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An Overview of Popular Digital Image Processing Filtering Operations

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***Abstract*— Digital image processing (DIP) is carried out to produce an altered image that is more suitable for the intended application. Image filtering and image warping are considered to be the most common methods of image processing. Within image filtering, these operations are carried out to aid the altering or enhancing an image to either remove specific features or highlight features of interest within the image. These operations are generally carried out in the pre-processing stage and can have very positive results on the quality of feature extraction and the results of image analysis. This paper aims to give a brief overview of some popular image filtering operations, focusing on edge detection filters, smoothing filters and the advantages of greyscale over colour images.**

Keywords— Digital Image Processing, Image Filtering, Image Quality, Smoothing Filters, Edge Detection, Greyscale

I. Introduction

The use of vision systems has increased significantly across a wide variety of industries over the past number of years, several of these include automotive, manufacturing and medical industry. These industries require highly effective systems in place at all times to ensure quality, accuracy and safety. An inefficient or poorly designed vision system on an autonomous car could lead to catastrophic events, therefore, the DIP hardware within these vision systems plays a significant role in ensuring optimised performance [1][2]. DIP is the processing of digital images with the use of a digital computer and can be broken into three groups; image compression, image enhancement and repair and measurement extraction. Image enhancement may include filtering for noise, sharpening or magnifying an image, which is of benefit for applications such as feature extraction or image analysis [2][3].

It is at this stage where image filters come into use. Image filtering operations are carried out to assist in altering or enhancing an image to either remove specific features or highlight features of interest within the image [2]. Figure 1 gives a basic step process of image processing, from when the image is captured to the output resulting image, with the main focus being on the image processing system stage, where the filtering operations will take place along with many other operations to obtain the desired output image.

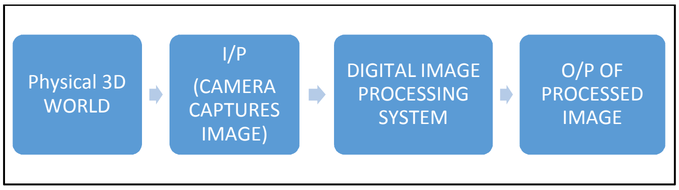

Figure 1 Basic Architecture of Digital Image Processing

II. Filtering Operations

This section aims to give an insight into various digital image filtering operations, broken up into three sub-sections; Edge Detectors, Smoothing Filters and Greyscale Images, while also briefly discussing image quality and its importance when storing these enhanced, altered and/or restored images. Before introducing some of the filtering operations used during DIP, it is important to speak of image quality and how filtering operations play a significant role in this.

A. Image Quality Metrics

Image Quality Metrics (IQM) quantifies the accuracy of a digital imaging system`s (DIS) capability to capture, process, store, compress, transmit and display the signals from an image. Within DIP systems, image quality (IQ) is found to be a very challenging assessment to carry out [1][2]. In a typical DIS, as an image is captured, it is converted into a digital signal within the camera and run through a processing stage (i.e. for filtering, reducing noise, compressing, storage and transmission). This is where filtering operations take place. Problems begin to occur when the image or video is then displayed on a screen as it can become distorted due to several factors such as motion blurring, gaussian noise, errors encountered during transmission and inadequate sensors. DIS’s, therefore, must be able to identify the IQ before the

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signal is stored or transmitted to enhance or control it. This is where IQM becomes crucial to DIP [4][6][7].

IQM can be used for a variety of applications;

- For benchmarking image processing algorithms to determine the most effective algorithm for the specific application
- To monitor IQ in quality control systems
- Can be embedded into an image processing system to optimise algorithms and parameter settings [4].

During an image quality assessment (IQA), there are two types; subjective and objective assessment methods. Subjective assessment involves human interaction to evaluate IQ. This method is the most reliable and accurate because humans are the ultimate user of multimedia applications. However, this method is also prolonged and costly as it requires constant human involvement [1][2]. Objective assessment computes the IQ automatically, which is becoming more desirable [4].

Effectively applying filtering operations during the image processing stage is of great importance to ensure that the required quality of the image is achieved for its application before it can be compressed, stored and transmitted.

B. Edge Detectors

Edges are projections of physical processes or changes in illumination. Edge detection is one of the most critical tasks in applications such as pattern analysis and recognition and can be used in almost every field of image analysis (object recognition, target tracking, etc.). As edges within an image contain essential features, they carry a significant portion of information with it. Edge detection techniques aim to focus on distinct edges within an image (e.g. for greyscale images there should not be two edges of the same brightness, and for colour images, edges with the same colour exist, but a visible edge will create a darker region along the edge) [8][9].

As edges are detected, this then allows for the filtering out of unwanted information within the image (e.g. surface texture), resulting in the reconstruction of a much smaller sized image of more relevance to the application [8][10]. Carrying out edge detection on colour images can be a much more difficult task compared to carrying out the same process on a grey image. This is because the detected edges within a colour image are generally not visible or thick, resulting in false edges being detected [8].

Edge detectors are susceptible to detecting false edges when using smaller kernel matrices. A method of rectification or alternative to this is running a first and second-order edge detection filter, where the second has increased neighbourhood size by a factor of 2 or 3, similar to the adaptive window methods used in other areas of imaging research [11]. The combination of results allows for the isolation of false positives due to noise. The downside to this, of course, is the possibility of the omission of features that are indeed edges but do not travel outside a single neighbourhood in size.

There are many methods used to carry out edge detection (Canny filter, Roberts filter, Sobel filter, etc.). These methods can be grouped into two categories, known as Gradient or Laplacian operators [3][12]. Gradient-based techniques require less complexity compared to Laplacian based techniques, as they detect edges by finding the maximum and minimum of the first derivative in the image, while Laplacian operators detect edges of the image involved by finding the zero-crossing in the second derivative [3][8][13].

1) Canny Filter

Canny edge detection (developed by John F. Canny in 1986) [14] is used to detect edges while also suppressing noise with the use of a multi-stage algorithm [13]. As noted in II.B, most edge detection filters are grouped into either the Laplacian or Gradient category, but the Canny filter, however, is based on the squared magnitude gradient, where any local points above the specified threshold are then identified as edges [12]. One of the advantages of the Canny filter is the acknowledgement and overcoming of white Gaussian noise (i.e. values of any pair of pixels at any time are uncorrelated) [15].

One of the issues found with the original Canny filter is that the filters criteria suggest that the optimal edge detector is infinitely wide, meaning that a limitless number of edges will be distinguished in the image, therefore, rendering the edge detector useless. To overcome this issue, combining other edge detector criteria with the Canny optimises the performance [14].

While noisy images do present a challenge for Canny filters, this has been addressed numerous times, a prime example being in 2002 where the addition of a Canny filter used similarly to Deriche's filter techniques, significantly improved signal to noise ratios when compared to Deriche's original filter [16]. When compared to the Sobel filter, Rana et al. found that the Sobel filter was unable to produce a smooth, thin edge, whereas the Canny filter could [17]. The Canny filter can also play a large part in the feature extraction portion of object recognition [18].

2) Sobel Filter

The Sobel operator, created by Irwin Sobel and Gary Friedman in 1968, is also known as the Sobel filter or the Sobel-Friedman operator and is very similar in operation to that of the Roberts Filter [17]. This filter performs a 2-D gradient measurement on an image, highlighting regions of high spatial frequency that correspond to edges (i.e. it finds edges at points where the gradient is found to be at is maximum). The Sobel filter generally uses a 3x3 kernel matrix in both the X and Y directions (individually) to detect edges [18][19].

As an edge has a 1-D shape of a ramp, by calculating the derivative (gradient) of the image, it allows for the edge to be highlighted more clearly as it results in deriving the maximum gradient. As edge pixel values are larger than their neighbouring non-edge pixel values, if the calculated gradient is larger than the predetermined threshold value, this denotes an edge. This is known as gradient filtering, which can be achieved by using the Sobel filter [3]. Figure 2 shows an edge as a result of intensity in a signal. Figure 3 shows the derivative/maximum gradient of this signal, which is above the predetermined threshold, denoting an edge.

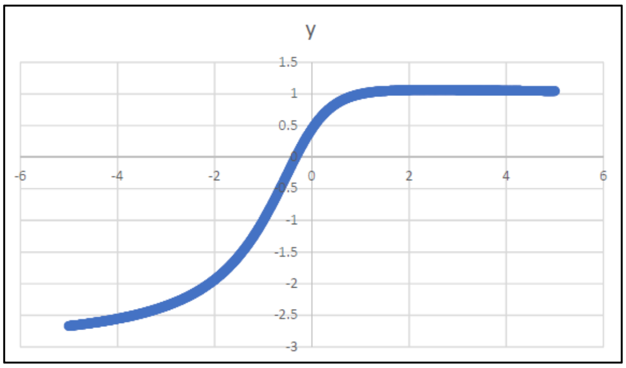

Figure 2 Signal with an edge

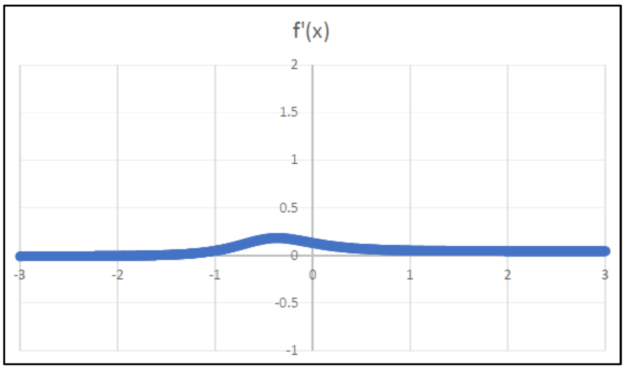

Figure 3 Derivative or gradient of signal

The Sobel filter can be very susceptible to the introduction of noise in images, resulting in these being distinguished as edges, however, with the use of larger kernel matrices this issue can be reduced [19]. The Sobel filter is very successful for image segmentation without any human involvement and can execute its filtering operation at a very fast rate while also producing thick, clear edges. Each time this filtering operation is carried out, it will produce the same output, making it one of the most widely used filtering operations in image processing [19].

C. Smoothing Filters

Since all edge detection results are easily affected by noise, filtering out of this noise is of great importance. Many methods of smoothing are based on an anisotropic modification of the heat conductance equation, but rather on a modification of the solution of the equation. An edge-preserving smoothing filter is essentially one which eliminates fine data points of an image while preserving those which are integral for the processing of an image. This, of course, is dependent on predetermined thresholds. Because a course structured image may contain edges, high and low frequencies, edge-preserving smoothing, therefore, cannot be achieved by the employment of linear filtering [19]

1) Gaussian Filter

Gaussian smoothing is based on the assumption, which has been experimentally verified on numerous occasions, that bold noise is a close approximation of Gaussian distribution, therefore removing this bold noise. However, as stated above, the fine details (i.e. fine details that lie outside the Gaussian distribution) are left [20][21]. Gaussian filtering has been used successfully, and remains a standard image processing step, for space scale filtering with applications such as blur removal in photographs [22]. It has proven popular due to its predictivity, symmetry and its decrease around the mean [23].

2) Median Filter

The Median filter (also known as the rank filter) is used to reduce noise within an image by locating pixels in the image that have extreme, improbable intensities and replacing them with a more suitable value (i.e. the Median value). Pixel values with extreme intensities are generally a cause of impulse noise, so it is important to remove these points [24][25]. Blurring is generally kept to a minimum when applying the Median filter, with only a slight loss of detail in an image after carrying out the filtering process. As its most important application is to attenuate Gaussian noise without blurring edges, the Median filter is one of the most commonly used filters within image processing applications [24]. However, this filtering process is not perfect and does come with its disadvantages such as edge jitter, streaking, and it can result in removing important image details [26].

This filtering process is very similar to the mean filter, with the main notable difference being that the Median pixel value is used to replace the neighbouring pixel values, whereas the mean filter will use the mean value as the replacement. The Median filter has been found to effectively preserve the useful detail in the image. Generally, the Median filter will focus on a 3x3 pixel neighbourhood, but to produce a more severe smoothing effect, a larger neighbourhood is required [1][26].

The Median is not affected by outliers, it is also a much more effective method of preserving sharp edges because the Median value will be an actual pixel value within the neighbourhood and not an unrealistic new value, which is generated when carrying out mean filtering [1].

D. Greyscale

Although colour can offer huge potential in machine vision, especially in applications such as navigation, autonomous intelligent vehicles (AIV`s), food inspection and surgical robotics, the data that is offered through colour images can take an extremely long time for post-processing to be carried out in comparison to greyscale [24]. Colour does not need to be altered or enhanced for it to be useful as it contains all of the information required. However, colour images will contain inhomogeneous data, given that all pixels are likely to contain multiple different colours in the image itself. In comparison to this, greyscale is homogenous and can, therefore, be processed as a single entity without window adaptation. Simple processing techniques for colour may involve subtracting two or combining three channels of colour for discrimination of colours to take place (channel meaning red, green, blue (RGB) or any other colour as a result of the combination of these three). However, the amount of digital processing required to decide on what actions to take in relation to these channels may be quite high and requires careful consideration [24].

Some simple greyscale operations include clearing the image or setting the contents of a photo to a constant level. Alternative operations include inverting an image (i.e. turning a photograph from negative to positive, or the reverse) or shifting the image up/down/left or right. These operations are made easier if the local intensities are made similar [24].

When converting to greyscale, it is important to ensure that local colour differences in the colour image (input image) are translated into differences in the grey level of the resulting image (output image) [27].

Converting an image to greyscale can be done in several ways;

- Lightness Method: (RGB max + RGB min) / 2
- Average Method: (R+G+B) / 3
- Luminosity Method (0.21 R + 0.72 G + 0.07 B). As we as humans are most perceptive to green, the luminosity method, therefore, accounts for this by giving green (G) the most weight [24].

While the luminance method is the most commonly used method when converting to greyscale, it can have a negative effect as much of the important image data can be lost during translation [27]. In an experiment to determine the most successful greyscale conversion method, Cordedlli et al. found that a conversion method based on RGB-derived information outperformed three other models tested. This experiment was carried out to be used in antibody detection in patients, where greyscale cameras were too costly, and RGB cameras provided an adequate amount of data [28]. There have been many works also into the colourisation of greyscale images, such as colour spaces developed by Ruderman et al. [29][30]. Although much noise makes it through a greyscale filter, many works have aimed at the eradication of this noise with a multitude of methods (e.g. fuzzy interference systems) [31][32].

III. Discussion & Conclusion

This paper aimed to give an introduction to digital image processing (DIP) while focusing on the filtering operations that take place during the image processing stage. DIP is the processing of digital images with the use of a computer and is used to alter, restore or enhance digital images to produce an image fit for its intended application. As there is an increase in the use of vision systems in many industries, the processing stage is of great importance to ensure the desired output is continuously achieved to ensure optimal performance from these systems [1]. The filtering operations introduced in this paper focused on three areas of filtering; edge detection, smoothing filters and greyscale images.

Edge detection in image processing plays a critical role as they contain features of great importance. As edges are detected, other information can then be removed or filtered out where deemed necessary, allowing for a smaller image focusing on the relevant application [8].

Smoothing filters are utilised to filter out noise within an image [23]. When focusing on greyscale images in comparison to colour images, greyscale does come with its advantages. Colour image data may take a very long time during post-processing and will contain inhomogeneous data, whereas greyscale data is homogenous and does not take as long during post-processing [27].

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