Improved Image Fusion Techniques

AUTHOR

Abdul Hameed Khan

352-FET/MSEE/S14

SUPERVISOR

PROF.DR. MUHAMMAD AMIR

CO- SUPERVISOR

DR. UMER JAVEED

DEPARTMENT OF ELECTRONIC ENGINEERING,

FACULTY OF ENGINEERING AND TECHNOLOGY

INTERNATIONAL ISLAMIC UNIVERSITY, ISLAMABAD

2017

Image analysis.

Image Fusion.

Genetic Algorithm

Improved Image Fusion Techniques

Thesis Submitted in Partial Fulfillment of the Degree Requirements of
MS in Electronic Engineering

BY

Abdul Hameed Khan

352-FET/MSEE/S14

TO

THE DEPARTMENT OF ELECTRONICS ENGINEERING

FACULTY OF ENGINEERING AND TECHNOLOGY

INTERNATIONAL ISLAMIC UNIVERSITY, ISLAMABAD (IIUI)

SESSION 2014-2017

(Acceptance by the Viva voce Committee)

Title of Thesis: Improved Image Fusion Techniques
Name of Student : Abdul Hameed Khan
Registration no : Reg no: 352-FET/MSEE/S14

Accepted by The Department of Electrical Engineering, Faculty of Engineering and Technology, International National Islamic University, Islamabad. In partial fulfillment of the requirements for the Master of Philosophy Degree in Master in Electronics Engineering.

Dean:
Dr. Muhammad Amir
Faculty of Engineering and Technology, IIU, Islamabad

Chairman:
Dr. Suheel Abdullah Malik
Department of Electrical Engineering,
Faculty of Engineering and Technology,
IIU, Islamabad.

External Examiner:
Dr. Ijaz Mansoor Qureshi
Professor , DEE, Air University ,
Islamabad.

Internal Examiner:
Dr. Adnan Umar Khan
Assistant Professor,
Department of Electrical Engineering,
Faculty of Engineering and Technology,
IIU, Islamabad.

Supervisor:
Dr. Muhammad Amir
Professor /Dean
Department of Electrical Engineering,
Faculty of Engineering and Technology,
IIU, Islamabad.

Co-Supervisor:
Dr. Umer Javeed
Assistant Professor,
Department of Electrical Engineering,
Faculty of Engineering and Technology,
IIU, Islamabad.

DECLARATION

I, **Abdul Hameed Khan s/o Abdul KarimKhan**,Reg.No:**352-FET/MSEE/S14,**student of MS in Electronics Engineering, Session 2014-2017, herewith express that thesis stuff printed in titled "**Improved Image Fusion Techniques"** pertains my thesis work, has not been published, released or submitted as research work, thesis or publication in any form in any University, Research Institution etc. in Pakistan or abroad.

Abdul Hameed Khan

ACKNOWLEDGEMENTS

All praise to almighty ALLAH (s.w.t) for his favors to accomplish this task. Many thanks to my advisor and guide **Prof. Dr Muhammad Amir**, who has been the guiding force behind this work. Next, I want to express my respects to Prof. Dr. I.M. Qureshi, Prof. Dr Naveed Aqdas and Assistant Prof. Dr. Umer Javeed for teaching me and helping me how to learn. They have been great sources of inspiration to me. I also expand my thanks to all faculty members, friends, classmates and staff of the Department of Electronic Engineering, Faculty of Engineering and Technology, International Islamic University, Islamabad. Who have helped and encouraged me during the route of Master's Degree. Most of all, thanks to my wife for her support in my studies. Thank you.

Dedicated to my Beloved Parents

ABSTRACT

Digital Image Fusion is the process of integrating the complementary as well as common information of a set of images of multimodality sensors and reducing the redundant information. The Fused image must contain superior information in terms of both subjectively and objectively. The image fusion algorithms are application specific and optimized according to the nature of fusion problem.

There are numerous applications of image fusion including medical imaging, remote sensing, and computer vision. This thesis focuses on two types of applications, Medical imaging and remote Sensing. In medical image fusion section CT (Computed Tomography) and MRI (Magnetic Resonance Imaging) images of human brain are used. CT provides better performance on denser tissues like bones and MRI shows soft tissue structure. While the fused CT & MRI images provide additional information to doctor and clinical treatment planning system. The second contribution of this thesis is related to remote sensing image fusion, where we fused satellite SAR (Synthetic Aperture Radar) images with optical images to provide more accurate information for intelligence and mission planning such as border surveillance, troops and military installations deployment. This information may further be used for better battle field management system.

Usually various algorithms are applied and image fusion performance parameters are evaluated to select the best suited algorithms. In this thesis we used images that are already registered and different methods of conventional and artificial intelligence are tested. Hence a hybrid approach is suggested in which evolutionary computing technique named Genetic Algorithm is applied along with Discrete Wavelet Transform (DWT) at pixel level which gives us better performance as compared to conventional fusion methods alone. We provide performance evaluation of proposed fusion algorithm on the basis of Entropy, Image Quality Index (IQI).RMSE (Root Mean Square Error), and PSNR (Peak Signal to Noise Ratio).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

DSP	Digital Signal Processing
CAD	Computer Aided Diagnostic
CT	Computerized Tomography
MR/MRI	Magnetic Resonance (Imaging)
PET	Positron Emission Tomography
SAR	Synthetic Aperture Radar
ICA	Independent Component Analysis
PCA	Principal Component Analysis
IHS	Intensity Hue Saturation
DWT	Discrete Wavelet Transform
GA	Genetic Algorithm
HR	High Resolution
LR	Low Resolution
PSNR	Peak Signal to Noise Ratio
MRA	Multi Resolution Approach
GUI	Graphical User Interface
PSNR	Peak Signal to noise ratio
RMSE	Root Mean Square Error
IQI	Image Quality Index
RGB	Red Green Blue

Chapter 1

Introduction

1.1 Image Fusion

Image fusion purpose is to create a composite or enhanced image form a set of input images. Images used for the fusion purpose may belong to different sources, Multi-sensory images (figure 1.1) as different sensors have different spectral and spatial resolutions. Fusion may be performed with same source, Multi-focus images (figure 1.2) with different area of scene focused i.e. when we try to focus a object in one scene the other objects in same scene are blurred or out of focus.

(a) Camera image (b) Range sensor image (c) Fused image

Figure 1.1: Multi-Sensors Image Fusion

(a) Watch focused (b) Books focused (c) Fused image Both watch & books focused

Figure 1.2: Multi-Focus Image Fusion

Image fusion requirements arise with the recent advance technological development in the sensors and increase of image accusation techniques. Recent technologies in imaging sensor give us a diverse nature of information. This information is alone not too much useful, but when we fuse the other sensor data with this, this will become more meaningful.

The requirement of image fusion in different application areas is increasing day by day, as the existing equipments as well as the fusion schemes not fulfills the current and near future demands. Some application areas of image fusion are remote sensing, medical imaging and computer vision. All of these application areas require different types of highlighted features (which are application specific) in the fused image, while no one particular sensor alone grant the such requisite details.

With fast technological developments more sensor available, which can easily interface with standard platforms, developments in algorithms and generation of new requirements are challenging areas, which significantly increases the research requirements in the field of image fusion.

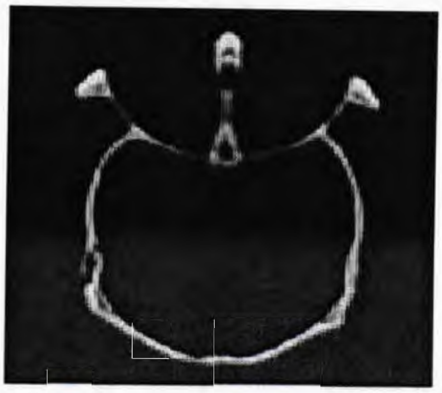
1.2 Applications of Image Fusion

Image fusion is deeply related to different fields of basic and applied sciences.

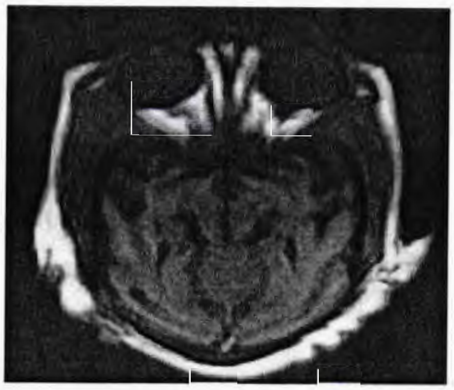
Such as Medical Imaging and Diagnostics, Robots and Computer Vision, Manufacturing Engineering, Military and law enforcement and remote sensing.

1.2.1 Medical Imaging & Diagnostics

In modern medicine and heath care, the role of image fusion is essential. Medical images are displayed on the screen to the medical professional for diagnosing diseases. In absence of medical image, doctor unable to localize a disease inside the body. In case of any abnormality of brain, a doctor need the different types of sensors data such as Xray, Computed Tomography (CT), Positron Emission Tomography (PET), Magnetic Resonance Imaging (MRI), Bone Scan etc. to evaluate the type and localization of disease inside brain. In figure 1.3 CT and MRI images fusion results are shown.



(a) CT Image



(b) MRI Image

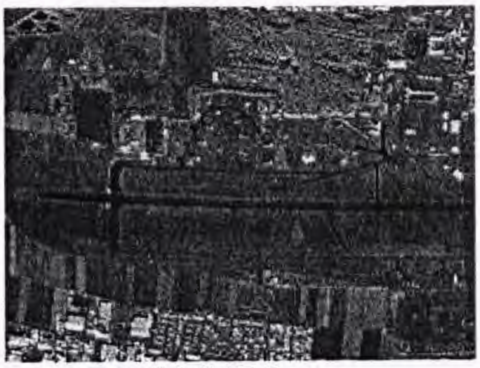
(c) Fused Image

Figure 1.3: Medical Imaging Image Fusion

1.2.2 Remote Sensing

In the field of remote sensing there are different types of sensors. Each sensor has its own unique type of information, which needs to be fused with other one for more meaningful information. In figure 1.4 satellite optical image is fused with Synthetic Aperture Radar (SAR) image.

(a) Optical image



(b) SAR Image

(c) Fused Image

Figure 1.4: Remote Sensing Image Fusion

1.3 Advantages of image fusion

High accuracy and reliability

- By evaluation of redundant information
- Requires sensors receiving identical properties of the scene/object

Feature vector with higher dimensionality

- By evaluation of complementary information
- Requires sensors receiving different properties of the scene/object

Faster acquisition of information

- Simultaneous data acquisition using multiple sensors

1.4 Organization of the thesis

The Thesis is structured as follows. Chapter 1 is about introduction and applications of image fusion. Chapter 2 consists of problem statement and the literature review of the fusion techniques like: Independent Component Analysis (ICA), Principal Component Analysis (PCA), Intensity Hue Saturation (IHS), Wavelets and Heuristic Computing techniques. Our purpose is to study these techniques and how they can be used to generate fused image. In Chapter 3, we describe the detail understanding of Genetic Algorithm (Heuristic Computing technique). In Chapter 4, Implementation of Genetic algorithms discussed in detail along with the evaluation criteria. Finally the results and comparisons on fused images are discussed. In Chapter 5 the conclusions and the future work are discussed.

Chapter 2

Problem statement and Literature Review

2.1 Problem Statement

The requirement of image fusion in different application areas is increasing day by day, as the existing equipments as well as the fusion schemes not fulfills the current and near future demands. There are different types of problems in the effective deployment of image fusion. Such as most of times, we required an image of high quality with the diverse type of information of same object. Also the quality of fused image is extremely dependent on the required application area. Some application areas of image fusion are remote sensing, medical imaging and computer vision. All of these application areas require different types of highlighted features (which are application specific) in the fused image, while no one particular sensor alone grant the such requisite details.

Other problems in image fusion is that quality of fused image is rely on the experience of operator, because in most of cases the image quality is evaluated on the basis of operator personal experience with reference to some parameters. Increase in customized solutions and requirements, lack of robust system are also the concern. With fast technological developments more sensor available, which can easily interface with standard platforms, developments in algorithms and generation of new requirements are challenging areas, which significantly increases the research requirements in the field of image fusion.

2.2 Literature Review:

A single composite image can be achieved from the set of input images by the procedure of image fusion. Resultant image, achieved past fusion must provide meaningful information for machines and also good perception for human use. The image fusion procedure can be accomplished with a lot of ways but they are categorically divided in to pixel based, feature based and the decision based fusion. Among the many variants, the mostly used techniques of image fusion are: Independent Component Analysis (ICA)[8], Intensity Hue Saturation (IHS)[7, 9], Principle component Analysis

(PCA)[9], Multiresolution type methods like : Wavelet Transforms[10, 13, 16], and Heuristic Computation Techniques(GA)[11, 12, 15].

2.2.1 Intensity Hue Saturation based Image Fusion:

In Intensity Hue Saturation fusion method a low-resolution image of RGB space is converted into the intensity, hue and saturation color space. Most of researchers resample the I-band to give the similar resolution like multispectral image, before conducting different fusions at this resolution level to produce a new intensity band [7, 9].the IHS based fusion is summarized as under (figure 2.1).

- First step is to registration of Panchromatic (PAN) image and Multispectral (MS) image.
- Re-sample the Multispectral image.
- Transform Multispectral image from Red Green Blue color in to the Intensity Hue Saturation space.
- Next step is matching panchromatic image to the histogram of the Intensity part of IHS.
- Change the Intensity part by panchromatic image.
- Switch the fused Multispectral image to the Red Green Blue color space for resultant fused image.

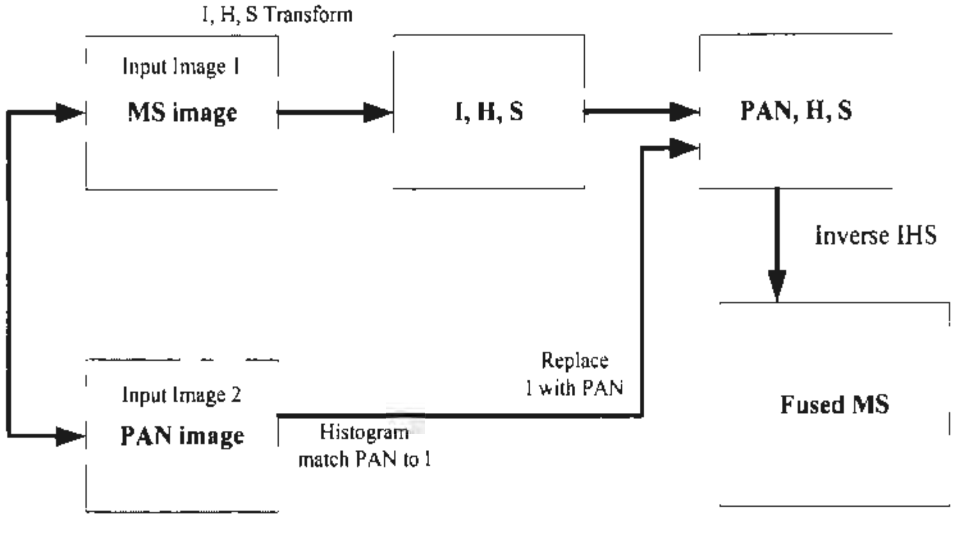


Figure 2.1: Image fusion Using IHS method

2.2.2 Independent Component Analysis.

ICA which is statistical in nature de-correlates the input images and reduces higher order statistics. It uses linear transformation. Combination system is unfamiliar and data variables are implicit a mixture of linear or nonlinear unknown variables [8]. The hidden variables are assumed to be non-Gaussian and also mutually independent. These variables are called the independent component, factors of observed data and can be originate by ICA. In [8] author, take images for fusion that are already registered and ICA transformation has been trained. All patches are isolated and normalized for input images. Finally, these patches are transformed to ICA domain and subtracted means are stored for final fused-image reconstruction. The complete process is summarized as following steps [8], also illustrated in figure 2.2.

- First, segment all images in the form of patches.
- Transform these patches to vectors.
- Move the vectors to ICA domain and get corresponding representations.
- Fuse the corresponding coefficients by appropriate fusion rule
- Form the composite representation.
- Finally move to spatial domain and reconstruct the image by averaging the overlapping image patches.

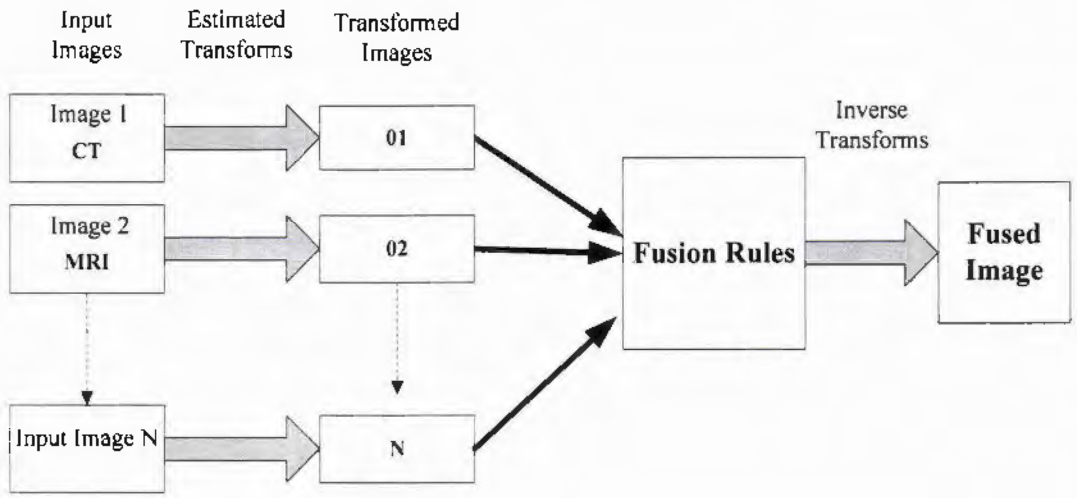


Figure 2.2: Image fusion Using ICA method.

2.2.3 Principal Component Analysis

Principal Component Analysis (PCA) fusion method is substitute to the Intensity Hue Saturation (IHS) fusion.PCA is statistical technique .The multivariate type data is transforms into uncorrelated variables by PCA [9]. PCA fusion procedure is shown in figure 2.3, the major steps involved in PCA fusion are:

- First step is to registration of Panchromatic (PAN) image and Multispectral (MS) image.
- Re-sample the Multispectral image.
- Change the Multispectral into PCA-1, PCA-2, ...by PCA .
- Next step is matching panchromatic image histogram with PCA-1.
- Change the PCA-1 with the panchromatic image.
- Change the PCA-1, PCA-2, ... and panchromatic by applying reverse PCA.

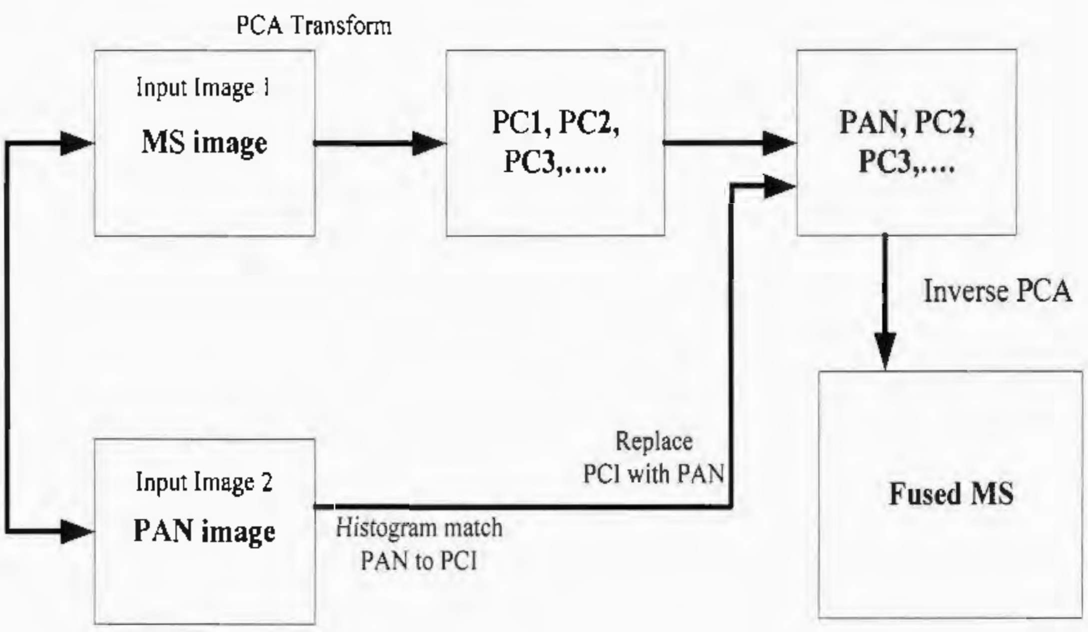


Figure 2.3: Image fusion Using PCA method

2.2.4 Wavelet Transform Based Fusion

The concept of image fusion is defined as combining multiple modalities images to a one version, by highlighting the characteristics of source images [10, 14]. An image fusion algorithm should maintain all possible relevant information coming from the source images and not add up any artifacts or inconsistencies (due to the process involved) that could interfere with interpretation of finally fused image. In the final fused image, the irrelevant information or noise should also be treated in such a way that they are minimized to a maximum possible value [10, 14].

In wavelets transform based fusion method, we first convert the original source images to wavelet domain by applying wavelet transform, perform different operations (apply fusion rules) in wavelet domain and again back to the image domain by taking inverse wavelet transform [10, 14]. When we decompose the input images we get two types of image coefficients. These are the approximate coefficients and the detail coefficients of the original images. The complete procedure is shown in figure 2.4.

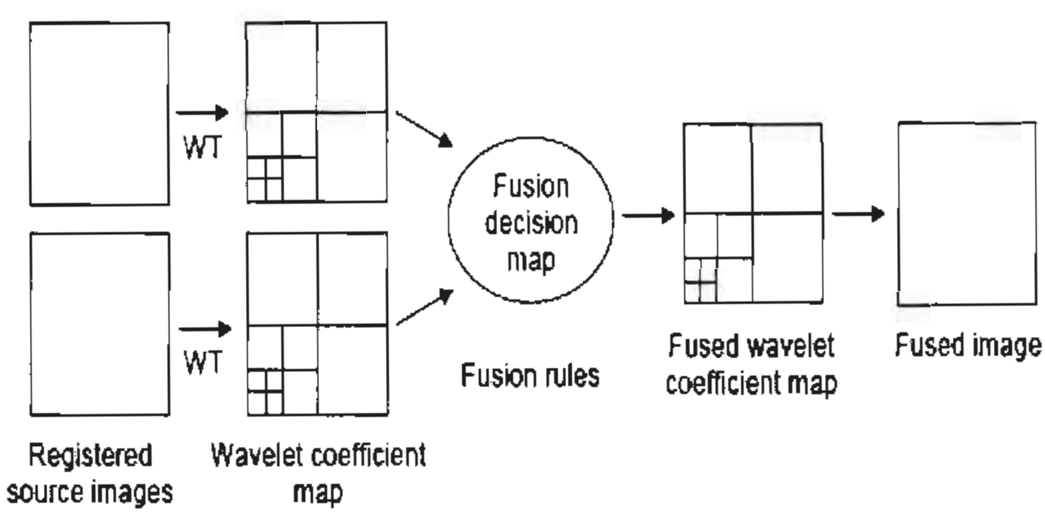


Figure 2.4: Image fusion using wavelet transform.

2.2.5 Heuristic Computing based image Fusion

Genetic Algorithm (GA) used to optimize the solution from large search space problems. The working of GA is based on a set of likely possible solutions. These likely possible solutions are called "chromosomes" in GA terminology. Each likely possible solution has a fitness value, which is assigned by algorithm after completing the cycle. These solutions are ordered in the population according to their fitness value, its means a solution with high (maximum or minimum, depending upon the nature of problem) fitness value is the chosen for kept and promote to next step that is, participate in reproduction. The remaining solutions which can't participate in selection of new generation are discarded. After make ordering to the fitness the next step is to expand the randomness behavior of the GA, because the possible solutions are to be limited the more the randomness by the Crossover mechanism. Crossover is the more beneficial as it increase randomness otherwise the GA get stuck to the solution which is not optimal and gives us wrong results. Similarly another mechanism called "mutation" is used in GA to increase the randomness behavior of algorithm. The difference between the cross over and mutation is that the crossover inter-changed the contents of likely possible solutions whereas the mutation makes the unplanned and unsystematic changes in contents. The mutation is necessary element as it plays re-generative role the building of GA, by recovering the lost contents of data that may be discarded during the selection due to ordering mechanism or crossover. This procedure continues until the optimal solution is not found or pre-defined stopping criteria not met.

Genetic Algorithm is applied in image fusion for optimization of fusion parameters [11, 23, and 24]. The major steps of genetic Algorithm are described as under and also the flow chart of GA is illustrated in figure 2.6.

1. Define the number of Chromosomes, the generation and the crossover and mutation rate.
2. Define the chromosome number of the population, and the initialization by random.
3. Follow steps 4-7 until number of generation found,
4. Evaluate the fitness by checking the objective function.
5. Make natural selection

6. Do crossover
7. Do Mutation
8. Make new chromosomes (Childs)
9. Optimum Solution

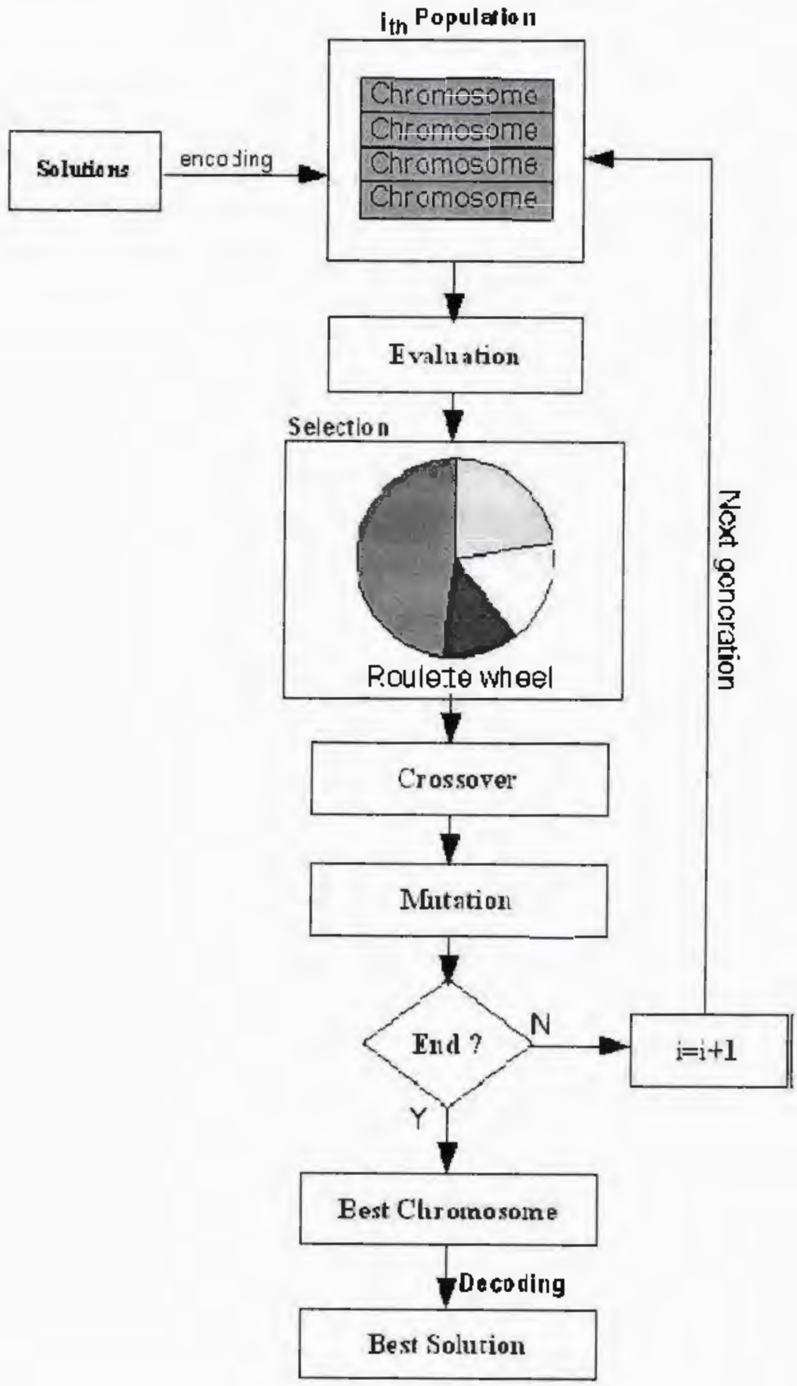


Figure 2.5: Flow chart of Genetic Algorithm

Chapter 3

Genetic Algorithm

3.1 Introduction

Genetic Algorithm (GA) is a member of heuristic computing algorithm's family. GA used to optimize the solution from large search space problems [16]. GA works at multipoint search mechanism in which the possible solutions of problem to be find the forms of groups not a single point search.[17, 18] The working of GA is based on a set of likely possible solutions called "population" in GA terminology. The generation of a set of likely possible solutions is a essential step to start GA [19]. Each likely possible solution has a fitness value, which is assigned by algorithm after completing the cycle. The fitness value of a likely possible value shows its status in the population. All Likely possible solutions are ordered in the population according to their fitness value, its means a solution with high (maximum or minimum, depending upon the nature of problem) fitness value is the chosen for kept and next step participate in reproduction [20]. The remaining solutions which can't participate in selection of new generation are discarded. This procedure continues until the optimal solution is not found or pre-defined stopping criteria not met.

After make ordering to the fitness the next step is to expand the randomness behavior of the GA, because the possible solutions are to be limited the more the randomness by the Crossover mechanism. Crossover is the more beneficial as it increase randomness otherwise the GA get stuck to the solution which is not optimal and gives us wrong results. And the optimal solution cannot achieve. Similarly another mechanism called "mutation" is used in GA to increase the randomness behavior of algorithm.

The difference between the cross over and mutation is that the crossover inter-changed the contents of likely possible solutions whereas the mutation makes the unplanned and unsystematic changes in contents. The mutation is necessary element as it plays re-generative role the building of GA, by recovering the lost contents of data that may be discarded during the selection due to ordering mechanism or crossover.

GA is applied in many core areas of life sciences and applied engineering due to its in-build stochastic multi-search mechanism.

3.2 Continuous Genetic Algorithm (CGA)

Optimization problems can be categorically separated by the type of variables. The variable may be of two types, either they are continuous or discrete. In continuous type variables, countless no of possible solutions exist, while the discrete type variables only limited possible solutions. So when there is requirement to find optimal solution, it is preferred to find solution with in a set of certain values (means use discrete type of variables). However when there is requirement of finding minimum solution use of continuous values are more appropriate. Typically the solutions represent in GA in the form of discrete type variables (binary type). However in most of cases, it is suitable to work with continuous variables. So use of continuous type GA having advantages of faster, occupy less storage space. Flowchart of continuous type GA shown in figure 3.1.

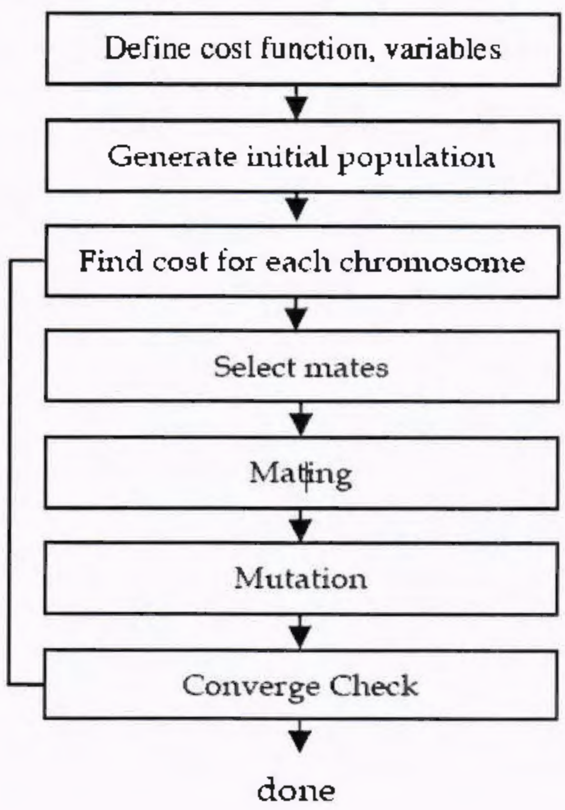


Figure 3.1: Flowchart of Continuous Genetic Algorithm. [22]

3.2.1 Working Methodology of Genetic Algorithm

The working methodology of Genetic Algorithm is as under [19].

3.3.2 Declaration of cost function.

Genetic Algorithm used to find the optimum solution .The problem which needs to be optimized is declared in Genetic Algorithm as cost function along with some parameters. These parameters are in form of vectors named chromosomes. A chromosome is basically an array of variables and its dimension is depend upon the no of variables. If chromosomes have Kx variables, given as $h_1, h_2, h_3.........hKx$ then array of chromosomes can be written as:[21]

$$Chrome = [h_1, h_2,...................hKx] \quad (1)$$

These variables have floating type values, every chromosome has a fitness achieved by evaluation of cost function at variables $h_1, h_2, h_3.........hKx$

$$Cost\_F = Func\ (Chrome) = Func\ [h_1, h_2,...................hKx] \quad (2)$$

Including equations (1) and (2) with some constraint formulate the problem. As genetic Algorithm is large search space method, so it must be restricted to look into appropriate space. This problem is solved by either the defining the criteria for stopping the algorithm or by searching in a logical reasonable space.

3.2.3 Generate Initial population

To start the Genetic Algorithm, the initial population must be described at beginning. Let **Kpops** be the initial population of the with every row of $1\times Kx$ chromosomes. Population is corresponds to a matrix with rows of chromosomes Kx , the complete matrix of $Kpops \times Kx$ can be generated by the equation no (3)

$$\mathbf{Pops} = \mathbf{rand}\ (Kpops \times K_X\ ) \quad (3)$$

All variables values ranges from 0-to-1, because of normalization. If not so, then normalized by equation 4.

$$K = (Kh - Kl)\, K_{norml} + Kl \tag{4}$$

where ***Kh*** is the highest value, ***Kl*** is lowest value and K_{norml} is the normalized one.

In chromosome family there is no equality, they have no equal rights and even they are not equally created. Every chromosome has its own repute (fitness) based on the assigned value achieved during the evaluation phase. The evaluation phase consist of passing all the variable through the cost function and checked at a given criteria [21]. From initial population, make a decision for separation good and bad chromosomes. Good chromosomes are those, who participate in to the competition of production for the next generation.

Kpops arranged according to the fitness values returned by solving the cost function for each chromosome, with the highest fitness chromosomes keep at top. So this process keeps running until fitness of all chromosomes not achieved and development of population. After that, the only ***Kkept*** out of ***Kpops*** are reserved for the purpose of mating and remaining destroyed. This creates empty space for the newly generated childs (off-springs in GA terminology) which are created after the mating procedure.

3.2.4 Make Pairing

A set of qualified chromosomes after passed through evaluation of objective function are chosen for the purpose reproduction designated as parents. Every couple has to produce two Childs (off-spring's) that contains properties from each of them.

3.2.4 Mating

Mating means coupling or combining of chromosomes for the purpose reproduction of new chromosomes. A couple of chromosome can be mate in several different ways. The very simple way is to categorize a point for crossover, then inter-change the contents of parents from this crossover point. We have the parents named ***Par1*** and ***Par1*** defined in equations (5) and (6).

$$Par1 = [M_1, M_2, \ldots\ldots\ldots\ldots MKx] \quad (5)$$

$$Par2 = [D_1, D_2, \ldots\ldots\ldots\ldots DKx] \quad (6)$$

Where the letters M and D represents the Mother and Father respectively. So the next step is to produce Childs (off-spring's), this task can be achieved by equation (7) and (8).

$$Ofsprg1 = [KM_1, KM_2, \ldots\ldots\ldots\ldots MKx] \quad (7)$$

$$Ofsprg2 = [KD_1, KD_2, \ldots\ldots\ldots\ldots DKx] \quad (8)$$

3.2.6 Natural Selection

Natural Selection is a process by which chromosomes are privileged in a logical manner for the purpose of reproduction [21]. It means that the chromosomes with good fitness having more chance to survive by participate in reproduction also their properties are transferred to the next coming generations while the chromosomes with bad fitness discarded and does not participate and transfer their properties to the next coming generations. GA works on the phenomena "survival of fittest".

Let us consider a case in which contents of two parents by equations (5) and (6) are uniformly interchanged. So the new equations (9) and (10) becomes.

$$Ofsprng1 = [KM_1, KD_2, KM_3 \ldots\ldots\ldots\ldots\ldots\ldots MKx] \quad (9)$$

$$Ofsprng2 = [KD_1, KM_2, KD_3 \ldots\ldots\ldots\ldots\ldots\ldots DKx] \quad (10)$$

The difficulty using this scheme is that no new contents are added only comes with dissimilar combinations. However in binary variables case equations (9) and (10) perform well. To create more randomness, must try some other mechanisms.

3.2.7 Mutation

Depending upon the type of function, there may be two types of function. One may have only one optimal point or local minima and other type may have more than one local minima's . If we have one type of minima function then there is no problem but if we have many minima's type function. Then it must handled carefully to avoid fast convergence. So other points of surface must also be checked and changed at random. This random change is done by the mutation process. For this purpose, the numbers generated at random are used with the rows and columns of variables. Mutation cause difference in variable so new types of variable generated.

3.2.8 Next Generation

Now the initial population is reached at a stage where categorically there are two types of chromosomes, one type is arranged according to the fitness values returned by solving the cost function for each chromosome, with the highest fitness chromosomes keep at top. Other type is the remaining bottom ordered chromosomes which can be achieved by interchanged by childs after the mating of chromosomes. Now its time for start of next generation so this process continue iterative manner whenever a optimum solution is not achieved or some pre-defined stopping criteria reached.

Chapter 4

Implementation of Genetic Algorithm in image fusion

4.1 Genetic Algorithm

Genetic Algorithm (GA) used to optimize the solution from large search space problems. The working of GA is based on a set of likely possible solutions. These likely possible solutions are called "chromosomes" in GA terminology. In "Natural selection" phase every chromosomes has a fitness value, which is assigned by algorithm after checking the cost function. These solutions are ordered in the population according to their fitness value, its means a solution with high (maximum or minimum, depending upon the nature of problem) fitness value is the chosen for kept and promote to next step that is, participate in reproduction. The remaining solutions which can't participate in selection of new generation are discarded. GA works on the phenomena "survival of fittest". After make ordering to the fitness the next step is to expand the randomness behavior of the GA, because the possible solutions are to be limited the more the randomness by the Crossover mechanism. Crossover is the more beneficial as it increase randomness otherwise the GA get stuck to the local minima which is not optimal and may provide wrong results. Similarly another mechanism called "mutation" is used in GA to increase the randomness behavior of algorithm. The difference between the cross over and mutation is that the crossover inter-changed the contents of likely possible solutions whereas the mutation makes the unplanned and unsystematic changes in contents. The mutation is necessary element as it plays re-generative role the building of GA, by recovering the lost contents of data that may be discarded during the selection due to ordering mechanism or crossover. This procedure continues until the optimal solution is not found or pre-defined stopping criteria not met. Genetic Algorithm is applied in image fusion for optimization of fusion parameters: like weights, threshold etc.

4.2 Image Fusion Using Genetic Algorithm

The fundamental steps in implementation of Genetic Algorithm are as under:

i. **Define the cost function and the variables.** In case of entropy , 3 variables are initialized. The detail of variables are as under

   a. W_{CT} = weights of the CT image
   b. W_{MRI} = weights of the MRI image
   c. E, $_F$ = Entropy of fused image

ii. **Define the initial population by random numbers:** The population is a matrix of size 100x3 dimension, as each row is consist of three variables, weights of the CT image, weights of the MRI image and Entropy.

iii. **Evaluate the fitness by checking the cost function:** Every chromosome has its own fitness based on the assigned value achieved during the evaluation phase. The evaluation phase consist of passing all the variable through the cost function and checked at a given criteria. From initial population, make a decision for separation good and bad chromosomes. Good chromosomes are those, who participate in to the competition of production for the next generation.

iv. **Make Pairing:** A set of qualified chromosomes after passed through evaluation of objective function are chosen for the purpose reproduction designated as parents. Every couple has to produce two Childs (off-spring's) that contains properties from each of them.

v. **Mating** means coupling or combining of chromosomes for the purpose reproduction of new chromosomes. A couple of chromosome can be mate in several different ways. The very simple way is to categorize a point for crossover

vi. **Natural Selection** is a process by which chromosomes are privileged in a logical manner for the purpose of reproduction. It means that the chromosomes with good fitness having more chance to survive by participate in reproduction also their properties are transferred to the next coming generations while the chromosomes with bad fitness discarded and does not participate and transfer their properties to the next coming generations. GA works on the phenomena "survival of fittest" We set **N keep** to 25% which means only 25 out of 100 selected while rejecting the remaining 75%.

vii. **Mutation:** Depending upon the type of function, there may be two types of function. One may have only one optimal point or local minima and other type may have more than one local minima's. If we have one type of minima function then there is no problem but if we have many minima's type function. Then it must handle carefully to avoid fast convergence. So other points of surface must also be checked and changed at random. This random change is done by the mutation process. We achieve Mutation by setting mutation rate to 25%.

viii. **Next Generation: Now** the initial population is reached at a stage where categorically there are two types of chromosomes, one type is arranged according to the fitness values returned by solving the cost function for each chromosome, with the highest fitness chromosomes keep at top. Other type is the remaining bottom ordered chromosomes which can be achieved by interchanged by Childs after the mating of chromosomes. Now it's time for start of next generation so this process continue iterative manner whenever a optimum solution is not achieved or some pre-defined stopping criteria reached.

4.3 Evaluation criteria- Image fusion

The purpose of image fusion is to enhance the quality of image. The quality of fused image can be checked by either two ways (1) compare the un-fused and fused image for visually enhanced image or (2) depending upon some statistical data made comparison. Evaluation criteria used in this thesis are explained in following sections.

4.3.1 Root Mean Square Error (RMSE)

The value RMSE can be calculated by equation 11. In which "O" is the reference image and "F" is the fused image [23, 25].

Mathematically,

$$\mathbf{E} = \sqrt{\frac{1}{MN}\sum\sum(\mathbf{O}(j,k) - \mathbf{F}(j,k))^2} \tag{11}$$

First, we have computed RMSE between source images CT and fused image F by equation 12.

$$\mathbf{E1} = \sqrt{\frac{1}{MN}\sum\sum(\mathbf{CT}(j,k) - \mathbf{F}(j,k))^2} \tag{12}$$

Similarly, computed RMSE between source image MRI and fused image F by equation 13.

$$\mathbf{E2} = \sqrt{\frac{1}{MN}\sum\sum(\mathbf{MRI}(j,k) - \mathbf{F}(j,k))^2} \tag{13}$$

Finally the overall RMSE value acheived by equation 14.

$$\mathbf{RMSE} = (\mathbf{EI}+\mathbf{E2})/2 \tag{14}$$

For better the fusion quality, the RMSE value should be smaller.

4.3.2 Image Quality Index (IQI)

IQI used for measurement of similarity between the un-fused and the fused image and is value ranges from -1 to 1[23].

Mathematically, given as in equation 15.

$$Q = \frac{\sigma_{xy}}{\sigma_x \sigma_{by}} \cdot \frac{2\bar{x}\bar{y}}{\bar{x}^2\bar{y}^2} \cdot \frac{2\sigma_x\sigma_y}{\sigma_x{}^2\sigma_y{}^2} \qquad (15)$$

where $\bar{x}$ and $\bar{y}$ is are mean value of images O and F, and $\sigma_x{}^2, \sigma_y{}^2, \sigma_{xy}$ represents the variance of O, F and covariance of O and F respectively.

4.3.3 Entropy

The amount of information contained in a image is referred as entropy. The fused images entropy increases as the information from both source images and added [22, 24, and 27]. Mathematically, entropy is usually given as in equation 16.

$$E = -\sum_{j=0}^{M-1} P_j log_2 P_j \qquad (16)$$

4.3.4 Peak Signal-to-Noise Ratio (PSNR)

Peak signal-to-noise ratio (PSNR) is basically the gap between the signal to the noise. A high value of PSNR means signal is well separated from noise. It is a ratio between the signal and the noise, it directly affects the image quality [22, 24,26].

As there is large variations in image, the PSNR is expressed in logarithmic scale. Mathematically, the value of the PSNR is given in equation 17.

$$\text{PSNR} = 10\log\frac{255}{\text{RMSE}^2} \qquad (17)$$

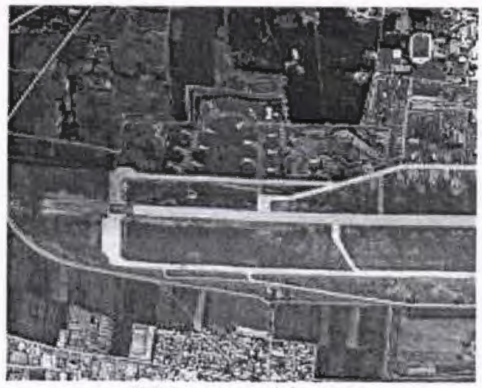
4.4 Results and Comparison

There are numerous applications of image fusion including medical imaging, remote sensing, and computer vision. This thesis focuses on two types of applications, Medical imaging and remote Sensing. In medical image fusion section CT (Computed Tomography) and MRI (Magnetic Resonance Imaging) images of human brain are used Figure 4.1 (a) & (c). CT provides better performance on denser tissues like bones and MRI shows soft tissue structure. While the fused CT & MRI images provide additional information to doctor and clinical treatment planning system as shown in Figure 4.1 (e).

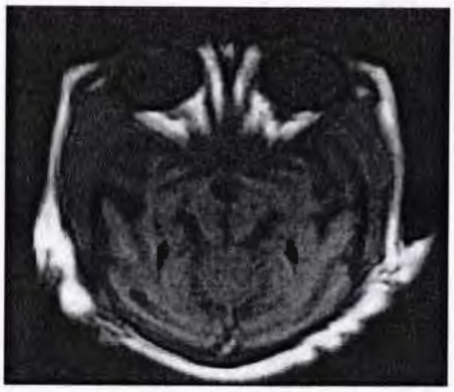
In remote sensing image fusion, we fused satellite SAR (Synthetic Aperture Radar) images (Figure 4.1 (b))with optical images (Figure 4.1(d))to provide more accurate information for intelligence and mission planning such as border surveillance, troops and military installations deployment. This information may further be used for better battle field management system as shown in table Figure 4.1 (f).

Usually various algorithms are applied and image fusion performance parameters are evaluated to select the best suited algorithms. In this thesis we used images that are already registered and different methods of conventional and artificial intelligence are tested. Hence a hybrid approach is suggested in which evolutionary computing technique named Genetic algorithm is applied along with discrete wavelet transform at pixel level which gives us better performance as compared to conventional fusion methods alone. We provide performance evaluation of proposed fusion algorithm on the basis of RMSE (Root Mean Square Error), PSNR (Peak signal to Noise Ratio), Image Quality Index and Entropy.

(a) CT Image



(b) Infrared image



(c) MRI Image

(d) SAR Image

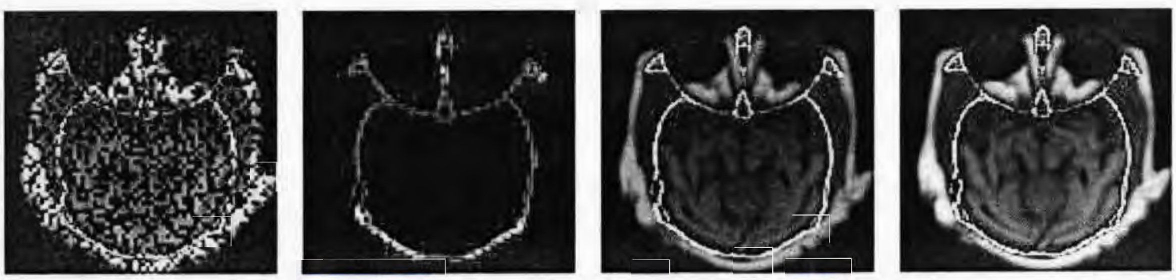
(e) Fused Image (a) & (c)

(f) Fused Image (b) & (d)

Figure 4.1: Images used for Experimentation

Started from the fundamental fusion method, simply take the average of both images at pixel-level and fuse them in to single image. The purpose of this experiment is to learn how the whole fusion process works and explore the different steps involved in it, so by deep understanding suggest improvement in process. Secondly, by exploring different image evaluation criteria's we learn how to evaluate the quality of fused images both the visually and the statistically. The resultant fused image of CT and MRI image by pixel level averaging method shown in Figure 4.1(e). As a starting point we have confirm the various parameters of image fusion evaluation criteria on already registered medical images such as CT, MRI images. Figure 4.1 shows the input images, to be used for fusion process and the resultant image (Figure 4.1(e)) after fusion.

In this work task is testing and verification of different fusion rules after applying appropriate filters to medical images (CT and MRI) and objective is to study the behavior of medical images under certain conditions and understanding the working of fusion schemes. This task is comprises on two parts, the first one is to pass through the medical images from appropriate filters, according to the nature of input images and second is to apply different fusion rules. As we used CT and MRI images so we applied a high pass filter to CT image, because CT image having only the bones structure. Similarly the MRI image is passed through the low pass filter, because having only the soft tissues such as brain anatomy.

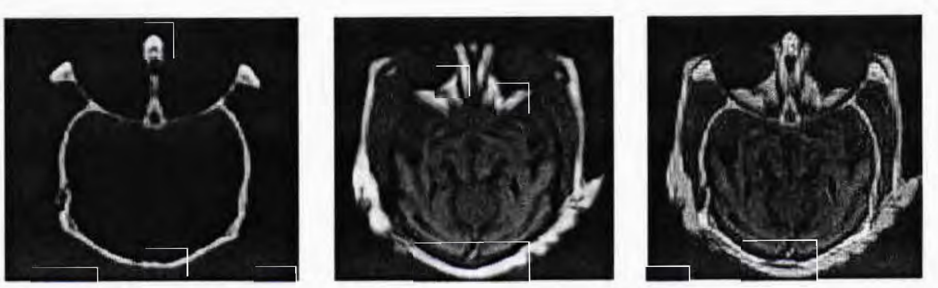


(a) Fuse_random (b) Fuse_minimum (c) Fuse_average (d) Fuse_maximum

Figure 4.2: Fusion rules applied after filtering

After pass through the images from filters, four fusion rules which are fuse-maximum, fuse-minimum, fuse-average, and fuse-random are implemented. The experimental results showed in Figure 4.2. It can be seen from Figure 4.2that when we applied fuse-random method, the fused image (Figure 4.2 (a)) highly degraded even the image distinct features demolished. In the same way when applied fuse-minimum method, the fused image (Figure 4.2 (b)) have poor contrast, some regions are too dark and the detail of image can't be seen. So we applied the next fuse-maximum method, the fused image (Figure 4.2 (d)) mask some regions of MRI image, which results in information loss. Finally, when we applied fuse-mean method, the fused image (Figure 4.2 (c)) smoothed to some degree due to the filtering effect.

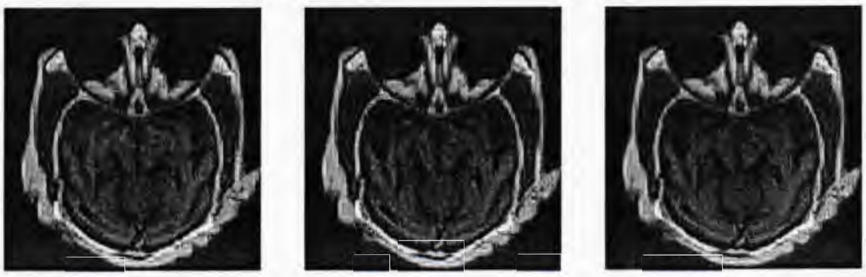
In development of discrete wavelet transformed DWT based image fusion experiment; we first decompose the input images (CT and MRI images) in to sub-images by wavelet transform. The sub images are sub-divided into different components namely vertical, horizontal, detail and approximate components (figure 2.4). The coefficients from these sub images are further used by a fusion rule. So we implement DWT based image fusion algorithm. Discrete Wavelet transform gives more good results than the averaging and filtering method. DWT based image fusion results shown in Figure 4.3(c). It is noticeable that the fused image contains the more useful information than the biomedical images of CT and MRI alone. Wavelets based fusion techniques have more potential to image fusion as various image processing algorithms can easily be implemented.



(a) CT image (b) MRI image (c) Fused by DWT

Figure 4.3: DWT based pixel-level fusion result

In development of block-level fusion scheme, block size of 4, 8, and 16 on medical images are tested and two types and results are generated. Results are shown in Figure 4.4 and 4.5. The image performance degraded due to the discontinuities and blocky artifacts. It is also observed that using mean based block fusion gives relatively better results as they are brighter but in some regions may look over bright. Also the block boundaries are more prominent in this scheme. DWT based block fusion having better contrast. Our results of DWT based fusion method are encouraging as compared to the fuse average and block fusion method. But at the same time Wavelet transforms have some limitations and drawbacks as well.



(a) 4x4 block fusion (b) 8x8 block fusion (c) 16x16 block fusion

Figure 4.4: DWT based block fusion results

(a) 4x4 block fusion (b) 8x8 block fusion (c) 16x16 block fusion

Figure 4.5: Mean based block fusion results

So switched towards the heuristic computing techniques like Genetic Algorithm (GA). Started GA from basic mathematical problems and then applied it to advance optimization problems like image fusion. Using GA three fusion techniques are proposed which are (1) GA Averaging fusion, (2) GA threshold fusion and (3) GA DWT and Averaging fusion. All techniques are implemented for image fusion evaluation criteria's and results are shown in table 6 for analysis purpose.

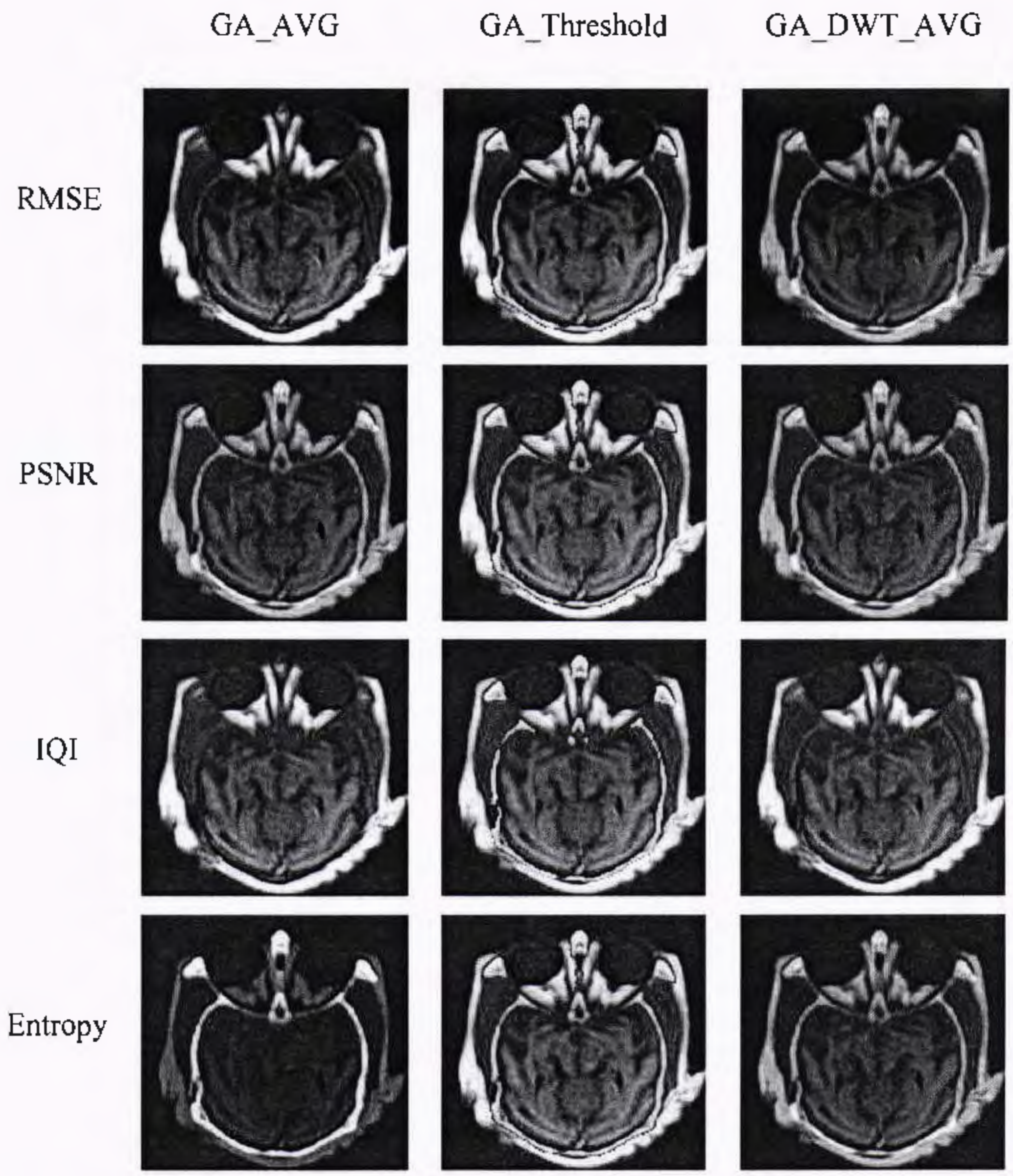


Figure 4.6: Comparison of Image Fusion evaluation criteria (Medical images)

We first developed GA-Averaging algorithm. Which is a pixel based method, where the weights for the fused image are estimated by GA along with averaging mechanism. Then second developed algorithm is GA-Threshold algorithm, where the threshold values for fussed image are estimated by GA. Finally GA-DWT-Averaging algorithm developed, in which the input images are first decomposed by discrete wavelet transform (DWT) then the coefficients of sub-images are fused by weighted average. All of the above algorithms are implemented on two types of images and done their comparison both the visually and statistically

We have made assessment on the basses of evaluation criteria as well as the visual results. For medical images when we compare from table 1 for RMSE measure GA-DWT-Averaging fusion gives us best result, while the GA-threshold gives brighter result but some regions of CT image not fused.GA-Averaging not performs proper fusion. These results also verified statistically from table 1 where the value of RMSE is minimum among the all. When we make comparison for Peak signal to noise ratio (PSNR) measure GA-DWT-Averaging fusion gives us best result, while the GA-threshold gives brighter result but some regions of CT image not fused. Here GA-Averaging performs proper fusion, more accurate than GA-threshold. These results also verified statistically from table 1 where the value of PSNR is maximum among the all. When comparing Image quality index (IQI) measure GA-DWT-Averaging fusion gives the most suitable results visually, while the GA-Averaging and GA-threshold methods fail. Finally when we make comparison for Entropy measure GA-DWT-Averaging fusion gives us best results visually, while the GA-threshold and GA-Averaging did not perform well even some regions of CT image not fused properly.

Medical Images					
	GA_Average	**GA_Threshold**	**GA_DWT_Average**	**Block Level**	**DWT**
Entropy	6.13	5.92	**6.98**	8.85	6.28
RMSE	41.50	43.44	**6.45**	40.32	15.45
PSNR	12.74	14.60	**15.74**	10.45	14.12
IQI	0.21	0.16	**0.98**	0.14	0.25

Table 1: Comparison of statistics Image Fusion evaluation criteria

For remote sensing images when we compare from table 2 for Root mean square error (RMSE) measure the GA-DWT-Averaging fusion gives us best result, while the GA-threshold gives more brighter result but some regions not fused. GA-Averaging also performs proper fusion. These results also verified statistically from table 2 where the value of RMSE is minimum among the all. When we make comparison for Peak signal to noise ratio (PSNR) measure GA-DWT-Averaging fusion gives us best result, while the GA-threshold gives brighter result but some regions not fused. Here GA-Averaging performs proper fusion, more accurate than GA-threshold. These results also verified statistically from table 2, where the value of PSNR is maximum among the all. When comparing for Image quality index (IQI) measure GA-DWT-Averaging fusion gives the most suitable result, while the GA- threshold and GA- Averaging perform relatively less. Finally when we make comparison for Entropy measure GA-DWT-Averaging fusion gives us best result, while the GA-threshold and GA-Averaging results are comparable. These results also verified statistically from table 2, where the value of Entropy is maximum among the all.

Remote Sensing Images					
	GA_Average	**GA_Threshold**	**GA_DWT_Average**	**Block Level**	**DWT**
Entropy	5.94	6.25	**6.94**	4.69	5.98
RMSE	20.68	22.19	**9.68**	25.76	11.65
PSNR	14.23	12.25	**15.66**	10.45	13.76
IQI	0.54	0.66	**0.92**	0.34	0.78

Table 2: Comparison of statistics Image Fusion evaluation criteria

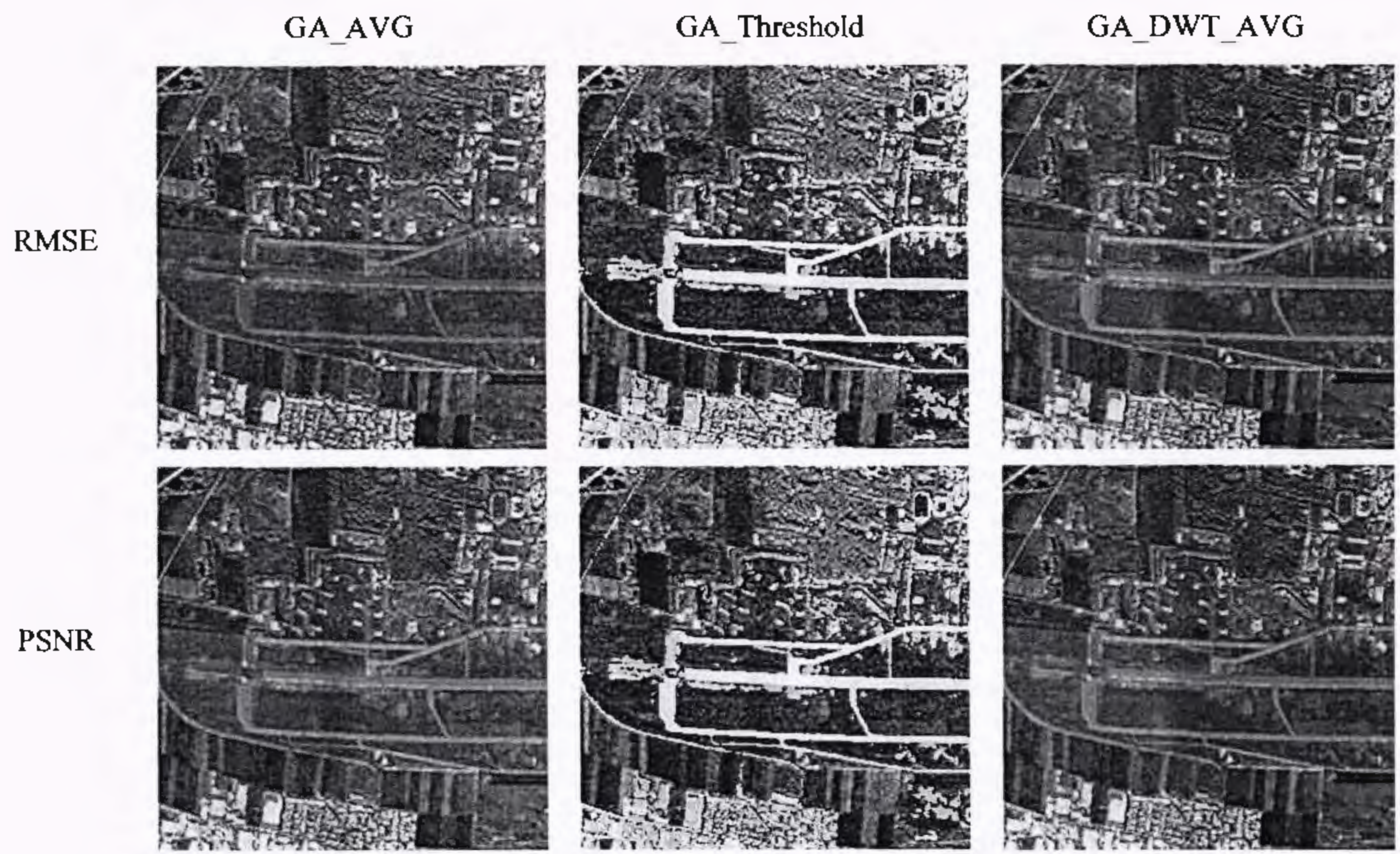


Figure 4.7: Comparison of Image Fusion evaluation criteria (remote sensing images)

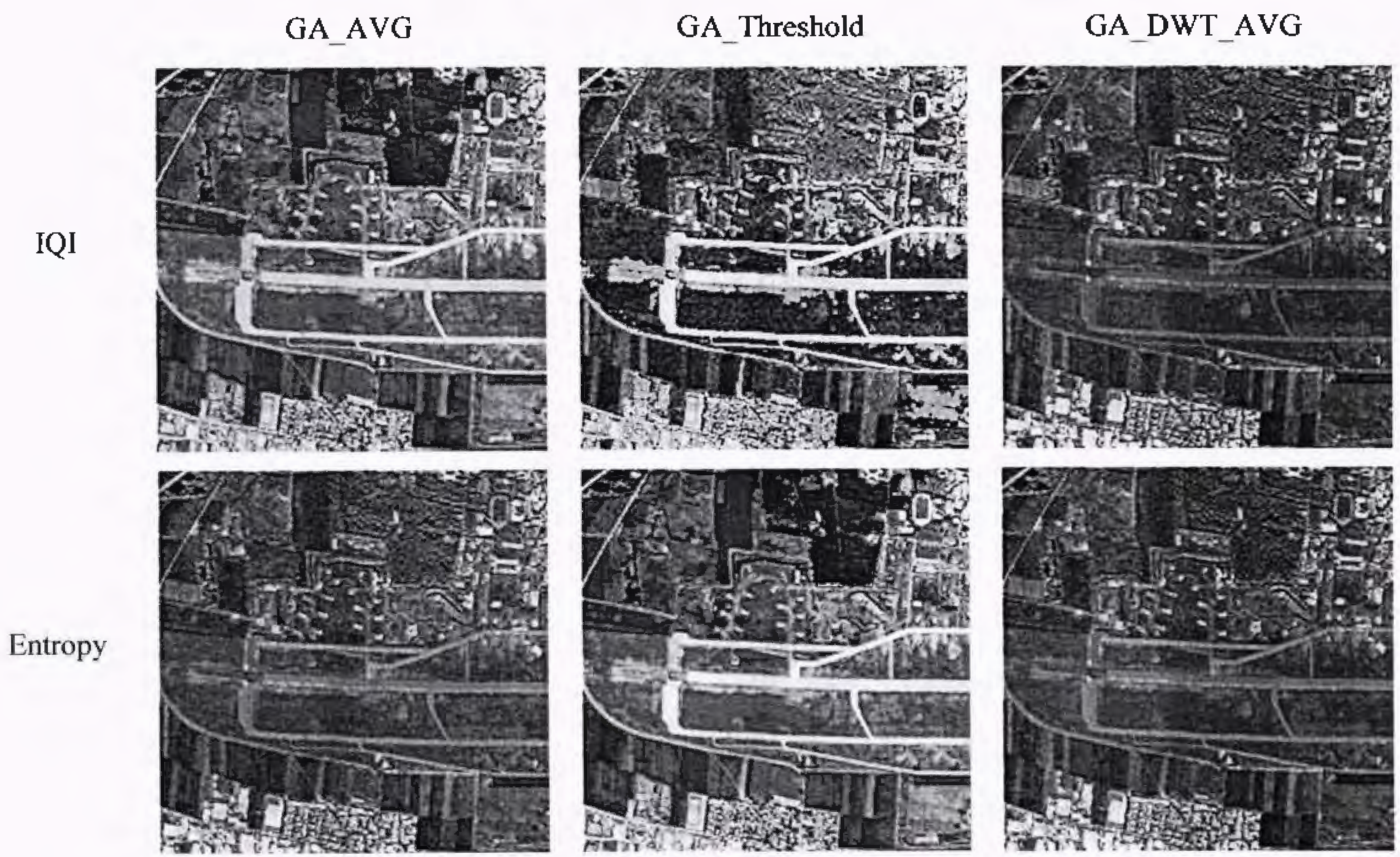


Figure 4.7: Comparison of Image Fusion evaluation criteria (remote sensing images)

Chapter 5

Conclusion and Future Work

5.1 Conclusion

This research work provides a good understanding of image fusion process. We tested proposed algorithms on medical and remote sensing images. The purpose of this thesis is to develop the improved image fusion techniques. We tested proposed algorithms on evaluation criteria's for image fusion like PSNR, RMSE, IQI and entropy. Numerous image fusion techniques were explored and successfully implemented using MATLAB. The visual quality assessment results are also compared with the statistical data recoded during the experimentation but the visual perception is more important.

The implemented image fusion techniques ranges from very basic to advanced level. They include Pixel level Averaging Method, Fusion using different fusion rules (fuse- maximum, fuse-minimum, fuse-average, and fuse-random) on filtered images, development of DWT based image fusion algorithm, block-level fusion schemes (with block size of 4, 8, and 16) like DWT based block fusion and mean based block fusion, and finally using GA three fusion techniques are proposed which are GA-Averaging fusion, GA- threshold fusion and GA-DWT-Averaging fusion,

In development of block-level fusion it can be seen from results that the image performance degraded due to the discontinuities and blocky artifact. It is observed that wavelet transforms (DWT) fusion performs better others, because those techniques add some artifacts in fused image, such as image degradation, poor contrast, information loss. Also the Wavelet-based techniques works fine in preserving the key spectral information and have more potential for image fusion as many image processing techniques can easily be performed.

GA based fusion has been performed using different sensor images. The healthiness of the proposed fusion techniques confirmed with images of medical (CT, MRI images) and remote sensing images (optical and SAR images). Employment of GA into the existing fusion techniques greatly enhances the fusion performance by finding the optimal values of fusion parameters.

We suggest using a wavelet-based approach along with Genetic Algorithm (GA-DWT-Average scheme) at pixel-level fusion. The experimental results of this method are compared with several existing algorithms. These results are evaluated based on a perceptual comparison, which can be verified statistically (table 1 and 2).

5.2 Future Work

This research work has explored and proposed important aspects of pixel level image fusion, especially the hybrid type algorithms that combine the conventional fusion methods with Heuristic computation algorithms. However there are still related work which have to be deal with in future.

- Explore other types of wavelets (such as multi wavelets etc) and implementation of new combinations of wavelets and GA, which may results in better fusion.

- Explore new methods of Image Registration as they will certainly enhance the efficiency of image fusion.

- A learning algorithm like neural networks used for assigning weights/ threshold values to the image fusion evaluation criteria's.

- The fusion process may be guided as per the requirements of application area, because involvement of multi-sensory imaging systems.

- Categorization of the image fusion evaluation criteria's on the basis of application area to evaluate the quality of a fused image for different types of sensors.

Chapter 6

References

[1] Constantinos, S. P., Pattichis, M. S.,&Micheli-Tzanakou, E. (2001).*"Medical imaging fusion applications: An overview"*, Paper presented at the Conference on Signals, Systems and Computers, 2001.

[2] Naidu, V., Divya, M., &Maha Lakshmi, P. (2017). *"Multi-Modal Medical Image Fusion using Multi-Resolution Discrete Sine Transform"*, Control and Data Fusion e-Journal, 1(2), 13-26.

[3] Zhan, L., Zhuang, Y., & Huang, L. (2017). *"Infrared and Visible Images Fusion Method Based on Discrete Wavelet Transform"*,Journal of Computers, 28(2), 57-71.

[4] Babu, C. R., &Rao, D. S. (2017). *"Comparison of Discrete Wavelet Transform (DWT), Discrete Cosine Transform (DCT) and Stationary Wavelet Transform (SWT) based Satellite Image Fusion Techniques"*,InternationalJournal Current Research Revised Volume, 9(12), 49.

[5] Hata, N., Dohi, T., Warfield, S., Wells, W., Kikinis, R., &Jolesz, F. A. (1998). *"Multimodality deformable registration of pre-and intraoperative images for MRI-guided brain surgery"*,Paper presented at the International Conference on Medical Image Computing and Computer-Assisted Intervention.

[6] Hall, D., &Llinas, J. (2001). *"Multisensor data fusion"*, CRC press.

[7] Al-Wassai, F. A., Kalyankar, N., & Al-Zuky, A. A. (2011). *"The IHS transformations based image fusion"*,arXiv preprint arXiv:1107.4396.

[8] Mitianoudis, N., &Stathaki, T. (2007).*"Pixel-based and region-based image fusion schemes using ICA bases"*,Information Fusion, 8(2), 131-142.

[9] Bhaskarrajan, N. J. *"Satellite Image Fusion using IHS and PCA Method"*.

[10] Chow, K. C. (2004).*"Fusion of images from dissimilar sensor systems"*, Monterey California.Naval Postgraduate School.

[11] Jyothi, V., Kumar, B. R., Rao, P. K., & Reddy, D. R. K. (2011). *"Image Fusion Using Evolutionary Algorithm (GA) "*,International Journal Computer Applications. 2(2), 322-326.

[12] Yu, M. (1998).*"Image segmentation using genetic algorithm and morphological operations"*.

[13] Haribabu, M., Bindu, C. H., & Prasad, K. S. (2013). *"A New Approach of Medical Image Fusion using Discrete Wavelet Transform"*, International Journal on Signal and Image Processing, 4(2), 21.

[14] Piella, G. (2003). *"A general framework for multiresolution image fusion: from pixels to regions"*, Information Fusion, 4(4), 259-280.

[15] Ahmed, T., Singh, D., Gupta, S., & Raman, B. (2016). *"An efficient application of fusion approach for hot spot detection with MODIS and PALSAR-1 data"*, Geocarto International, 31(7), 715-738.

[16] Taher, G. M., El Taweal, G., Wahed, M. E., &Fouad, A. (2013). *"Image fusion approach with noise reduction using Genetic Algorithm"*, International Journal of Advanced Computer Science and Applications, 4(11).

[17] Goldberg, D. E. (1989). *"Genetic algorithms in search, optimization, and machine learning"*, 1989. Reading: Addison-Wesley.

[18] Nambiar, R., & Mars, P. (1992). *"Genetic and annealing approaches to adaptive digital filtering"*, Paper presented at the Conference on Signals, Systems and Computers, 1992.

[19] Le Moan, S., Mansouri, A., Hardeberg, J. Y., &Voisin, Y. (2013). *"Saliency for spectral image analysis"*, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 6(6), 2472-2479.

[20] Mohanta, R. K., &Sethi, B. (2011). *"A review of genetic algorithm application for image segmentation"*, International Journal Computer Applications, 3(2), 720-723.

[21] Haupt, R. L., &Haupt, S. E. (2004). *"Practical genetic algorithms"*, John Wiley & Sons.

[22] Sivanandam, S., &Deepa, S. (2008). *"Genetic algorithm implementation using matlab"*, Introduction to Genetic Algorithms (pp. 211-262): Springer.

[23] Mumtaz, A., Majid, A., &Mumtaz, A. (2008). *"Genetic algorithms and its application to image fusion"*, Paper presented at the 4th International Conference on Emerging Technologies, 2008. ICET 2008.

[24] Erkanli, S., &Rahman, Z.-u. (2010). *"Enhancement technique for uniformly and non-uniformly illuminated dark images"*, Paper presented at the 10th International Conference on Intelligent Systems Design and Applications (ISDA), 2010.

[25] Kannan, K., &Perumal, S. A. (2007). *"Optimal decomposition level of discrete wavelet transform for pixel based fusion of multi-focused images"*, Paper presented at the International Conference on Computational Intelligence and Multimedia Applications, 2007.

[26] Wang, A., Sun, H., & Guan, Y. (2006). *"The application of wavelet transform to multi-modality medical image fusion"*,Paper presented at the Proceedings of the 2006 IEEE International Conference on Networking, Sensing and Control, 2006. ICNSC'06.

[27] Erkanli, S., Li, J., &Oguslu, E. (2012). *"Fusion of Visual and Thermal Images using Genetic Algorithms"*,Bio-Inspired Computational Algorithms and Their Applications: InTech.