Chapter- 2

TOOLS AND TECHNIQUES FOR IMAGE FUSION

2.1. FUNDAMENTAL CONCEPTS OF IMAGE FUSION

Image fusion is a technique of generating an image that bears the information possessed in multiple images [30-50]. The process involves in gathering vital information from each individual image and fuse to engender new resultant image. This methodology improves the quality of the resultant image in terms of information described in it. This is achieved by applying certain numerical operators with which the crucial information of the image is extracted, later this survived significant information from all the images is collected to generate the final image. Thus it is evident from the process that the final fused form of the images holds all the prominent information of the input images. The technique also ensures single fused image in place of multiple image modalities.

Image fusion finds its application in various fields in the current scenario of technology. It has emerged as a quite handy tool in medical diagnosis where a wide variety of image modalities are fused to single image for better and fruitful diagnosis. The technology is also used in remote sensing and satellite imaging. Generally different multivariate images like Infra-Red, Thermal and Ultra Violet images are employed in remote sensing and fusing these different images would provide all the significant information contained in them. This falls to the class of multi-sensor data fusion. Every variant of image is generated using specific sensor system with associated technology. In satellite imaging, the images captured are of high resolution with multi-spectra components. These images are transmitted via two steps in two different forms known as panchromatic image whose resolution is mentioned in terms of coarser resolution. Later, these two forms of image information are fused to reconstruct the original image. From instrumentation perspective, we find certain limitations and in many cases it is termed as inaccuracy and inefficiency. For such cases, the image fusion technology is the only solution.
Earlier the image fusion step involves in simple averaging. The method typically considers the intensities of the pixels of the input images and generate the final output fused image by simple averaging of these numerical values. Another simple method is application of high pass filters. However, these methods produced poor results. This paved a path towards exploring the advanced techniques for image fusion. Wavelet transformation, Curvelet transformation and pyramidal fusion are considered as some advanced techniques for image fusion. General image fusion methods classification is given as

a) Spatial domain fusion

b) Transform domain fusion

Spatial domain fusion process involves in injecting the high frequency details of the image into up-sampled version of the image. Simple averaging, Brovey method, principal component analysis (PCA) and high pass filtering based technique are examples of spatial domain fusion methods. There are several drawbacks with the spatial domain based fusion system. Spatial distortion is termed as a severe disadvantage in such techniques and often considered to be a deteriorating factor in image classification mechanism. To overcome the spatial distortion the concept of transformation domain is proposed. The transformation method is a multi-resolution technique [43] and is quite efficient in handling images for remote sensing and satellite communications.

2.2 EVOLUTION OF IMAGE FUSION

The evolution of image fusion concept for the precision level image processing applications [39-55] can be explained using the following Fig.2.1
The crude form of image fusion mechanism involves in low level mathematical calculation like addition, subtraction, division and averaging on pixel intensities. These technique are well appreciated for images with high brightness and contrast. However they have adverse effects on images with low contrast and brightness as they often tend to blur the image. Considering these, later pyramid transformation (PT) technique has emerged as a sophisticated approaches in dealing fusion process. It is also considered that it would be better to perform the fusion in the transform domain. PT technique is proved to be such appropriate transform. The algorithm involves in constructing the PT of the fused image using the PT of the source images. This is followed by extraction of the fused image by applying inverse PT. In the due course of time it is egressed as a popular transformation technique with advantages listed as follows:

a) Capability of furnishing information in terms of the acute contrast changes
b) Capability of rendering both spatial and frequency domain localization.

Different variants of pyramid transformation methods adopted and developed are as follows.
a) Laplacian Pyramid
b) Ratio-of-low-pass Pyramid
c) Gradient Pyramid
d) FSD Pyramid
e) Morphological Pyramid etc.

In the recent past, Wavelet Transformation based decomposition technique started taking over the existing PT for image fusion. In actual sense, WT can be assumed as a special type of PT based decompositions. It keeps back all the features of PT while being highly descriptive in terms of theoretical and mathematical perspectives. A wide scope of research in this field is discovered with advances like multi-wavelets which were later emerged as praiseworthy applications in image fusion.

### 2.3 IMAGE REPRESENTATION

The human visual system (HVS) incurs input image like an accumulation of spatially distributed luminant energy [20]. This type of representation is termed as optical image. Optical images are general types of images that a camera captures. Later these are constituted as video like an analog electrical signal. These are further sampled to transform in to a digital image which is represented as S(r, c).

The digital image S(r, c) is interpreted as a 2D array of data. This is called as Pixel representation. Each pixel magnitude refers to certain feature of the image in spatial system. One such is the brightness of the image. Finally the whole image is transformed in to a matrix of data with rows and columns to fit the 2D array representation. Each row in the matrix corresponds to a vector. Basing on the mapping there are many image formats [71-80].

#### 2.3.1 Binary Image

The elementary type of image representation is called the "Binary image". It typical uses only two levels. The two levels are referred to as black and white which are mentioned as ‘0’ and ‘1’. This type of image representation is considered as a 1
bit/pixel image. This is due to the reason that it takes only 1 binary digit to represent each pixel. These types of images are often used to depict low level information of the picture like its outline or shape. Especially in applications like optical character representation (OCR) where only the outline of the character is required to realize the letter representing it. The binary images are generated from the system of gray scale images through a technique called thresholding. The two level thresholding simply acts as a decision factor above which it switches to numerical '1' and below which it switches to numerical '0'.

![Binary Images](image.png)

Fig.2.2: Examples of binary images
2.3.2 Gray Scale Image

Gray scale image (GSI) are denoted as monochrome, or single-color image. Such images possess brightness information only. Hence no color information is contained by them. However, the brightness is represented at different levels. Typical 8-bit image holds a range of 0-255 brightness levels known as gray levels. Here 0 refers to black and 1 refers to white. The 8-bit representation is obvious with the fact that the computer actually handles the data in 8-bit format. Below Fig.2.3 (a) and (b) are two examples of such GSI.

![Fig.2.3: Examples of GSI](image)
2.3.3 Color images

Color image (CI) can be modelled as three band monochrome image data, where each band of the data corresponds to a different color.

![Fig. 2.4: Examples of CI](image)

The actual information stored in the digital image data is brightness information in each spectral band. When the image is displayed, the corresponding brightness information is displayed on the screen by picture elements that emit light energy corresponding to that particular color. Typical color images are represented as red,
green, and blue or RGB images. Using the 8-bit monochrome standard as a model, the corresponding color image would have 24 bit/pixel – 8 bit for each color bands (red, green and blue).

![RGB images](image)

(a) $S_R(r,c)$  
(b) $S_G(r,c)$  
(c) $S_C(r,c)$

Fig.2.5: Representation of CI as individual color (RGB) images.

The following figure illustrate that in addition to referring to arrow or column as a vector, we can refer to a single pixel red, green, and blue values as a color pixel vector – (R, G, B).

![Color pixel vector](image)

Fig.2.6: A color pixel vector consists of the red, green and blue pixel values (R, G, B) at one given row/column pixel coordinate (r, c)
For many applications, RGB color information is transformed into mathematical space that decouples the brightness information from the color information. The hue/saturation/lightness (HSL) color transform allows us to describe colors in terms that we can more readily understand. The lightness is the brightness of the color, and the hue is what we normally think of as “color” and the hue (ex: green, blue, red, and orange). The saturation is a measure of how much white is in the color (ex: Pink is red with more white, so it is less saturated than a pure red).

2.3.4 Multispectral Images

A multispectral image is one that captures image data at specific frequencies across the electromagnetic spectrum. Multispectral images typically contain information outside the normal human perceptual range. This may include infrared, ultraviolet, X-ray, acoustic or radar data. Source of these types of image include satellite systems, underwater sonar systems and medical diagnostics imaging systems.
2.3.5 Computer Graphics

Computer graphics is a specialized field within that refers to the computer science realm that refers to the reproduction of visual data through the use of computer.

In computer graphics, types of image data are divided into two primarily categories:
1. Bitmap image (or raster image): can represented by our image model \( I(r, c) \), where we have pixel data and corresponding brightness values stored in file format.

2. Vector images: refer to the methods of representing lines, curves shapes by storing only the key points. These key points are sufficient to define the shapes, and the process of tiring theses into an image is called rendering after the image has been rendered, it can be thought of as being in bit map format where each pixel has specific values associated with it.

2.4 DIGITAL IMAGE FORMATS

Image formats are standardized means of organizing and storing digital images [77]. Image files are composed of digital data in one of these formats that can be rasterized for use on a computer display or printer. An image file format may store data in uncompressed, compressed, or vector formats. Once rasterized, an image becomes a grid of pixels, each of which has a number of bits to designate its color equal to the color depth of the device displaying it. Most the type of file format fall into category of bitmap images. In general, these types of images contain both header information and the raw pixel data. The header information contain information regarding

i. The number of rows (height)

ii. The number of columns (Width)

iii. The number of bands.

iv. The number of bit per pixel.

v. the file type

vi. Additionally, with some of the more complex file formats, the header may contain information about the type of compression used and other necessary parameters to create the image, \( I(r,c) \).
2.4.1 BMP format (Bitmap image File Format)

The BMP file format, also known as bitmap image file or device independent bitmap (DIB) file format or simply a bitmap, is a raster graphics image file format used to store bitmap digital images, independently of the display device (such as a graphics adapter), especially on Microsoft Windows and OS/2 operating systems.

The BMP file format is capable of storing 2D digital images of arbitrary width, height, and resolution, both monochrome and color, in various color depths, and optionally with data compression, alpha channels, and color profiles.

2.4.2 TIFF (Tagged Image File Format)

Tagged Image File Format is one of the most popular and flexible of the current public domain raster file formats. They are used on World Wide Web (WWW). GIF files are limited to a maximum of 8 bits/pixel and allows for a type of compression called LZW. The GIF image header is 13 byte long & contains basic information.

2.4.3 JPEG (Joint Photo Graphic Experts Group)

This is the right format for those photo images which must be very small files, for example, for web sites or for email. JPG is often used on digital camera memory cards. The JPG file is wonderfully small, often compressed to perhaps only 1/10 of the size of the original data, which is a good thing when modems are involved. However, this fantastic compression efficiency comes with a high price. JPG uses lossy compression (lossy meaning "with losses to quality"). Lossy means that some image quality is lost when the JPG data is compressed and saved, and this quality can never be recovered. JPEG images compression is being used extensively on the WWW. It’s, flexible, so it can create large files with excellent image equality.

2.4.4 VIP (visualization in image processing) formats:

It is developed for the CVIP tools software, when performing temporary images are created that use floating point representation which is beyond the standard 8
bit/pixel. To represent this type of data the remapping is used, which is the process of taking original image and adding an equation to translate it to the range (0-225).

2.4.5 Graphics Interchange Format (GIF)

GIF uses an indexed representation for color images (with a palette of a maximum of 256 colors), the LZW (Lempel–Ziv–Welch) compression algorithm, and a 13-byte header.

2.4.6 Portable Network Graphics (PNG)

PNG is an increasingly popular file format that supports both indexed and truecolor images. Moreover, it provides a patent-free replacement for the GIF format.

2.5 MEDICAL IMAGE MODALITIES

The earliest medical images used light to create photographs, either of gross anatomic structures, or if a microscope was used, of histological specimens. Light is still an important source for creation of images. However, visible light does not allow us to see inside the body.

2.5.1 X-Rays

X-rays were first discovered in 1895 by Wilhelm Conrad Roentgen, who was awarded the 1901 Nobel Prize in physics for this achievement. The discovery caused worldwide excitement, especially in the field of medicine; by 1900, there already were several medical radiological societies. Thus, the foundation was laid for a new branch of medicine devoted to imaging the structure and function of the body. Principle of an X-ray system with image intensifier. X rays impinging on the image intensifier are transformed into a distribution of electrons, which produces an amplified light image on a smaller fluorescent screen after acceleration.

The image is observed by a television camera and a film camera and can be viewed on a computer screen and stored on a CD-ROM or a PACS. X-ray technology is the oldest and most commonly used form of medical imaging.
Fig.2.10: X-ray image model

X-rays use ionizing radiation to produce images of a person’s internal structure by sending X-ray beams through the body, which are absorbed in different amounts depending on the density of the material. In addition, included as “x-ray type” devices are also mammography, interventional radiology, computed radiography, digital radiography and computed tomography (CT). Radiation Therapy is a type of device which also utilizes either x-rays, gamma rays, electron beams or protons to treat cancer.

X-ray images are typically used to evaluate:

a) Broken bones

b) Cavities

c) Swallowed objects

d) Lungs

e) Blood vessels

f) Breast (mammography)

2.5.2 ULTRASOUND

Diagnostic ultrasound, also known as medical sonography or ultrasonography, uses high frequency sound waves to create images of the inside of the body. The
ultrasound machine sends sound waves into the body and is able to convert the returning sound echoes into a picture. Ultrasound technology can also produce audible sounds of blood flow, allowing medical professionals to use both sounds and visuals to assess a patient’s health.

![Ultrasound image model](image.png)

Fig.2.11: Ultrasound image model

Ultrasound is often used to evaluate:

a) Pregnancy

b) Abnormalities in the heart and blood vessels

c) Organs in the pelvis and abdomen

d) Symptoms of pain, swelling and infection

### 2.5.3 POSITRON EMISSION TOMOGRAPHY (PET)

PET is a nuclear imaging technique that provides physicians with information about how tissues and organs are functioning. PET, often used in combination with CT imaging, uses a scanner and a small amount of radiopharmaceuticals which is injected into a patient’s vein to assist in making detailed, computerized pictures of areas inside the body.
PET is often used to evaluate:

a) Neurological diseases such as Alzheimer’s and Multiple Sclerosis

b) Cancer

c) Effectiveness of treatments

d) Heart conditions

2.5.4 COMPUTED TOMOGRAPHY (CT)

Computed Tomography (CT), also commonly referred to as a CAT scan, is a medical imaging method that combines multiple X-ray projections taken from different angles to produce detailed cross-sectional images of areas inside the body. CT images allow doctors to get very precise, 3-D views of certain parts of the body, such as soft tissues, the pelvis, blood vessels, the lungs, the brain, the heart, abdomen and bones. CT is also often the preferred method of diagnosing many cancers, such as liver, lung and pancreatic cancers.
CT is often used to evaluate:

a) Presence, size and location of tumors
b) Organs in the pelvis, chest and abdomen
c) Colon health (CT colongraphy)
d) Vascular condition/blood flow
e) Pulmonary embolism (CT angiography)
f) Abdominal aortic aneurysms (CT angiography)
g) Bone injuries
h) Cardiac tissue
i) Traumatic injuries
j) Cardiovascular disease

2.5.5 PET-CT

For added precision, physicians use a medical imaging technique that combines PET and CT. This allows images acquired from both devices to be taken sequentially and combined into a single superposed image. PET-CT serves as a prime tool in the delineation of tumor volumes, staging and the preparation of patient treatment plans. The combination has been shown to improve oncologic care by positively impacting active treatment decisions, disease recurrence monitoring and patient outcomes, such as disease-free progression.
Magnetic Resonance Imaging (MRI) is a medical imaging technology that uses radio waves and a magnetic field to create detailed images of organs and tissues. MRI has proven to be highly effective in diagnosing a number of conditions by showing the difference between normal and diseased soft tissues of the body.

MRI is often used to evaluate:

a) Blood vessels
b) Abnormal tissue
c) Breasts
d) Bones and joints
e) Organs in the pelvis, chest and abdomen (heart, liver, kidney, spleen)
f) Spinal injuries

g) Tendon and ligament tears

2.6 IMAGE QUALITY METRICS

Image Quality is a characteristic of an image that measures the perceived image degradation (typically, compared to an ideal or perfect image). Imaging systems may introduce some amounts of distortion or artifacts in the signal, so the quality assessment is an important problem.

There are several techniques and metrics that can be measured objectively and automatically evaluated by a computer program. Therefore, they can be classified as Full Reference Methods (FR) and No-Reference Methods (NR). In FR image quality assessment methods, the quality of a test image is evaluated by comparing it with a reference image that is assumed to have perfect quality. NR metrics try to assess the quality of an image without any reference to the original one.

The image quality indices try to figure out the some or the combination of the various factors that determine the quality of the image. Some of the critical factors that the image quality metrics are given as follows.

a. Mean Square Error (MSE)

b. Peak Signal to Noise Ratio (PSNR)

c. Average Difference (AD)

d. Normalized Cross Correlation (NCC)

e. Maximum Difference (MD)

f. Normalized Absolute Error (NAE)

g. Laplacian Mean Square Error (LMSE)

i. Structural Similarity Index Metric (SSIM)
However, only some of the above mentioned image metrics are used in this thesis. They are explained in details in terms of their meaning and calculation as follows.

2.6.1 Mean Square Error (MSE)

The expression for evaluating the MSE is given as

$$\text{MSE} = \frac{1}{mn} \sum_{i=1}^{m} \sum_{j=1}^{n} (A_{ij} - B_{ij})^2$$ \hspace{1cm} (2.1)

Where

$m$ is the height of the Image implying the number or pixel rows

$n$ is the width of the image, implying the number of pixel columns.

$A_{ij}$ being the pixel density values of the perfect image.

$B_{ij}$ being the pixel density values of the fused image.

Mean square error is one of the most commonly used error projection method where, the error value is the value difference between the actual data and the resultant data. The mean of the square of this error provides the error or the actual difference between the expected/ideal results to the obtained or calculated result. Here, the calculation is performed at pixel level. A total of $m*n$ pixels are to be considered. $A_{ij}$ will be the pixel density value of the perfect image and $B_{ij}$ being that of the fused image. The difference between the pixel density of the perfect image and the fused image is squared and the mean of the same is the considered error. MSE value will be 0 if both the images are identical.

2.6.2 Peak Signal to Noise Ratio (PSNR)

The expression for PSNR is given as

$$\text{PSNR} = \frac{1}{mn} \sum_{i=1}^{m} \sum_{j=1}^{n} (A_{ij} - B_{ij})$$ \hspace{1cm} (2.2)

Where
\( m \) is the height of the Image implying the number or pixel rows

\( n \) is the width of the image, implying the number of pixel columns.

\( A(i,j) \) being the pixel density values of the perfect image.

\( B(i,j) \) being the pixel density values of the fused image.

Average Difference, as explained by the term itself, is the average value of the difference between the actual/ideal data and the obtained/resultant data. In our case, the corresponding pixel values of the perfect Image \( A \) and the fused image \( B \) is considered. The difference of the corresponding pixel density values is averaged to obtain the metric. This metric helps in providing the overall average difference between the corresponding pixels of the two images proving us a value that specifies, how much different is the fused image from the perfect image.

### 2.6.3 Structural Content (SC)

The expression for the calculating the SC is given as

\[
SC = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} (A_{ij})^2}{\sum_{i=1}^{m} \sum_{j=1}^{n} (B_{ij})^2} \tag{2.3}
\]

Where

\( m \) is the height of the Image implying the number or pixel rows

\( n \) is the width of the image, implying the number of pixel columns.

\( A(i,j) \) being the pixel density values of the perfect image.

\( B(i,j) \) being the pixel density values of the fused image.

Here the ratio between the content of the both the expected and the obtained data. Practically, it is the ratio between the net sum of the square of the expected data and the net sum of square of the obtained data. In our case we calculate the ratio between the net sum of the square of the pixel densities of the perfect image.
and the net sum of the square of the pixel densities of the fused image. For the fused and perfect image being identical, the Structural Content metric value would be 1. But SC being 1 does not mean that the fused and perfect image are identical.

2.6.4 Maximum Difference (MD)

Mathematically the MD is represented as

$$MD = \max |A_{ij} - B_{ij}|$$

Where, $$i = 1, 2, 3, \ldots m$$; and $$j = 1, 2, 3, \ldots n$$

$$m$$ is the height of the Image implying the number or pixel rows

$$n$$ is the width of the image, implying the number of pixel columns.

$$A (i,j)$$ being the pixel density values of the perfect image.

$$B (i,j)$$ being the pixel density values of the fused image.

Maximum Difference is a very simple metric that gives us the information of the largest of the corresponding pixel error. The difference between each of the corresponding pixel densities is calculated. The biggest difference value of these is considered as the metric here. This metric reflects a high value when in any part of the two images, a significant difference exists.

2.6.5 Laplasian Mean Square Error (LMSE)

The expression for evaluating the LMSE is given as

$$LMSE = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} (\nabla^2 A - \nabla^2 B)^2}{\sum_{i=1}^{m} \sum_{j=1}^{n} (\nabla^2 A)^2}$$

Where $$m$$ is the height of the Image implying the number or pixel rows

$$n$$ is the width of the image, implying the number of pixel columns.

$$A (i,j)$$ being the pixel density values of the perfect image.
B\ (i,j)\ being\ the\ pixel\ density\ values\ of\ the\ fused\ image.

Laplacian Mean Square Error, as explained by the term, the normal mean square error calculation. But the difference here is that the mean square error is calculated not based on the expected and obtained data but based on the laplacian value of the same. Thus, the laplacian of each of the values is calculated and then the net sum of the square of the error (difference) is calculated which is divided by the net sum of the square of the laplacian of the expected data.

2.6.6 Structural Similarity Index Metric (SSIM)

The Structural Similarity Index measures the similarity between two images. It is an improved version of traditional methods like PSNR and MSE. SSIM is considered to be one of the most effective and consistent metric.

SSIM is calculated based on two parameters -

(a) K\ vector\ being\ a\ constant\ in\ the\ SSIM\ index\ formula\ with\ default\ value:

\[
K = [0.01 0.03]
\]

(b) L\ being\ the\ dynamic\ range\ of\ the\ images.\ In\ our\ case\ the\ default\ value\ of

\[
L = 255.
\]

The values C1 and C2 are calculated based on the following formula:

\[
C_1 = (k_1 * L)^2 \quad \text{(2.6)}
\]

\[
C_2 = (k_2 * L)^2 \quad \text{(2.7)}
\]

G\ being\ a\ Guassian\ filter\ window\ with\ default\ value\ given\ in\ matlab\ as\ special\ ('gaussian', 11,1.5),\ the\ input\ images\ A\ and\ B\ are\ low\ pass\ filtered\ with\ G\ giving\ \mu_1\ and\ \mu_2\ respectively.\ The\ filter\ operation\ or\ convolution\ operation\ performed\ is\ denoted\ by\ "\cdot\".
\[ \mu_1 = A \cdot G \]  \hspace{1cm} (2.8)

\[ \mu_2 = B \cdot G \]  \hspace{1cm} (2.9)

Then the values, \( \sigma_1^2 \), \( \sigma_2^2 \) and \( \sigma_{12}^2 \) are calculated based on the following formula.

\[ \sigma_1^2 = (A_{ij}^2 \cdot G) - \mu_1^2 \]  \hspace{1cm} (2.10)

\[ \sigma_2^2 = (B_{ij}^2 \cdot G) - \mu_2^2 \]  \hspace{1cm} (2.11)

\[ \sigma_{12}^2 = (A_{ij}B_{ij} \cdot G) - \mu_1 \cdot \mu_2 \]  \hspace{1cm} (2.12)

Once the above values are calculated, finally the SSIM value is calculated based on the following formula:

\[ \text{SSIM}(x, y) = \frac{(2\mu_x \mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \]  \hspace{1cm} (2.13)

The SSIM index is a decimal value between 0 and 1. A value of 0 would mean zero correlation with the original image, and 1 means the exact same image. 0.95 SSIM, for example, would imply half as much variation from the original image as 0.90 SSIM. Through this index, image and video compression methods can be effectively compared.

### 2.6.7 Benchmarking

The following table depicts the ideal value a metric will have in case the fused image and the perfect image are identical. In case, the fused image is not perfect, the table specifies the range of the value the metric will span between.
Regarding the image quality metrics readings, the more significant aspect is its absolute value. Our main objective is to identify the difference/error value in the fused image with respect to the perfect image, the sign does not hold much of significance in our case.

### 2.7 CONCLUSION

A brief discussion on the fundamental concepts of various tools and techniques are presented in this Chapter. Image fusion is the important mechanism which is widely dealt in this thesis using several transformation techniques. Hence a basic definition and the evolution of image fusion is presented. Different modalities of medical provide a variety of information during medical diagnosis. A reference to the all the different types of medical image modalities are given with examples and their

<table>
<thead>
<tr>
<th>Metric</th>
<th>Ideal Value</th>
<th>Error Value</th>
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<tbody>
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<td>Mean Square Error</td>
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<td>&gt; 0</td>
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<td>Peak Signal Noise Ratio</td>
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<td>&gt;1</td>
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<td>&lt;1 and &gt;0</td>
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<td>Normalized Cross Correlation</td>
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<td>&gt;1 or &lt;1</td>
</tr>
<tr>
<td>Maximum Difference</td>
<td>0</td>
<td>&gt;0</td>
</tr>
<tr>
<td>Normalised Absolute Error</td>
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<td>&gt;0 and &lt;1</td>
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<td>Laplacian Mean Square Error</td>
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<tr>
<td>Structural Similarity Index</td>
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<td>&gt;0 and &lt;1</td>
</tr>
</tbody>
</table>
applications individually. In addition to this, a thorough revision of various image quality metrics used in this thesis is also given.