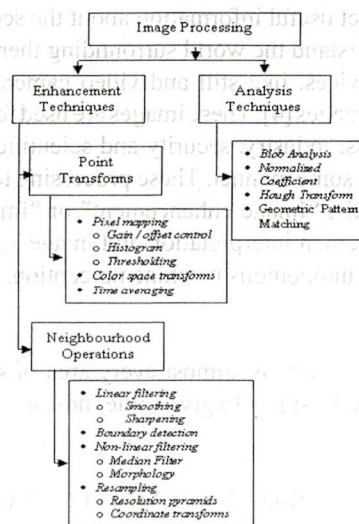


Figure 1 : Classification of Image Processing Techniques

2.1.1. Point Transform Techniques

Pixel mapping point transforms include a large set of enhancements that are useful with scalar-valued pixels (*e.g.* monochrome images). Pixel maps are most useful when the function is computed based on global statistics of the image. Histogram specification is a powerful pixel mapping point transform wherein an input image is processed so that it has the same distribution of pixel values as some reference image. The pixel map for histogram specification is easily computed from histograms of the input and reference images. Histogram specification is a useful enhancement prior to an analysis step. Thresholding is a commonly used enhancement whose goal is to segment an image into *object* and *background*. A threshold value is computed and pixels above or below which are considered as "object" and others as "background". Thresholding is very effective as it directly identifies objects against a background and eliminates unimportant shading variation. But when the image has overlapping scenes, then thresholding technique fails and often results with significant loss of robustness and accuracy.

Colour space conversion is used to convert between, for example, the RGB space provided by a camera to the HIS space needed by an image analysis algorithm. Accurate colour space conversion is computationally expensive but can be quite effective in image processing applications [5]. A method that can be used for handling very low contrast image is time averaging. This method reduces noise without affecting the original signal by averaging multiple images over time. The principal disadvantage of time averaging is the time needed to acquire multiple images from a camera [3].

2.1.2. Neighbourhood Operations

The best of neighbourhood operations is linear filter, which can amplify or attenuate selected spatial frequencies that results in smoothing and sharpening. Linear filters can be defined by a convolution operation, where output pixels are obtained by multiplying each neighbourhood pixel by a corresponding element of a like shaped set of values called a kernel, and then summing those products. The application of filters to an image emphasizes of the image boundaries.

Boundaries are usually defined to occur at points where the rate of change of image brightness is a local maximum, *i.e.* at peaks of the first derivative or, equivalently, zero crossings of the second derivative. The goal of any boundary detection algorithm is to emphasize features of interest (the boundaries) and attenuate everything else. The shading produced by an image and image discontinuities are the two major problems faced by boundary detection algorithms.

Non-linear filters are designed to work with blocks of desired shapes rather than spatial frequencies are useful in image enhancement. Median filters and morphological filters are the most famous techniques under non-linear filtering [6]. In median filter, the output at each pixel is the median of the corresponding input neighbourhood. The effect of a median filter is to attenuate image features smaller in size than the neighbourhood and pass image features larger than the neighbourhood. Morphology refers to a broad class of non-linear shape filters and is defined by a matrix of elements applied to input image neighbourhoods, but instead of a sum of products, a minimum or maximum of sums is computed. These operations are called erosion and dilation, and the matrix of elements is usually referred to as a probe rather than a kernel. Erosion followed by a dilation using the same probe is called an opening, and dilation followed by erosion is called closing. The advantages of applying filters are there is no significant edge loss and can handle noise better than linear filters.

In image processing, it is often desired to use a different sampling technique (example different resolution or orientation) that is different from the one offered by capturing device. This is made possible by digital re-sampling techniques. The resulting series of images are called a resolution pyramid. A resolution pyramid forms the basis of many image analysis algorithms that follow a coarse-to-fine strategy. Another important class of resampling algorithms are coordinate transforms, which can shift by subpixel amounts, rotate and size images and convert between Cartesian and polar representations. Three methods is common use are nearest neighbour, which is the fastest, bilinear interpolation, which is more accurate but slower and suffers some loss of high frequency components and cubic convolution, which is very accurate but slowest.

2.2. Image Analysis

The fundamental problem of image analysis is pattern recognition, where the goal is to recognize image patterns and determine their position, orientation, size, etc. It is considered challenging as a specific object can give rise to a wide variety of images and similar-looking objects may be present in the scene that must be ignored. This section discusses four main image analysis techniques namely, (i) Blob Analysis (ii) Normalized Correlation (iii) Hough Transform and (iv) Geometric Pattern Matching.

Blob analysis is one of the widely used method for industrial pattern recognition. The technique first classifies image pixels as object or background, join the classified pixels to make discrete objects using neighbourhood connectivity rules and then compute various moments of the connected objects to determine object position (1st moments), size (0th moment), and orientation (principal axis of inertia, based on 2nd moments). The advantages of blob analysis include high speed, sub-pixel accuracy and the ability to tolerate and measure variations in orientation and size. Disadvantages include inability to tolerate touching or overlapping objects, poor performance in the presence various forms of image degradation, inability to determine the orientation of certain shapes (*e.g.* squares), and poor ability to discriminate amongst similar looking objects.

Normalized correlation (NC), is a member of a class of algorithms known as template matching, which starts with a training step wherein a picture of an object to be located (the template) is stored. At run-time the template is compared to like-sized subsets of the image over a range of positions, with the position of greatest match taken to be the position of the object. The degree of match (a numerical value) can be used for inspection, as can comparisons of individual pixels between the template and

image at the position of best match. The advantages of NC are that it can tolerate touching or overlapping objects, performs well in the presence of various forms of image degradation. But this technique has the disadvantage of not having the ability to tolerate and measure variations in orientation and size.

The Hough transform is a method for recognizing parametrically defined curves such as lines and arcs, as well as general patterns. It starts with an edge detection step, which makes it more tolerant of local and non-linear shading variations than NC. When used to find parameterized curves the Hough transform is quite effective; for general patterns NC may have a speed and accuracy advantage, as long as it can handle the shading variations.

Geometric Pattern Matching (GPM) is replacing NC template matching as the method of choice for industrial pattern recognition. Template methods suffer from fundamental limitations related to time and accuracy, imposed by the pixel grid nature of the template itself and it is known that pixel grids are often not reliable. These limitations are avoided by GPM by representing an object as a geometric shape, independent of shading and not tied to a discrete grid. When combined with advanced pattern training and high speed, high-accuracy pattern matching modules, the result is a truly general purpose pattern recognition and inspection method. GPM produces several advantages like they are easy to train, offer rotation, size and shading independence, robust under low contrast, noise, poor focus and missing and unexpected feature conditions, very fast and most importantly provide high accuracy.

3. Conclusion

Digital image processing is a broad field with an extensive literature. This paper is a summarization of some important image processing techniques that are commonly used. Often a complete digital image processing system combines many of the image enhancement and analysis methods discussed above.

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