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(Review Article)

Exploration of image processing in various domains: A review

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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. Computer digital image technology is a very important branch of the computer application discipline, and its application areas include measurement, computer-aided design, physics, three-dimensional simulation and other industries. Moreover, with the improvement of computer hardware performance, image processing algorithms have improved the application of digital image processing technology. This Review article focuses on the current digital image processing technology and its application in Medical, forest protection and other fields of today's interest.

Keywords: Image processing; EM; Digital Image; Analog image; MSE; PSNR; SSIM; MAE; AP; LNG;BIM;CSIR;CBIR; VF;OCT;HM-VGG;CNN;RNN; LSTM; NB; GNB

1. Introduction

An image may be defined as a two-dimensional function, f(x, y), where x and y are spatial (plane) coordinates, and the amplitude off at any pair of coordinates (x, y) is called the intensity or gray level of the image at that point. When x, y, and the amplitude values of f are all finite, discrete quantities, we call the image a digital image. 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 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 Processing

The digital image processing steps can be categorised 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.

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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 pre-processing, such as scaling.

Image enhancement refers to the process of manipulating an image to improve its visual quality and interpretability for human perception. This technique involves various adjustments that aim to reveal hidden details, enhance contrast, and sharpen edges, ultimately resulting in an image that is clearer and more suitable for analysis or presentation. The goal of image enhancement is to make the features within an image more prominent and recognizable, often by adjusting brightness, contrast, colour balance, and other visual attributes.

Image restoration serves as a pivotal process aimed at reclaiming the integrity and visual quality of images that have undergone degradation or distortion. Its objective is to transform a degraded image into a cleaner, more accurate representation, thereby revealing concealed details that may have been obscured. This process is particularly vital in scenarios where images have been compromised due to factors like digital image acquisition issues or post-processing procedures such as compression and transmission. By rectifying these issues, image restoration contributes to enhancing the interpretability and utility of visual data.

Colour 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. Colour image processing involves the study of fundamental concepts in colour models and basic colour processing in a digital domain. Image colour 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.

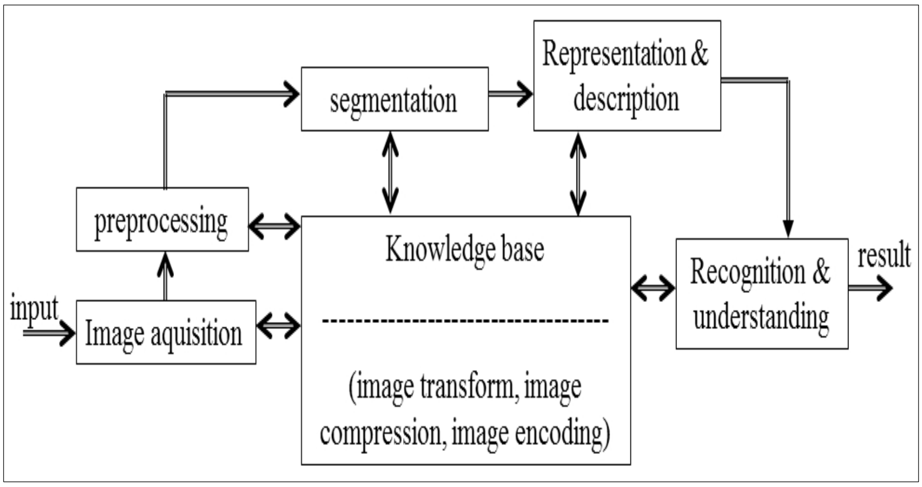

Figure 1 A schematic diagram of the process of digital image processing

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.

Recognition is the process that assigns a label to an object based on its descriptors. Recognition topic deals with the methods for recognition of individual objects in an image.

3. Features of Digital Image Processing

- **Reproducibility is good**: Digital image processing technology records and saves image information in binary format. As long as the original information is accurate, the processing of copying the image will not have any influence on the original image, and thus it can guarantee the real information.
- **High processing resolution**: Digital image processing technology differs from analog technology in that it records information in the form of pixel lattices. Therefore, the storage accuracy of an image largely depends on the number of quantization bits used in the conversion and the current digital image. It can have 8, 12, 16, or higher.
- **Wide range of applications**: Given the basic principles of digital image processing technology, it can be derived from a variety of sources, from microbes to space images, from human skeletons to lakes and mountains. Without being limited to the target's environment, they can accurately reflect their objective appearance and size. These images can all be processed by the same processing method.
- **Flexible processing**: Traditional analog images are limited by the optical principles they generate, and thus cannot be processed in accordance with people's wishes, and can only be processed linearly; while digital images are different, it can be used for any operation including linearity. Operations and non-linear operations greatly increase the flexibility of processing and make processing easy.
- **Large compression space**: Since digital images record and preserve information in the form of pixels, the pixel points of the brother-in-law image are not encouraged by each other, but there is some kind of connection. As long as this link is identified, a certain means of recording can be used, without having to record pixel by pixel, thereby compressing the storage space. Especially for image images, the contents of the two frames before and after are often not very different, with more than 90% of the data being the same, and the compression ratio can be very large.

4. Metrics for image processing operations

Evaluation metrics serve as pivotal tools in the assessment of the efficacy and impact of diverse image processing techniques. These metrics serve the essential purpose of furnishing quantitative measurements that empower researchers and practitioners to undertake an unbiased analysis and facilitate meaningful comparisons among the outcomes yielded by distinct methods. By employing these metrics, the intricate and often subjective realm of image processing can be rendered more objective, leading to informed decisions and advancements in the field.

4.1. Mean squared error (MSE)

The average of the squared differences between predicted and actual values. It penalizes larger errors more heavily.

$$MSE = \left(\frac{1}{M * N}\right) * \sum (Original_{(i,j)} - Denoised_{(i,j)})^2$$

where, M and N are the dimensions of the image. $Original_{(i,j)}$ *and* $Denoised_{(i,j)}$ are the pixel values at position (i, j) in the original and denoised images respectively.

4.2. Peak signal-to-noise ratio (PSNR)

PSNR is commonly used to measure the quality of restored images. It compares the original and restored images by considering the mean squared error between their pixel values.

$$PSNR = 10 * \log_{10}\left(\frac{MAX^2}{MSE}\right)$$

where, MAX is the maximum possible pixel value (255 for 8-bit images), MSE is the mean squared error between the original and denoised images.

4.3. Structural similarity index (SSIM)

SSIM is applicable to image restoration as well. It assesses the similarity between the original and restored images in terms of luminance, contrast, and structure. Higher SSIM values indicate better restoration quality.

$$SSIM_{(x,y)} = \left(2 * \mu_x * \mu_y + c_1\right) * (2 * \sigma_{xy} + c_2)/(\mu_x^2 + \mu_y^2 + c_1) * (\sigma_x^2 + \sigma_y^2 + c_2).$$

where, μ_x and μ_y are the mean values of the original and denoised images. σ^2_x and σ^2_y are the variances of the original and denoised images. σ_{xy} is the covariance between the original and denoised images. $c1$ *and* $c2$ are constants to avoid division by zero.

4.4. Mean absolute error (MAE)

The average of the absolute differences between predicted and actual values. It provides a more robust measure against outliers.

$$MAE = \left(\frac{1}{n}\right) * \sum |y_{actual} - y_{predicted}|$$

where n is the number of samples.

4.5. Average precision (AP)

AP measures the precision at different recall levels and computes the area under the precision- recall curve. Used to assess object detection and instance segmentation models.

4.6. Accuracy

The ratio of correctly predicted instances to the total number of instances. It’s commonly used for balanced datasets but can be misleading for imbalanced datasets.

$$Accuracy = \frac{(True\ Positives + True\ Negatives)}{Total\ Prediction}$$

4.7. Precision

The ratio of true positive predictions to the total number of positive predictions. It measures the model’s ability to avoid false positives.

$$Precision = \frac{True\ Positives}{True\ Positives + False\ Positives}$$

5. Related Work

In this paper [2], compared different image segmentation algorithms. Image segmentation is a procedure, which split a picture, which are comparative in some viewpoint and change over it into paired frame for preparing. Segmentation process is the primary step in many image processing. Procedure incorporates object characteristic and portrayal and detail estimation. Higher request errand takes after the grouping of object. Hence, classification, imagining of region of interest in any image, description plays a substantial role in image segmentation. There are numerous segmentation algorithms available in the literature, which split an image into number of regions based on some picture attributes like pixel quality esteem, shading, colour, shape etc. These all calculations are described based on the segmentation strategy utilized. Segmentation method split the region using different method such as single or multiple thresh-holding, segmentation on parallel region, segmentation using clustering, edge detection, and also segmentation on fuzzy logic technique etc. The chosen methodology are Otsu's calculation, K-means, quad tree, Delta E, Region developing and fth calculations. To check the execution of the calculation, they applied 6 straightforward and complex pictures accessible in the literature. The obtained result demonstrates the viability of the division. The paper provides the best approach for segmentations.

Advantages

- It can segment the image by simply finding edges in the image.
- Higher order task follows the classification of object.

Disadvantage

- The methods are difficult to identify multiple objects.

Agriculture is a most essential and antiquated occupation in India. As economy of India depends on farming creation, most extreme care of nourishment generation is fundamental. Vermin like infection, organism and microorganisms makes contamination plants with misfortune in quality and amount creation. There is vast measure of misfortune of rancher underway. Consequently, legitimate care of plants is essential for same. This paper [3] introduces a review of utilizing picture preparing techniques to distinguish different plant sicknesses. Picture preparing gives more proficient approaches to distinguish sicknesses caused by parasite, microorganisms or infection on plants. Negligible perceptions by eyes to identify illnesses are not precise. Overdose of pesticides causes hurtful constant illnesses on individuals as not washed appropriately. Overabundance utilizes likewise harms plants supplement quality. It brings about colossal loss of creation to rancher. Subsequently utilization of picture handling strategies to identify and group illnesses in rural applications is useful. The application uses normal method like segmentation with clustering, colour extraction and classification to identify plant disease.

Advantages

Picture preparing gives more proficient approaches to distinguish sicknesses caused by parasite, microorganisms or infection on plants. Subsequently utilization of picture handling strategies to identify and group illnesses in rural applications is useful.

Disadvantages

Negligible perceptions by eyes to identify illnesses are not precise.

Platform errands are the most critical work items in Liquefied Nature Gas (LNG) plant support ventures and a compelling advancement checking methodology can be gainful to partners through the better control to the financial plan and calendar of the whole venture [4]. This exploration is concentrated on examining discoveries and lesson learnt from the platform advance observing contextual analysis of a LNG plant support extend. A novel approach by utilizing Building Data Modeling (BIM) and picture preparing advancements to consequently gauge framework advance through site photographs is being creating. The current scaffolding progress and productivity monitoring in LNG plants can be done by visual observations through site supervisors. The accuracy of the progress estimation depends on the judgements of supervisors and their experience. The photos can be efficiently collected and analyzed. Combining with Building Information Modelling (BIM) platform, the results have potential to be relatively accurate than the conventional site observations given that the cost information is embedded in BIM model and automatic process can be potentially achieved. Due to the complexity of the plant facility, the scaffolding design and the layout of the scaffolding installation can be irregular shaped. They influence the performance of the scaffolding recognition algorithm a lot. In addition, the captured photos at site only gather the outer layer information of scaffolding. The implementation contractors as well as the plant operator all indicated that as long as the accuracy of the proposed recognition processes can be averagely and slightly higher than the conventional manual rough estimations, the proposed approach is considered reliable. Content Based image retrieval (CBIR) is permanent technique for discovery various images from large Dataset. CBIR uses the image visual content for colour, shape and texture to index and represent image. The paper [5] gives detailed of CBIR with feature extraction and performance parameter. It gives various feature extraction method of texture, colour and shape which are commonly used. For feature extraction feature in visual image is are texture, shape and colour etc. The visual feature is common feature and domain feature. For colour feature extraction Colour slot, colour requirement and similarity measurements are used for extraction. Colour sets and colour data moments are also used as histogram of colour. For texture include significant knowledge about structure surface arrangement. Texture gives valuable surface data about their relationship and structure with surrounding. Shape dose not refer to the image shape but to the distinct region shape that is being sought out. Features of shape are separated into two different classes region based and boundary based. Boundary based uses only shape boundary whereas shape feature if region based use complete shape region.

Image Segmentation is a standout amongst the hugest errands as it grants identifying the related areas of the pictures and disregard inconsequential data. Any mistake during this phase may cause serious problems to the subsequent methods of the image-based systems. The segmentation process is usually very complex since most of the images present some kind of noise. In this work [6], two techniques have been combined to deal with such problem: one derived from the graph theory and other from the anisotropic filtering methods, both featuring the utilization of related data keeping in mind the end goal to classify every pixel in the picture with higher precision.

Advantages

The method gives an especial emphasis to the neighbourhood information to correctly classify a given image pixel under analysis, preserving, with more accuracy, homogeneous and contiguous regions in the images, avoiding the presence of spurious isolated pixels.

Disadvantages

The performance of the proposed method will be compared with the results of other important approaches, such as the recently proposed median-based versions of the Otsu's method. The proposed technique will be assessed on other image databases.

Abramovich [7] proposed an automated method using a deep learning regression model to assess fundus image quality. The model accurately distinguishes between high- and low-quality images, aligning closely with doctors' evaluations, thus improving diagnostic efficiency in ophthalmology. Recent advancements in adversarial neural networks have addressed challenges in semantic segmentation for medical imaging, providing insights into improving models like the HM-VGG for complex medical image segmentation tasks [8]. The challenge of training robust models with limited annotated data has been a focus of many studies. For example, Wang et al. [9] proposed a deep transfer learning approach for breast cancer image classification, which is particularly relevant for addressing the issue of small sample sizes in clinical settings. Their method showcases the potential of transfer learning to enhance diagnostic accuracy, aligning with the goals of the HM-VGG model in glaucoma detection. A key challenge in medical image analysis is the integration of multiple data modalities. The importance of multimodal data fusion in enhancing diagnostic accuracy has been widely recognized.

A deep learning-based multimodal fusion approach improved object recognition by integrating diverse data types, which directly supports the multimodal nature of the HM-VGG model, combining Visual Field (VF) and Optical Coherence Tomography (OCT) images to improve glaucoma detection [10].

Research into spatiotemporal feature representation and data-driven feature extraction in multidimensional datasets has also contributed to the development of models capable of handling complex, multimodal data. Though primarily focused on time-series data, these techniques offer valuable insights into feature extraction methods that can be adapted to medical image analysis [11].

Akter [12] used Convolutional Neural Network (CNN) models to clinically interpret Temporal-Superior-Nasal-Inferior-Temporal (TSNIT) retinal optical coherence tomography scan images to differentiate between normal and glaucomatous optic neuropath.

Zhang[13] used DenseNet169 & 201, and ResNet50 for feature extraction. Bodapati et al. [14] proposed a blended feature extraction model. Authors fused features from VGG16 and Xception. [15] obtained feature representations from retina images using InceptionV3 pre-trained weights. The authors used Messidor-2 in training and testing. XGBoost was used as a classifier with an accuracy of 91.40% on Messidor-2. Besides deep learning-based feature extraction, feature selection is also essential in image classification tasks. There are many feature selection techniques to find the optimal subset of features from a given data in the literature. Some points are essential in deciding on a feature selection technique, such as contribution to the classifier's performance, reducing overfitting, or minimizing training time [16]. During the training, deciding on the number of iterations (models) is critical. Too many numbers can reason for overfitting, while very few numbers can reason for under fitting. Validation methods help to choose the correct number of iterations. Gradient boosting uses decision trees as base learners generally [17].

The paper [18] utilized a combination of GWO and SVM for breast cancer prediction. UCI dataset was used for experiments. It was found that SVM-GWO achieves 100% accuracy for prediction whereas a 99.29% accuracy rate was achieved without feature selection. The results were compared with other classification algorithms and it was found that in terms of sensitivity, accuracy, and specificity, SVM-GWO outperforms all. As compared to work done in the literature, the proposed method increased diagnosis accuracy by 27.68%.

The Paper [19] proposed a meta-heuristic algorithm named "Feature Selection based on WOA (FSWOA)". FSWOA was used to reduce the dimensionality of medical data. The accuracy of the proposed FSWOA observed on several medical datasets was 87.10% for Hepatitis, 97.86% for Breast Cancer, 78.57% for Pima Indians Diabetes and 77.05% for Starlog Disease. [20] the paper used EM to analyze the data and after normalizing, the neural network multilayer perceptron structure with WOA was used to predict breast cancer. The accuracy achieved after performing preprocessing and reducing dimensions of the dataset was 99% and it comes out to be a good machine learning method in comparison to other techniques used.

Meera & Nalini [21] conducted a comparative analysis of data mining methods for breast cancer prediction based on execution time and classification accuracy as performance measures. This study used NB and J48 data mining algorithms. The performance of NB and J48 was compared in terms of classification accuracy and execution time. The results show that NB had an accuracy of 64% whereas J48 had an accuracy of 60%. This study concluded that NB is a better classification algorithm with a higher accuracy rate and less execution time as compared to J48.

Naive Bayes (NB) classifies samples using a probabilistic classification approach. NB is considered a simple and popular algorithm for many classification problems. GNB is a variant of the NB algorithm which is used for the classification of continuous data using the gaussian distribution. In GNB, the standard deviation and mean of each given class corresponding to every sample in the training data is calculated and classification is performed according to these calculations [22].

The titled 'SmokeNet: Satellite Smoke Scene Detection Using Convolutional Neural Network with Spatial and Channel-Wise Attention' [23], aimed to detect wildfire smoke using a large-scale satellite imagery dataset. It proposed a new CNN model, SmokeNet, which incorporates spatial and channelwise attention for enhanced feature representation. The USTC_SmokeRS dataset, consisting of 6225 images across six classes (cloud, dust, haze, land, seaside, and smoke), served as the benchmark. The SmokeNet model achieved the best accuracy rate of 92.75% and a Kappa coefficient of 0.9130, outperforming other state-of-the-art models.

Based on the plot, Ref. [24] was the second-best performer with the second-highest score of almost thirty-five. This publication, entitled 'Fast forest fire smoke detection using MVMNet', was published in 2022. The paper proposed multi-oriented detection based on a value conversion-attention mechanism module and mixed-NMS for smoke detection. They obtained the forest fire multi-oriented detection dataset, which includes 15,909 images. The mAP and mAP50 achieved were 78.92% and 88.05%, respectively.

Recurrent neural network (RNN) that is particularly well suited for sequential data and time-series analysis. When applied to the hyperspectral imaging of crops, LSTM can leverage the sequential nature of spectral bands or temporal changes in crop conditions. LSTM can analyse hyperspectral data to monitor crop health by identifying stress factors such as diseases, pests, and nutrient deficiencies. By learning the temporal patterns of crop health indicators, it can provide early warnings and actionable insights. By analysing temporal hyperspectral data, LSTM can predict crop yields more accurately. It can incorporate changes in spectral signatures over the growing season to make informed yield predictions [25].

In crops such as oil palm, the detection of diseases such as basal stem rot stands out, with authors such as ref. [26] placing it at near-infrared (NIR) lengths. In crops such as potatoes, diseases such as late blight [27] are detected, or the disease known as bacterial wilt in peanut plants, in which the sensitivities of the wavelengths in the NIR region were significantly different between the various stages of the disease [28].

6. Application of Image processing

The image processing spread across all areas of developing technology and it became back bone for the most trending technology like ML, AI. It spread all the fields like Agriculture, Medical, Forest protection, Physics and chemistry, Traffic, Weather forecasting and environment pollution etc as shown in the Table 1 below.

Table 1 Application Analysis Table of Digital Image Processing

Field	Application
Physics and Chemistry	Spectrum Analysis
Biology and Medicine	Cell analysis; CT; X-ray analysis
Environment Protection	Research of atmosphere
Agriculture	Estimation of plants
Irrigation Works	Lake, river, and dam
Weather	Cloud and weather report
Communication	Fax; TV; phone
Traffic	Robot; products
Economics	IC-card
Military	Missile guidance; training

7. Conclusion

This comprehensive review paper embarks on an extensive exploration across the diverse domains of image denoising, enhancement, segmentation and feature extraction. By meticulously analyzing and comparing these methodologies, it offers a panoramic view of the contemporary landscape of image processing. In addition to highlighting the unique strengths of each technique, the review shines a spotlight on the challenges that come hand in hand with their implementation. Automatic fire detection in forests is a critical aspect of modern wildfire management and prevention, this concept also covered in this review. In treatment of Breast cancer, Eye related issues, and other body parts treatment depend on x-ray, MRI, ultra-scan which uses image processing concept. So the world depended on the image processing. We tried to cover all the area of image processing during the survey for different issues.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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