Effect of ortho-rectification on image fusion techniques for Kompsat-3 image

Pilot Project Report

Submitted for partial fulfilment of the requirement for Post Graduate Diploma in Remote Sensing and Geographic Information System

Submitted by:

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March-2014

DECLARATION

I undersigned hereby declare that the report entitled as “EFFECT OF ORTHO-RECTIFICATION ON IMAGE FUSION TECHNIQUES FOR KOMPSAT-3 IMAGE”, is a genuine academic work done under the guidance of **Dr. Anil Kumar** Scientist of Indian Institute of Remote Sensing, Dehradun, India. The work completed and submitted by myself. The report content is not copied from any source although I may have conferred with others and drown upon a range of sources cited for this work.

Signed ____________

DISCLAIMER

This document describes work undertaken as part of pilot project undertaken for partial fulfillment of the requirement for the Post Graduate Diploma course in Remote Sensing and Geographic Information System at the Center of Space Science and Technology Education in Asia and the Pacific (CSSTEAP), Dehradun. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the Faculty.

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CERTIFICATE

This is to certify that Mr. Lukhmonjon Karimjonovich Dadojonov has carried out pilot project study entitled “**Effect of ortho-rectification on image fusion techniques for Kompsat-3 image**” for partial fulfilment of the requirement for the post graduate course in remote sensing and geographical information systems at the Centre for Space Science and Technology Education in Asia and the Pacific (CSSTEAP). This work has been carried out at Indian Institute of Remote Sensing (IIRS), Dehradun, India.

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ABSTRACT

Today due to quick developing cadastral system in developing country, these countries demand of large-scale maps and conventional methods of mapping cannot satisfy these requirements, because it is requires many times, human resource involvement and in case of large area, it is not economically efficiently. Therefore, most countries nowadays for cadastral application using high-resolution satellite images. Today several commercial satellites such as Quickbird, IKONOS, Worldview-2, GeoEye, Cartosat-2 and Kompsat-3 (recently launched by Korean Aero-Space Exploration Agency) are providing high-resolution images with accuracy within sub-meter in Panchromatic mode. No sensors mentioned above due to some technical limitation cannot provide same resolution of image in Multispectral mode. However, we can enhance the spatial resolution of multispectral images through merging different types of images. This study investigated the possibilities of fusing Kompsat-3, Panchromatic and Multispectral data for extracting more information from images and generating large-scale maps, which are required for cadastral or other applications. The research site was located north-west part Catalonia province, Spain with irregular terrain. One of the main objectives of the research was to study the effect of ortho-rectification with and without GCPs to image fusion for that purpose research site was chosen with irregular terrain. The second none less important objective of research was to define, which image fusion technique maximum preserving spatial information as well as spectral information. The result of the various techniques and image combination applied were evaluate by using Correlation Coefficient (CC) for spatial distortion and ERGAS method for spectral distortion.

ACKNOWLEDGMENTS

I would like to express my sincere thanks to all the people who have assisted me during the preparation of this thesis.

First of all, I would like express my sincere gratitude to Dr. Y.V.N. Krishna Murthy, Director, Indian Institute of Remote Sensing(IIRS)/ CSSTEAP for allowing me study for the degree of post graduate diploma in remote sensing and geographic information system and do my this pilot project.

I am grateful to my supervisor **Dr. Anil Kumar** Scientist / Engineer “SF”, Photogrammetry and Remote Sensing Department, IIRS. I am grateful for his kind guidance, help and support at all stages of my project research work, providing impressive advices and suggestions, supervision and inspiration during the preparation of this report.

I wish to express my sincere thanks to Mrs. Shefali Agrawal, Head of Photogrammetry and Remote Sensing Department, IIRS for providing me valuable suggestion and support.

I wish to express my sincere thanks to all faculty of IIRS/ CSSTEAP especially:

- Dr. Sarnam Singh, Course Director for providing suggestions, guidance, technical supporting to complete this project.
- Dr. Yogesh Kant, Course Coordinator, for handling of course, providing suggestions and guidance while staying at CSSTEAP/IIRS.

In addition. I would like to thank Mr. Kurbonnazar Abdugafforov, Director of “Centre of Real Estate Registration in Khujand city” under Institution “Implementation centre of the Land Registration and Cadastre System” for sustainable Agricultural project, who supported me to apply to this course.

I am grateful to my respected parents for their support, love and encouragement. I also very much thankful to my brothers and sister for their mental and financial support.

I would also like to express my deep appreciation to my wife and children for their support and love.

Finally, I would like to express my appreciation to all PG Diploma fellows at CSSTEAP who studied in 18th PG course on Remote Sensing and Geographic Information System. Their companionship and the exchange of problems and experiences has been most rewarding. In addition, of course, I wish to thank all the others not mentioned individually for their assistance.

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March 2014

Dehradun, INDIA

LIST OF ACRONYMS AND ABBREVIATIONS

AIO	Area of Interest
BROV	Brovey Transform
CP	Check Point
CPU	Computer Processing Unit
DEM	Digital Elevation Model
DN	Digital Number
GCP	Ground Control Point
GIS	Geographic Information System
GPS	Global Positioning System
HPF	High Pass Filter
IHS	Intensity Hue Saturation
IR	Infrared
ISPRS	International Society of Photogrammetry and Remote Sensing
KOMPSAT	Korean Multi-purpose Satellite
Lat	Latitude
Long	Longitude
LUT	Look-up Table
MSS	Multispectral Scanner
PAN	Panchromatic
PCA	Principal Component Analysis
pp.	Pages
PRI	Precision Image
RGB	Red Green Blue
RMSE	Root Mean Square Error
RS	Remote Sensing
UTM	Universal Transvers Mercator
VIR	Visible and near Infrared
WGS-84	World Geodetic System from 1984
XS	Multispectral

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1. Introduction

In many developing countries due to improving land cadastre system there is demand of large-scale maps (1:5000, 1:2000 and larger). Conventional methods of mapping through surveying and updating existing map requires many times, financial expenditure and human resource involvement or sometimes some areas are unreliable.

Therefore, nowadays most countries for this application resort for using of aerial and satellites images with fine spatial resolution. Data, which are capturing with these type of satellites such as Kompsat-3, Quickbird, IKONOS, GeoEye, Worldview-2 and Cartosat-2 providing fine spatial resolution data in panchromatic mode, but they are not proving same spatial resolution in multispectral mode. However, we can enhance the capacity of images through merging different types of data such as Panchromatic and Multispectral data to obtain more information, and to achieve image information to generate large-scale maps for different applications particularly for cadastral.

In the presented study, it have been examined different fusion techniques and explore various metrics that can be used to judge the image quality of the fused image. One of the key issues investigated was the influence of geometric distortion and corrections of remote sensing data on the result of pixel based digital image fusion. Other investigated issue to define, that how much accurate was Rational Polynomial Coefficient calculated for images. In addition by help of quality assessment using visual as well metric methods to define which image fusion techniques increasing spatial resolution of image as well as preserves spectral information of image.

1.1 Research objectives:

The main objectives of this study were follows:

- To study the effect of ortho image rectification (with or without GCPs) on image fusion.
- To evaluate image fusion techniques such as;
    - Gram- Schmidt,
    - Ehlers,
    - PCA,
    - Modified IHS resolution merge,
    - Wavelet Principal Component,
    - Wavelet Intensity Hue Saturation,
    - Wavelet Single Band,
    - Brovey transform,
    - Multiplicative,
    - High Pass Filter and
    - ESRI for KOMPSAT-3 data maps.
- To compare the image fusion outputs using quantitative method.
- To integrate the spatial information from the high-resolution data with multispectral data for application in land cadastral mapping.

1.2 The research questions in this study were follows:

- How image geometry effects image fusion results?

- Which image fusion technique preserves spatial as well spectral information?
- Which method may help for quantitative assessment of image fusion results?
- How image fusion may help for object identification as well measurements in cadastral applications?

2. Digital Image Fusion: A Review

With the availability of multisensor, multitemporal, multiresolution and multifrequency image data from operational Earth observation satellites, the fusion of digital image data has become a valuable tool in remote sensing image evaluation. Data covering different portions of the electromagnetic spectrum at different spatial and spectral resolution are providing by operating sensors. Advanced analytical or numerical data fusion techniques have to be developed for the full exploration of increasingly sophisticated multisource data (Shen 1990). Fused images provide increased interpretation capabilities and more reliable result since data from different characteristics are combined. The images vary in spectral and spatial resolution give a more complete view of the observed objects. The aim of image fusion is to integrate complementary data in order to obtain more information, which can not be derived from single sensor data alone.

The review forms a key to understanding of image fusion for the other chapters. The review aims to describe and explain the pixel based image fusion of Earth observation satellite data as a contribution to multisensory and integration oriented data processing. The collected literature have been summarized and grouped into four relevant sections. Following this introduction, first a definition of digital image fusion is given. The review continues with benefits of image fusion and issues in image fusion. It concludes with the discussion on the advantages and disadvantages of image fusion in remote sensing.

2.1 Definition

There have been many terms used in the literature on image fusion. Some terms define different approaches to image fusion, others can be used synonymously. The most commonly used expressions for image fusion are summarized below and the differences in meaning categorized. There follows a short introduction to levels in image fusion in order to explain image fusion, as understood by the author, for the further comprehension of this review.

2.1.1 Terms in literature

A general definition of image fusion is “Image fusion is a combination of two more different images to form a new image by using a certain algorithm” (Van Genderen and Pohl, 1994). Franklin and Blodgett (1993) and Keys et al. (1990) describe the fusion as the computation of tree new values for a pixel based on the known relationship between the input data for the location in the image. The input images differ in terms of spatial, spectral, and temporal characteristics expressions accepted in this context are image merging (Carper et al., 1990), image integration (Welch and Ehlers, 1988) and multisensory data fusion (Franklin and Blodgett, 1993). With phrases with “data” rather than “image” have a very similar meaning: often, in this case, not only remote sensing images are fused but further ancillary data (e.g. topographic maps, GPS coordinates, geographical information, etc.) contributing to resulting image (Harris et al., 1989).

2.1.2 Review of Image fusion techniques

As stated above, image fusion as an algorithm, which combines two or more different digital images to build a new image with modified digital numbers. It is relevant to mention that the data has different attributes (spatial, spectral and temporal resolution) in order to integrate complementary information.

Image fusion, or as it is generally expressed, pan-sharpening is performing at three different levels according to the stage at which fusion takes place:

1. Pixel,
2. Feature, or
3. Decision level (Mangolini, 1994; Shen, 1990; Rogers and Wood, 1990)

Image fusion at pixel level means fusion at the lowest level referring to the merging of measured physical parameters. It uses raster data that is at least co-registered but most commonly geocoded. Fusion at feature level required the extraction of the objects recognized in a various data sources, e.g. using segmentation procedures. Features correspond to characteristics extracted from the initial images, which depend on their environment, such as dimension, shape and neighborhood (Mangoliny, 1994). These similar objects (e.g regions) from multiple sources are assign to each other and then fused for further assessment using statistical approaches or Artificial Neural Network (ANN). Decision or interpretation level fusion represents a method that uses value-added data where the input images are processed individually for information extraction. The information obtained is then combined applying Bayes or Dempster-Shafer's rule to reinforce common interpretation and resolve differences and furnish a better understanding of the observed objects (Shen, 1990.) Techniques used to fuse data on a pixel level were described in **Section 2.3** Image fusion Techniques.

This literature review mainly tackles pixel-based image fusion, which presumes accurately registered/ geocoded imagery. The geocoding plays an essential role because misregistration causes artificial colors or features in multisensory data to a common pixel spacing and map projection, although the latter applies only in the case of geocoding.

2.2 Advantages of image fusion

Image fusion is a tool for combining multisource imagery using advanced image processing techniques. Its aim is to integrate disparate and complementary data to enhance the information apparent in the images as well as to increase the reliability of the interpolation. This leads to more accurate data (Keys et al., 1990) and increased utility (Rogers and Wood, 1990). It has also been stated that fused data provides for robust operational performance, i.e. increased confidence reduced ambiguity, improved reliability and improved classification (Rogers and Wood, 1990). From studying the literature, it appears that scientist applying digital image fusion to:

- ✓ Sharpen images (Chavez et al., 1991);
- ✓ Improve geometric corrections (Strolb et al., 1990);
- ✓ Provide stereo-viewing capabilities for stereo photogrammetry (Bloom et al.,1988);
- ✓ Enhance certain features not visible in either of the single data alone (Leckie, 1990);
- ✓ Complement data sets for improved classification (Schistad-Solberg et al., 1994);
- ✓ Detect changes using multitemporal data (Duguay et al., 1987);

2.3 Image fusion techniques

In general, the techniques can be grouped into two classes: 1. Colour related techniques and 2. Statistical/ Numerical method. The first comprises the colour composition of three image channels in the RGB colour space as well as more sophisticated colour transformations, e.g. intensity-hue-saturation (IHS) and hue-saturation-value (HSV). Statistical approaches are developed on the basis of channel statistics including correlation and filters. Techniques like as Principal-Component-Analysis (PCA) and registration belong to this group. The numerical methods follow simple arithmetic like image differencing and ratios but also include adding a channel to other image bands. The next sections describe these techniques in more detail.

2.3.1 Intensity-hue-saturation

The HIS color transformation effectively separates spatial (I) and spectral (H, S) information from a standard RGB image. It relates to the human color perception parameters. The mathematical context is expressed in Equation 2-1 (a-c). I relates to Intensity while v_1 and v_2 represent intermediate variables which are needed in the transformation. H and S stand Hue and saturation (Harrison and Jupp, 1990).

$$\begin{pmatrix} I \\ V_1 \\ V_2 \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \\ \frac{1}{\sqrt{6}} & \frac{1}{\sqrt{6}} & -\frac{2}{\sqrt{6}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 \end{pmatrix} * \begin{pmatrix} R \\ G \\ B \end{pmatrix} \quad \text{(a)}$$

Equation 2-1

$$H = \tan^{-1}\left(\frac{V_2}{V_1}\right) \quad \text{(b)} \qquad H = \sqrt{V_1^2 + V_2^2} \quad \text{(c)}$$

There two ways to applying the IHS technique in image fusion: direct and substitutional. The first refers to the transformation of the image channels assigned to I, H and S (Rast et al., 1991). The second transform three channels of the data set representing RGB into the IHS colour space, which separates the colour aspect into its average brightness (intensity). This corresponds to the surface roughness, its dominant wavelength contribution (hue) and its purity (saturation) (Carper et al., 1990; Gellispie et al., 1986). Both these types of information are related to the surface reflectivity or composition (Grasso, 1993). Then a fourth image channel replaces one of the components, which is to be integrated. In many published studies the channel that is replaced one of the IHS components is contrast stretched to match the letter. A revers transformation from IHS to RGB as presented in Equation 2-2 converts the data into its original image space to obtain fused image (Harrison and Jupp, 1990).

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{6}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{6}} & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{3}} & -\frac{2}{\sqrt{6}} & 0 \end{pmatrix} * \begin{pmatrix} I \\ V_1 \\ V_2 \end{pmatrix}$$

Equation 2-2

IHS become a standard procedure in image analysis. It provides color enhancement of highly corrected data (Gillespie et al., 1986), geological feature enhancement (Daily, 1983), the improvement of spatial resolution (Carper et al., 1990; Welch and Ehlers, 1987) and the fusion of disparate data sets (Ehlers, 1991; Harris et al., 1990).

The use of IHS technique in image fusion is manifold, but based on one principal: the replacement of one of the tree components (I, H or S) of one data set with another image. Most commonly, the intensity channel is substituted. Chavez et al., (1991) verified the exchange of the intensity channel I of XS by Pan with the statement that the two bands are spectrally approximately equal to each other. Replacing the intensity – the sum of the bands by a higher spatial resolution value and reversing the IHS transformation leads to composite bands. These are linier combinations of the original (resampled) multispectral bands and the higher resolution panchromatic band (Campbell, 1993).

2.3.2 Brovey Transform

The Brovey Transform, named after its author, is a formula that normalized three MS bands used for a RGB display, and multiplies the result by any other desired data to the intensity or brightness component to the image. The algorithm is shown in **Equation 2-3**_where DN_{fused} means the DN of the resulting fused image produced from the input data in 'n' bands multispectral multiplied by the high resolution image $DN_{highers}$ (Augenstain, pers.comm. 1994).

$$\mathbf{DN_{fused}} = \frac{DN_{b1}}{DN_{b1} + DN_{b2} + DN_{b3}} * DN_{highers} \qquad \text{Equation 2-3}$$

It is used for image sharpening and commonly used for combinations of TM/PAN or XS/PAN. The advantage of the Brovey Transform is that is preserves the spectral information while sharpening the scene.

2.3.3 Principal Component Analysis

PCA is useful for image encoding, image data compression, image enhancement, digital change detection, multitemporal dimensionality and image fusion. It is a statistical technique that transform a multivariate data set of intercorrelated variables into a data set of new uncorrelated linier combinations of the original variables. It generates a new set of axes, which are orthogonal (Yesou et al., 1993).

The approach for the computation of the principal components (PCs) comprises the calculation of the;

1. Covariance (unstandardized PCA) or correlation (standardized PCA) matrix
2. Eigenvalues, -vectors
3. PC's

Two types of PCA can be performed: ***selective*** and ***standard.*** The latter uses all available bands e.g. 1-n of the input image, the selective PCA uses only selection of bands, which are chosen based on a priori knowledge or application purposes (Yesou et al., 1993). For TM the first three PCA contain 98-99% of the variance and are therefore sufficient to represent the information.

PCA in image fusion has two approaches:

1. PCA of multichannel image replacement of first principal component (PC1) by different sensor image ('Principal Component Substitution'-PCS) (Chavez et al., 1991)

or

2. PCA of all multi-image data channels (Yesou et al., 1993).

The first version follows the idea of increasing the spatial resolution of a multichannel (e.g. XS) image by introducing an image with higher resolution, e.g. PAN. The channel, which will replace PC1 is stretched to the variance and average of PC1. The higher resolution image replaces PC1 since it contains the information, which is common to all bands while the spectral information is unique for each band (Chavez et al,. 1991); a similar reasoning is given in Shettigara (1992) with PC1 accounts for maximum variance which can maximize the effect of the high resolution data in one image. The image channels of the different sensors are combined into one image file and PCA is calculated from the all channels. Some examples of image fusion applying the first and the second methods of PCA are reported in Yesou et al. (1993) and Richards (1984), respectively.

2.3.4 High Pass Filtering

Another approach to enhance the spatial resolution of multispectral data adds the spatial to the spectral information: high pass filtering (HPF) in combination with band addition. The high spatial resolution image is filtered with a small high pass filter resulting in the high frequency part of the data, which are related to the spatial information. This is added pixel wise to the low-resolution bands. Application of the HPF to the Pan have been published in Jutz and Chorowicz (1993), Tauch and Kahler (1988), Shettigara (1992) and Mangolini et al. (1993). They added the resulting images to all three multispectral input channels of a colour composite. Nevertheless, Shittigara (1992) commenting on the HPF method, noted that it has limitations in passing on important textural information from the high-resolution band.

2.3.5 Ehlers technique of fusion

The Ehlers fusion is based on an IHS transform coupled with a Fourier domain filtering. This technique is extended to include more than 3 bands by using multiple IHS transforms until the number of bands is exhausted. A subsequent Fourier transform of the intensity component and the panchromatic image allows an adaptive filter design in the frequency domain. Using fast Fourier transform (FFT) techniques, the spatial components to be enhanced or suppressed can be directly accessed. The intensity spectrum is filtered with a low pass filter (LP) whereas the panchromatic spectrum is filtered with an inverse high pass filter (HP). After filtering, the images are transformed back into the spatial domain with an inverse FFT and added together to form a fused intensity component with the low-frequency information from the low resolution multispectral image and the high-frequency information from the high resolution image. This new intensity component and the original hue and saturation components of the multispectral image form a new IHS image. As the last step, an inverse IHS transformation produces a fused RGB image. These steps can be repeated with successive 3-band selections until all bands are fused with the panchromatic image. The Ehlers fusion shows the best spectral preservation but also the highest computation time.

2.3.6 Wavelet resolution merge

The wavelet fusion method is based on the wavelet decomposition of images into different components based on their local frequency content. Wavelet transforms provide a framework in which a signal is decomposed, with each level corresponding to a coarser resolution, or lower frequency band. There are two main groups of transforms, continuous and discrete. Discrete transforms are more commonly used and can be subdivided in various categories. Although a review of the literature produces a number of different names and approaches for wavelet transformations, most fall into one of the following three categories: decimated, undecimated, and non-separated.

2-D Discrete Wavelet Transform

A 2-D Discrete Wavelet Transform of an image yields four components:

- approximation coefficients W_φ
- horizontal coefficients W_ψ^H – variations along the columns
- vertical coefficients W_ψ^V – variations along the rows
- diagonal coefficients W_ψ^D – variations along the diagonals (Gonzalez and Woods, 2001)

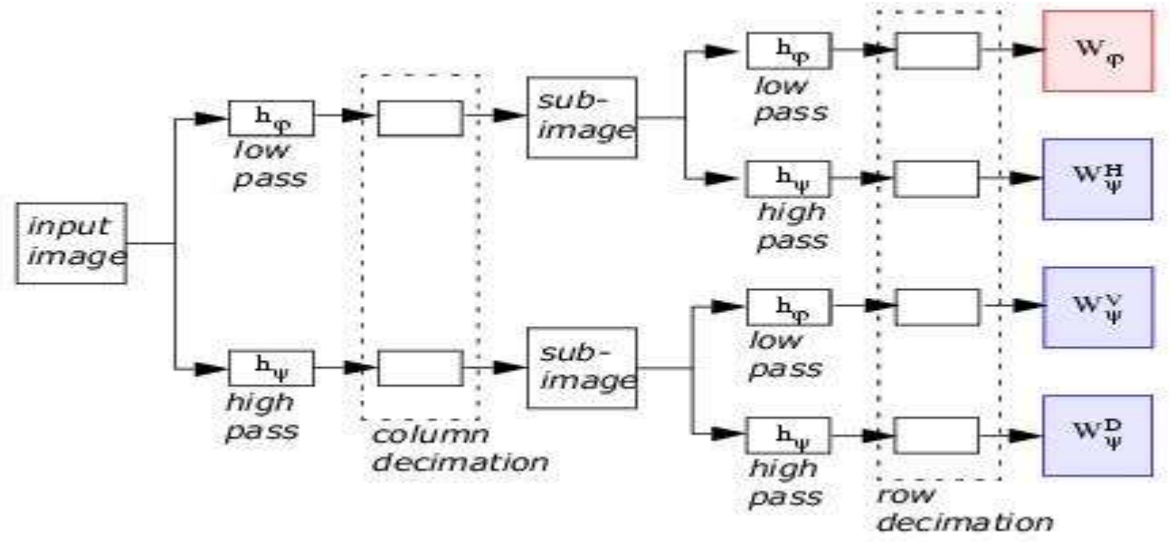


Figure 2-1: Schematic Diagram of the Discrete Wavelet Transform - DWT

Symbols h_φ and h_ψ are, respectively, the low-pass and high-pass wavelet filters used for decomposition. The rows of the image are convolved with the low-pass and high-pass filters and the result is downsampled along the columns. This yields two subimages whose horizontal resolutions are reduced by a factor of 2. The high-pass or detailed coefficients characterize the image's high frequency information with vertical orientation while the low-pass component contains its low frequency, vertical information. Both subimages are again filtered columnwise with the same low-pass and high-pass filters and downsampled along rows.

Thus, for each input image, we have four subimages each reduced by a factor of 4 compared to the original image; W_φ, W_ψ^H, W_ψ^V, and W_ψ^D.

2.3.7 Multiplicative transformation algorithm

The Multiplication model combines two data sets by multiplying each pixel in each band of the MS data by the corresponding pixel of the Pan data (Pohl.C,1997). To compensate for the increased Brightness Values (BV), the square root of the mixed data set is taken. The square root of the multiplicative data set, reduces the data to a combination reflecting the mixed spectral properties of both data sets:

$$MLT_{i,j,k} = \sqrt{a \times b \times Pan_{i,j} \times MS_{i,j,k}}$$ Equation 2-4

Where MLT is the output image and i and j are pixels of band k. Pan and MS are the panchromatic data and multi-spectral data respectively. To compensate for this effect, weighting coefficients A and B can be used. As Cliche and Bonn (1985) noted, "however arbitrary, the weights used for the panchromatic and infrared channels increase the spatial resolution from 20 to 10 m and preserve much of the infrared information.

2.3.8 Gram-Schmidt fusion algorithm

The Gram Schmidt fusion simulates a panchromatic band from the lower spatial resolution spectral bands. In general, this is achieved by averaging the multispectral bands. As the next step, a Gram Schmidt transformation is performed for the simulated panchromatic band and the multispectral bands with the simulated panchromatic band employed as the first band. Then the high spatial resolution panchromatic band replaces the first Gram Schmidt band. Finally, an inverse Gram Schmidt transform is applied to create the pan-sharpened multispectral bands. This method usually produces good results for fusion images from one sensor, but it is also a statistical procedure like the PC, so that the fusion results may vary depending on the selected datasets.

2.3.9 ESRI fusion technique

The ESRI pan-sharpening transformation uses a weighted averaging and the additional near-infrared band (optional) to create its pan-sharpened output bands. The result of the weighted average is used to create an adjustment value (ADJ) that is then used in calculating the output values. For example:

ADJ = pan image - WA
Red_out = R + ADJ
Green_out = G + ADJ
Blue_out = B + ADJ
Near_Infrared_out = I + ADJ

For the ESRI pan-sharpening transformation, the weight values of 0.166, 0.167, 0.167, and 0.5 (R, G, B, I) provide good results when using QuickBird imagery. By changing the near-infrared weight value, the green output can be made more or less vibrant.

The simple mean transformation method applies a simple mean averaging equation to each of the output band combinations. For example:

Red_out= 0.5 * (Red_in + Pan_in)
Green_out = 0.5 * (Green_in + Pan_in)
Blue_out= 0.5 * (Blue_in + Pan_in)

In all cases, the sum of the weights given to each band should equal 1; however, if they do not, the algorithm will make the necessary adjustments when calculating the transformation to each band.

2.4 Issues in image fusion

Image fusion has many aspects to be considered. A suggested approach in the selection of an appropriate technique follows first the definition of the intended application in order to be able to select the proper data, technique and evaluation procedure for image fusion. The selection of the sensor depends on satellite and sensor characteristics such as:

- Orbit;
- Platform:
- Imaging geometry of optical and radar satellites (depression, incidence angle);
- Spectral, spatial and temporal resolution.

The availability of the specific data plays an important role too. It depends on the satellite coverage, operational aspects of the space agency running the satellite, atmospheric constrains such as cloud cover, financial issues, etc. The next step is the choice of a suitable fusion level. The preprocessing steps are depend on this. The geocoding is of vital importance for pixel based image fusion. In relation to the geometric correction of the data, further consideration of the following detail is required:

- Geometric model
- Ground control points (GCP’s)
- Digital elevation model
- Resampling method, etc.

Depending on application, seasonal and weather conditions might be relevant to the fused result, while of course, the same is valid for the observed area. The topography spatially has a great influence on the constitution of fused remote sensing data besides the actual ground cover and land use.

2.5 Limitations of Image Fusion

In terms of levels in image fusion the pixel based method have the advantage of using the most original data over fusion at future level or information level. It avoids loss of information, which occurs during a feature extraction process, although is a constraint in the necessity of accurate geocoding, including a resampling of the data.

The use of multisensor data is limited by several factors such as:

- Lack of simultaneously acquired multisensory data,
- Limited compatibility of the data, and
- Lack of available ground truth (Lazano-Garcia and Hoffer, 1993)

Naturally, when working with image from different sensors the data volumes increase, which demands powerful software and large hardware system to handle the imagery. Since more than one scene has to purchased for multisensor image fusion the costs also increase significantly. Characteristics of fused image data depend very much on the applied technique. The constraint are related to the disturbance of spectral content of the input data and a blurring effect when introducing images with low SNR. The user of multisensory data in the context of image fusion has to be aware of the physical characteristics of the input data in order to be able to select appropriate processing method and to judge the resulting fused data.

3. Study area and Data used

3.1 Study area

The research site is located on the Occidental valley, east part of Catalonia province, Spain. It extends from 41^0 27’54” N to 41^0 31’38” N and from 1^0 53’5.43” E to 1^0 58’ 28.13” E (CRS: WGS). Study area especially was selected with irregular terrain for task of to study the effect of ortho-rectification on image fusion with ranging of relief from 27.0 meter to 896.0 meter (ellipsoidal height). *Figure 3-1* indicates the location of the research site in the north-east part of Spain.

Research site also was chosen with complex landform, such as urban system and agriculture for task of to study the effect of image fusion for identification of these type of features.

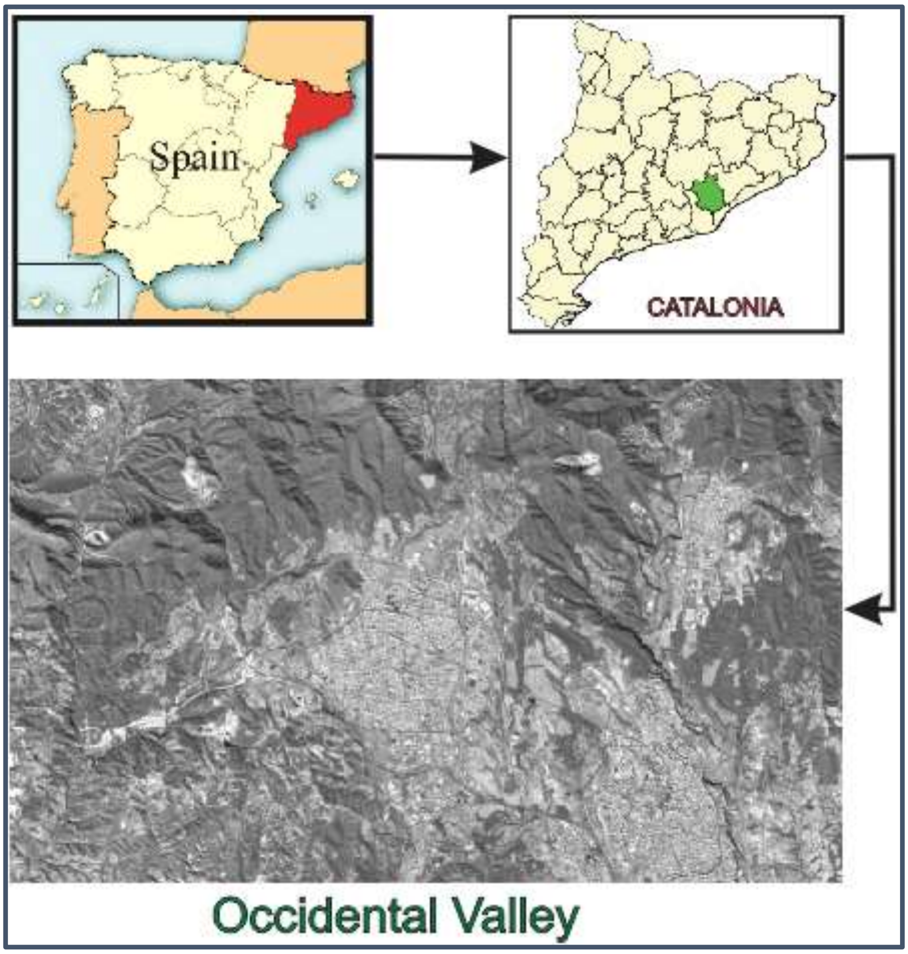


Figure 3-1: Location of research area Occidental valley, Catalonia province, Spain.

3.2 Data used

The remote sensing data and ancillary data used for the study are given below.

3.2.1 The Kompsat-3 Bundle (Pan + MS) product type with product level 1R and 1G data was used in this study. The details of the datasets are given in ***Table 3.1***.

Table 3.1. Configuration of Kompsat-3 sensor.

Orbit type	Near polar, Sun synchronous
Altitude	685 km
Inclination	98.13 degree
Revolving time	98.5 minutes
Spectral bands	450-900 nm Pan (Panchromatic) 450-520 nm MS (Multispectral), blue 520-600 nm MS, green 630-690 nm MS, red 760-900 nm MS, NIR (Near Infrared)
Optics	- Korsch-type telescope design on a CFRP optical bench - 80 cm diameter of primary mirror aperture (the mirror is lightweighted) - All mirrors (5) are of Zerodur design - Focal length = 8.6 m - F number = f/12
GSD (Ground Sample Distance)	- 0.7 m for Pan band - 2.8 m for MS bands
Swath width	16.8 km (at nadir)
Data quantization	14 bit
Data of Acquisition	5th February 2013

Ancillary data as Ground control points was collected from Google Earth source.

4. Methodology

4.1 Introduction

As it was mentioned, the first aim of the research was to study the effect of ortho-rectification on image fusion techniques, therefore for this task in pre-processing part was implement with different models of geocoding such as polynomial and differential. The geometric correction and geo-referencing procedure included the evaluation of different geocoding approaches along with analysis of the influence of ground control points selections on the geometry. The preprocessing part was include only geometric correction and it is not required radiometric correction, because used data was already radio-metrically corrected.

The overall methodology of this study has been shown by work flow diagram in Figure 4.1.

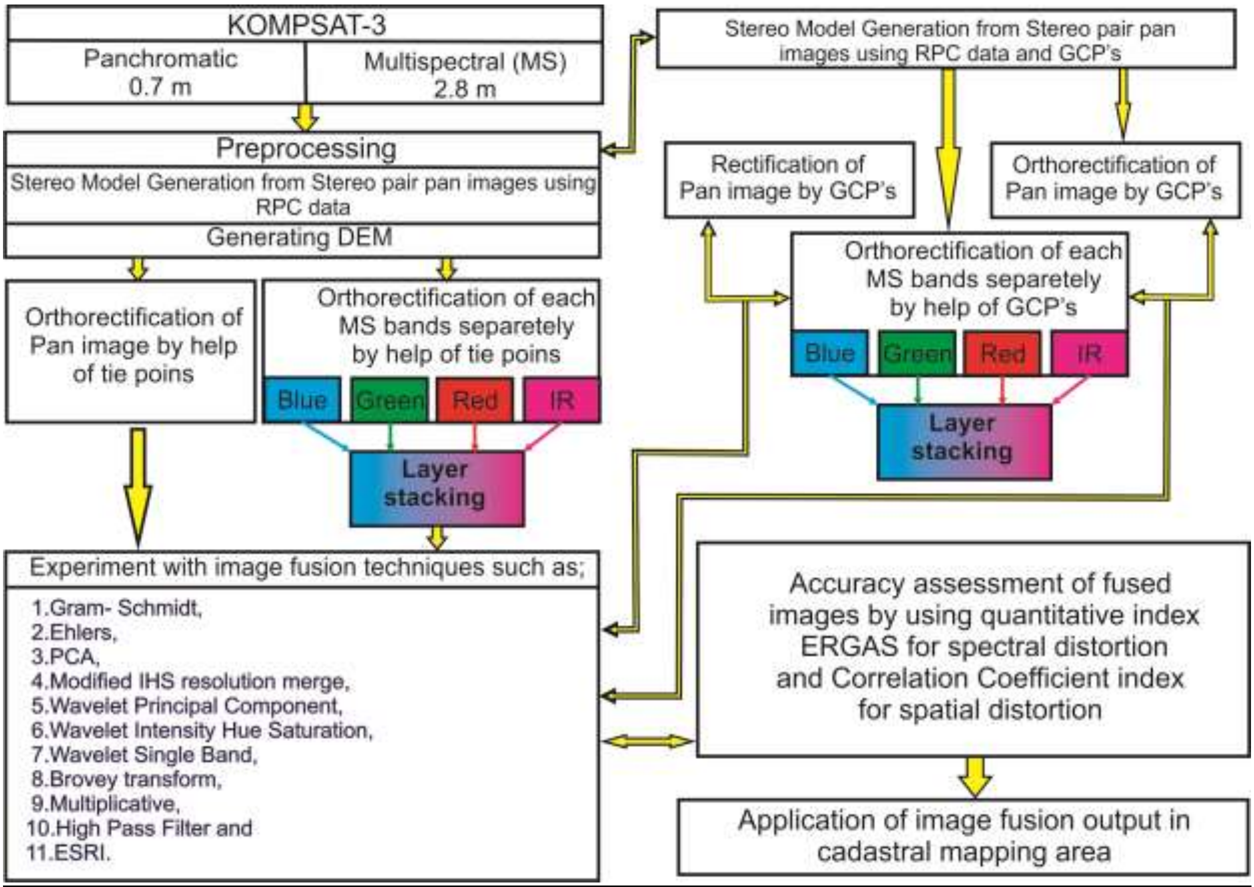


***Figure 4.1**:* Research methodology.

4.2 Geometric corrections

4.2.1 Terms

The definitions of three common expression were discussed here as used by the author in order to clarify some terms that frequently occur in the following sections. The extent of geometric correction depends on the application. There are three possibilities:

1. Co-registration
2. Geo-referencing

3. Geocoding

In some cases it is not necessary to rectify data to a certain map projection and assign geographic coordinates. For a simple comparison of two different data sets, it might be sufficient to co-register the images using an affine or polynomial transformation based on tie point measurements. For geo-referencing, the user assigns coordinates to the image pixels via the geometric correction model but does not actually rectify and resample the data. Only transformation equation are defined in order to be able to relate image processing and interpretation results to a geographic location. The third possibility transforms the image into a map-like object where each pixel is in its geometrically correct position and has coordinates. In the context of pixel based image fusion, geocoding is an essential pre-processing step, which has to be performed as accurately as possible in order to make the data compatible on a pixel-by-pixel basis.

4.2.2 Geometric models

There are various possibilities for correcting image data in the multisensor environment. Depending on their purpose, image can be registered to:

- Other image
- Maps, or
- The ground.

Two images can be co-registered by registering each of them to a map coordinate base separately, as described below. Alternatively, an image can be registered to a previously geocoded image. If dereferencing is not important, one image can be chosen as a master to which the other (known as a slave) is to be registered. In this case, tie points located in two overlapping images are measured to transform one image into the geometry of the other. The images are then comparable on a pixel by-pixel basis. In rectifying an image to the geometry of a map, the ground control points identified in the image are determined in the map or by conventional surveying methods or GPS. Then the image will be transformed into the geometry and projection of the map. Relief distortion are not corrected. Thirdly, GCP's and the digital information on the terrain height stored in a DEM were used to rectify the image. In this case the image is also corrected for local variation of terrain. Early work on digital image rectification used geometric models which were developed in photogrammetry. Non parametric approaches (polynomial rectification) as well as parametric methods (differential, projective and collinearity models) with additional parameters, in combination with least-square adjustments, were suggested for describing the imaging process (Bahr, 1976; Dowman and Gugan, 1985; Konencny, 1976).

The non-parametric method is based on ground control points (GCP's) and/or tie points (common points in different images) which are used to calculate a polynomial that approximates the image acquisition model. The parametric approach reconstructs the image acquisition procedure and needs the sensor parameters, including the orbit description, to model the image formation. Hereafter, the former method is called the polynomial model, the latter the sensor model. The use of one or the other depends on the data (observed ground), the availability of ancillary information, and on the accessibility of suitable software and hardware.

4.2.2.1 Polynomial rectification

The polynomial method is a relatively simple approach to correct images geometrically. It corrects distortion of the image relative to a set of control points. It is sensor independent and based on statistical principles. A number of well distributed and accurately determined points are selected in both the image and the reference (other image or map as described above). In correction process, numerous points were located both in the distorted image (column, row and digital numbers) and in the reference map or master image (ground coordinates X, Y, Z). The original image is shifted, rotated, scaled and warped to fit the reference points (Novak, 1992). Different numbers of control points were needed depending on the degree of the polynomial. With increasing order (Equation 4-1 to 4-3), more control points were need to calculate the unknowns. A first-order polynomial describes the translation, rotation, scaling and obliquity of an image. The second order polynomial adds parameters for torsion and convexity. The additional parameters introduced in the third order cannot be explained by physical effects (Toutin, 1994).

$$X= a_0+a_1x+a_2y$$
$$Y= b_0+b_1x+b_2y$$

Equation 4-1:First polynomial order (6 unknowns)

$$X= a_{0+\ldots}+a_3x^2+a_4xy+ a_5y^2$$
$$Y= b_{0+\ldots}+b_3x^2+b_4xy+ b_5y^2$$

Equation 4-2:Second polynomial order (12 unknowns)

$$X= a_{0+\ldots}+a_6x^3+a_7x^2y+ a_8xy^2+ a_9y^3$$
$$Y= b_{0+\ldots}+b_6x^3+b_7x^2y+ b_8xy^2+ b_9y^3$$

Equation 4-3: Third polynomial order (20 unknowns)

Each points delivers at least two measurements (planimetric coordinates: x,y). The polynomial equation can be solved after a sufficient number of points have been collected. In the case of redundant information, a least-square adjustment of the measurements is applied to determine the best fitting polynomial and its accuracy. This method also offers the possibility of detecting blunders. The polynomial approach correct the image only locally because it depends on the control point locations and their distribution. For flat terrain and a good distribution of points (no extrapolation) it ensures a well corrected image. This model is not useful for strong height variations in the terrain and can lead to large errors in regions, which were not covered by control points. It requires a high number of GCP’s. The method does not consider sensor characteristics and can therefore be applied to any image data. All the GCP’s distributions listed above were corrected simultaneously (Novak, 1992, Toutin, 1994).

4.2.2.2 Sensor model

As the name indicates, this model is sensor specific. It requires knowledge of the geometry of image aqusition and orbit parameters which describe the position and movement of the platform (ephimaris) as well as information on the observed terrain. The elements accounted for sensor model are:

- Platform (position, velocity, orientation),

- Sensor (orientation angles, IFOV, line, integration time),
- Earth (geoid/ellipsoid including elevation),
- Cartographic projection (ellipsoid, plane).

A sensor model is a set of equations giving the relationship between image pixel (l, c) coordinates and ground (X, Y) coordinates for every pixel in the image. Typically, the ground coordinates are given in a geographic projection (latitude, longitude). The sensor model can be expressed either from image to ground – forward model – or from ground to image – inverse model. This can be written as Equations 4-4 and 4-5:

$$\text{Forward} \quad X = f_X(l, c, h, \vec{\theta}) \quad Y = f_Y(l, c, h, \vec{\theta})$$ Equation 4-4

$$\text{Inverse} \quad l = g_l(X, Y, h, \vec{\theta}) \quad c = g_c(X, Y, h, \vec{\theta})$$ Equation 4-5

Where $\vec{\theta}$ is the set of parameters, which describe the sensor and the acquisition geometry (platform altitude, viewing angle, focal length for optical sensors, Doppler centroid for SAR images, etc).

Types of sensor model:

There exists two main types of sensor models. On one hand, it is so-called *physical models*, which are rigorous, complex, eventually highly non-linear equations of the sensor geometry. As such, they are difficult to inverse (obtain the inverse model from the forward one and vice-versa). They have the significant advantage of having parameters with physical meaning (angles, distances, etc.). They are specific of each sensor, which means that a library of models is required in the software. A library which has to be updated every time a new sensor is available.

On the other hand, we have general analytical models, which approximate the physical models. These models can take the form of polynomials or ratios of polynomials, the so-called rational polynomial functions or Rational Polynomial Coefficients, RPC, also known as *Rapid Positioning Capability*. Since they are approximations, they are less accurate than the physical models. However, the achieved accuracy is usually high: in the case of Kompsat-2, RPC models have errors lower than 0.02 pixels with respect to the physical model. Since these models have a standard form they are easier to use and implement. However, they have the drawback of having parameters (coefficients, actually) without physical meaning.

Rational Polynomial Coefficients (RPC) model. In providing a generic representation of the camera’s or sensor’s object-image geometry, the RPC model allows derivation of a simple, efficient and accurate DEM. Indeed, it has been demonstrated by Grodecki (2001), Grodecki and Dial (2003), Tao and Hu (2002) and Fraser and Hanley (2003) that RPC provides the end users of high-resolution, satellite imagery with an ability to perform full photogrammetric processing, including block adjustment, 3-D feature extraction, DEM generation and orthorectification. The beauty of using RPC is that it is sensor independent, which means that the user does not need to know all of the specific internal and external camera information. In short, it is simply a lot less complicated than other approaches. The name “rational polynomial” derives from the fact that the model is expressed as the ratio of two cubic polynomial expressions. It is a simple, empirical mathematical model that relates image space (line and column position) to latitude, longitude, and height above the ground. In other words, it provides a functional relationship between the object space's i, h coordinates and the image space (L, S) coordinates, as mention in Equation (4-6):

$$L = \frac{N_s(\emptyset,\ \lambda,\ h)}{D_s(\emptyset,\ \lambda,\ h)}, \qquad S = \frac{N_l(\emptyset,\ \lambda,\ h)}{D_l(\emptyset,\ \lambda,\ h)} \qquad \text{Equation (4-6)}$$

where Ø is the geodetic latitude, λ is the geodetic longitude, h is the height above the earth's ellipsoid surface, S is the image sample and L is the line. Hence any single image involves two such rational polynomials, one for calculating the sample position and one for computing the line position.

5. Data analysis and result

5.1 Image fusion processing

As previously described, in present study 11 image fusion techniques were studied with different combination of geometrically corrected images used in this study to study the effect of image geometry on fused image. In pre-processing part such as stereo model generating, deriving DEM from stereo pair and geometric correction tasks was used the LPS module of Erdas software and for image fusion processing three different package of software have been used such as;

- Erdas 9.2,
- ENVI 4.5 and
- ArcGIS 10.

5.2 Input data

As mentioned above with the aim to study of ortho-rectification's effect to image fusion output different combination geometrically corrected data have been used. The data combination, which have been used were as follows:

- PAN normal rectified (through polynomial model)/MS ortho-rectified image
- PAN ortho-rectified using tie points/MS ortho-rectified using tie points
- PAN ortho-rectified using GCP,s/MS ortho-rectified using GCP,s

5.2.1 Ancillary data

Ancillary data such as GCP's were collected from Google earth resource in geographic coordinate system and transformed to UTM projection coordinate system and, than used. The total number of GCP's were 7 and they were well distributed in study area.

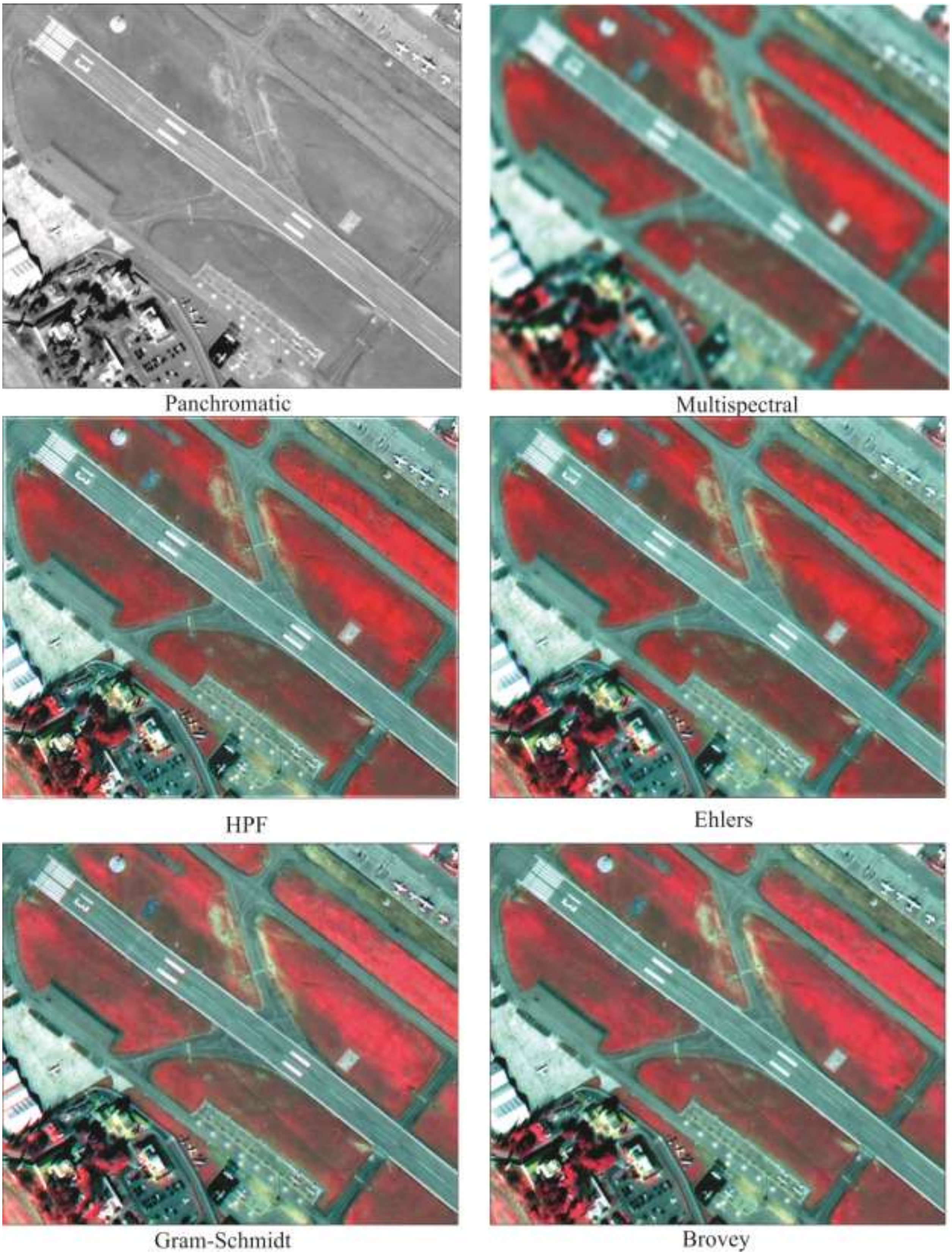
5.3 Image fusion quantitative assessment.

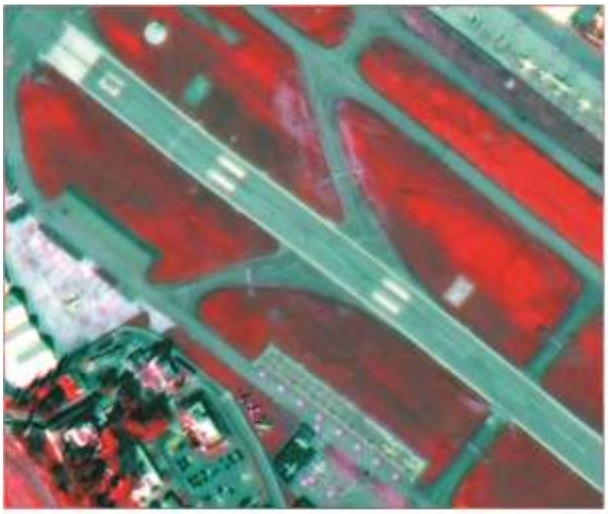
For analysis and evaluate of accuracy of output fused images was used visual method as well as quantitate indexes. In comparing the spatial quality, it is relatively easy to judge spatial quality just by looking at the image. For example in Figure 5-1 HPF and Ehlers demonstrate clear edges whereas Wavelet experiences what is called a stair-casing effect. Similarity for all the other images this pattern follows. In order to be more accurate as mentioned above metric method have been used to evaluate the images as well. To judge the spatial quality of the pan-sharpened images compared the high frequency data from the panchromatic image to the high frequency data from each band of the fused image using a method proposed by Zhou in 2004. To extract the high frequency, data was applied with convolution mask to the images as shown in Equation 5-1:

$$\text{mask}=\begin{bmatrix}-1 & -1 & -1\\ -1 & 8 & -1\\ -1 & -1 & -1\end{bmatrix} \text{……… Equation 5-1}$$

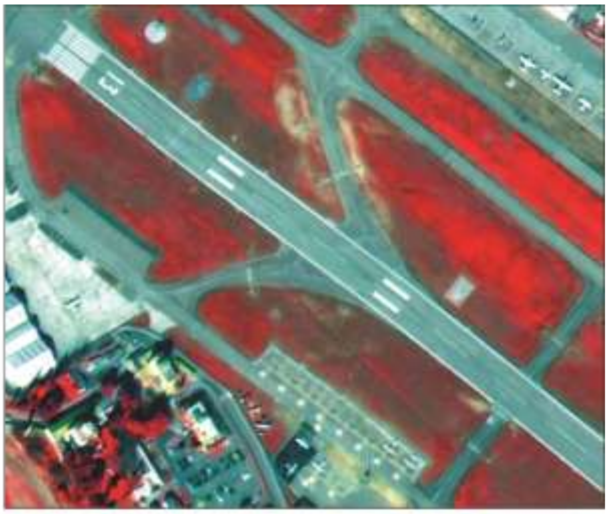
The resulting filtered images have been compared by considering the Correlation Coefficients between each band of fused image and the Panchromatic image. The closer the average correlation coefficient is to one, the more closely the edge data of the fused image matches the edge data of the Panchromatic, indicates better spatial quality. In the result of spatial metric, it partially confirmed result of visual analysis that HPF image fusion technique has the highest spatial quality, but in case of Ehler fusion technique it's not confirmed. In addition, it misleads about evaluating ESRI fusion technique. In Table 5-1 Gram-Schmidt has a lower spatial value than Multiplicative, however Gram-Schmidt visually looks better. Here it has been observed that there is a discrepancy in this metric. Moreover the result of spatial metric shown that spatial accuracy of combination PAN normal rectified and MS ortho-rectified images higher, than combination of PAN ortho-rectified and MS ortho-rectified images this misleads, also can be considered as discrepancy in this metric and usefulness of present metric will be described in conclusion part.

Figure 5-1 Output of image fusion techniques by using combination of PAN ortho-rectified image by help of tie points and Multispectral ortho-rectified image by help of tie points.

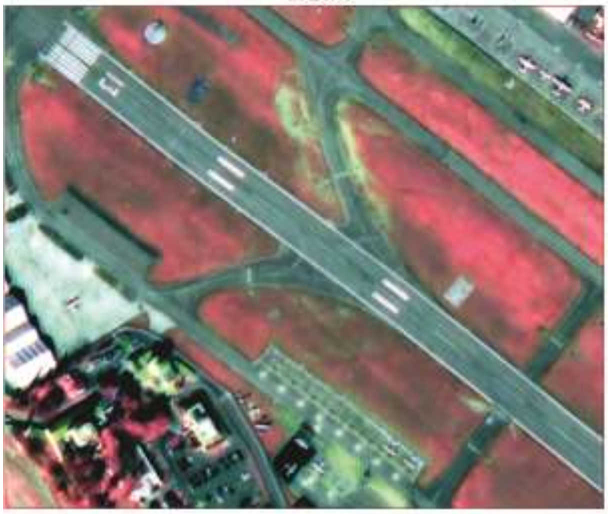




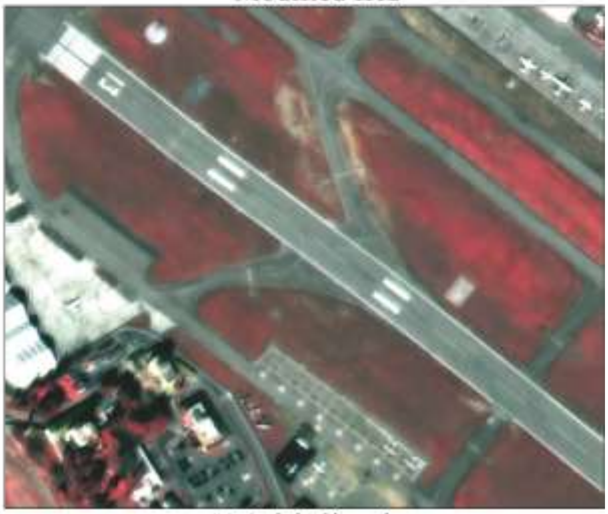
ESRI



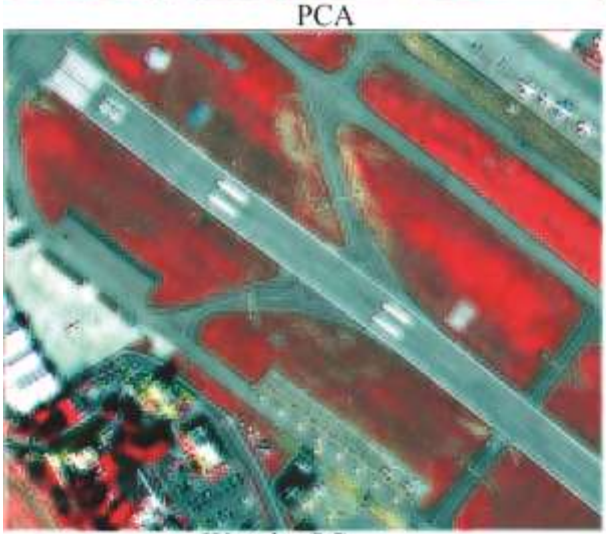
Modified IHS



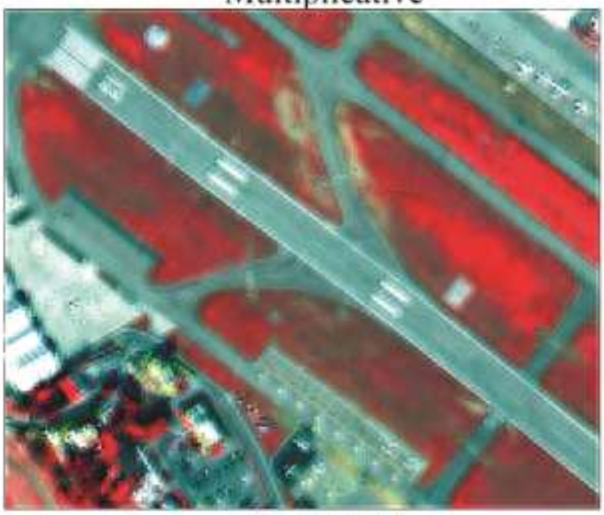
PCA



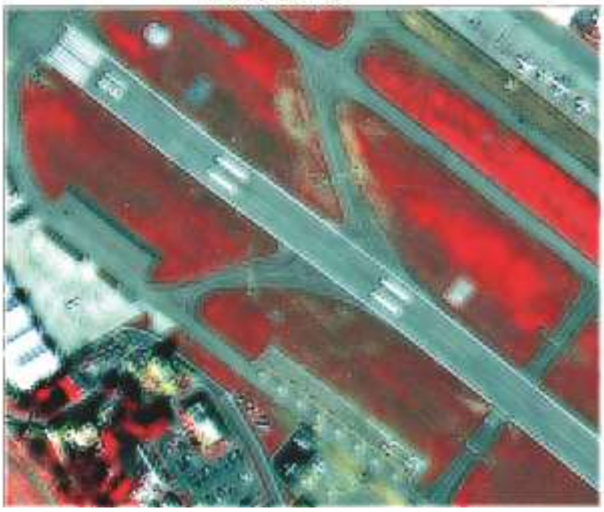
Multiplicative



Wavelet-PC



Wavelet-IHS



Wavelet-Single band

5.3.1 Correlation Coefficient index.

As mentioned in previous section for accuracy assessment of spatial distortion Correlation Coefficient metric method have been used. The quantity r, called the linier Correlation Coefficient, measures the strength and the direction of a linear relationship between two variables. The linear correlation coefficient sometimes referred to as the Pearson product moment correlation coefficient in honor of its developer Karl Pearson.

The mathematical expression for computing ***r*** has been given in Equation 5-2:

$$\mathbf{r} = \frac{n\sum xy-(\sum x)(\sum y)}{\sqrt{n(\sum x^2)-(\sum x)^2}\sqrt{n(\sum y^2)-(\sum y)^2}} \qquad \text{Equation 5-2}$$

Where **n** is the number of pairs of data.

The value of r is such that $-1 \leq r \leq +1$. The + and – signs are used for positive linier correlations and negative linier correlations, respectively.

- ✓ Positive correlation: If x and y have a strong positive linier correlation, r is close to +1. An r value of exactly +1 indicates a perfect positive fit. Positive values indicate a relationship between x and y variables for x increases, values for y also increase.
- ✓ Negative correlation: If x and y have a strong negative linier correlation r is close to -1. An r value of exactly -1 indicates a perfect negative fit. Negative values indicate a relationship between x and y such that as values for x increase, values for y decrease.
- ✓ No correlation: If there is no linier correlation or a weak linier correlation, r is close to 0. A value near to zero means that there is a random, nonlinear relationship between the two variables.
- ✓ Note that r is a dimensionless quantity; that is, it not depend on the units employed.
- ✓ A perfect correlation of ± 1 occurs only when the data points all lie exactly on a straight line. If r =+1, the slope of this line is positive. If r =-1, the slope of this line negative.
- ✓ A correlation greater than 0.8 is generally described as strong, whereas a correlation less than 0.5 is generally described as weak. These values can vary based upon the "type" of data being examined. A study utilizing scientific data may require a stronger correlation than a study using social science data.

The results of visual analysis as well as applying Correlation Coefficient quantitative index for quality assessment of spatial distortion on fused images are shown in Table 5-1.

Table 5-1: Result of Quality assessment of spatial distortion by using Correlation Coefficient quantitative index.

Fusion Techniques	*Images ortho-rectified with GCP*	*Images ortho-rectified without GCP*	*Normal rectified Pan image + MS ortho-rectified image*	*Evaluation by visual analysis of output images*
HPF	*0.99338207*	*0.995750726*	*0.990589712*	*1*
Ehlers	*0.984296515*	*0.965382162*	*0.950583228*	*2*
Gram-Schmidt	*0.974511631*	*0.981397719*	*0.999224171*	*3*
Brovey	*0.986396468*	*0.987925843*	*0.999154892*	*4*
ESRI	*0.747110175*	*0.748086746*	*0.74606528*	*5*
Modified IHS	*0.959302341*	*0.94498359*	*0.914050086*	*6*
PCA	*0.956909404*	*0.972090424*	*0.99936205*	*7*
Multiplicative	*0.984131598*	*0.98804909*	*0.99936205*	*8*
Wavelet PC	*0.949935683*	*0.933872208*	*0.814783094*	*9*
Wavelet IHS	*0.940440559*	*0.970974965*	*0.736218386*	*10*
Wavelet Single Band	*0.948598069*	*0.960544023*	*0.702673369*	*11*

5.3.2 ERGAS index.

In second part of accuracy assessment for spectral distortion measurements of fused image another type of index such as ERGAS has been used.

Ranchin and Wald (2000) proposed an error index that offers a global picture of the quality of a fused product. This error is called ERGAS, the French acronym for relative dimensionless global error in synthesis, and is given by Equation 5-3:

$$\text{ERGAS} = 100\,\frac{d_h}{d_i}\sqrt{\frac{1}{L}\sum_{i=1}^{L}\left(\frac{RMSE\,(I)}{\mu\,(I)}\right)^2} \quad \text{Equation 5-3}$$

Where d_h and d_i is the ratio between pixel sizes of PAN and MS, e.g., 1:4 for Kompsat-3, IKONOS and Quickbird data, μ(I) is the mean (average) of the I^{th} band and L is the number of bands. This index measures a distortion, and thus must be as small as possible.

The results of quality assessment of spectral distortion on fused images by using ERGAS quantitative index are shown in Table 5-2.

Table 5-2: Result of Quality assessment of spectral distortion by using ERGAS quantitative index.

Fusion Techniques	Images ortho-rectified with GCP	Images ortho-rectified without GCP	Pan normal rectified image + MS ortho-rectified image
Reference value	0	0	0
HPF	0.862409416	0.880711715	1.272853784
Modified IHS	0.907286821	1.109999718	1.648984157
Ehlers	0.919448174	0.888993325	1.304615597
Gram-Schmidt	1.012740142	1.060576127	1.648221591
PCA	1.054751155	1.115844131	1.731020339
ESRI	1.185260189	1.25818788	1.939815772
Wavelet Single Band	1.413162898	1.475833239	1.733225313
Wavelet PC	1.427579026	1.374011008	1.45869808
Wavelet IHS	1.43221965	1.53407138	1.787696008
Brovey	1.438876515	1.531008246	2.352455141
Multiplicative	1.443005392	1.525617908	1.731020339

CHAPTER VI:

6. Conclusions and Recommendations

The main objective of this research was to investigate the effect of image geometry on fused image and to define which technique preserving spatial resolution as well as preserving spectral information on fused image. Based on objectives it has been observed spatial and spectral distortion most depend on pre-processing such as geometric correction and radiometric correction. Moreover, in process of applying various geometric correction model defined that differential model for geometric correction is much accurate for purpose of increasing spatial resolution of multispectral image comparing with polynomial model, which was confirmed by visual analysis method as well as by applying quantitative index. According to this research work, out of 11 different image fusion techniques the High Pass Filtering and Ehlers techniques was found as best method of image fusion for purpose of increasing spatial resolution of multispectral image in case of merging PAN and MS image of Kompsat-3 sensor. For purpose of preserving spectral information was found that out of 11 different image fusion techniques the High Pass Filtering, Ehlers and modified IHS shown the best result. For accuracy assessment of spatial distortion method proposed by Zhou in 2004 have been used, so first PAN image as well as fused image have been filtered using 3x3 convolution mask applying Laplacian filter. Then Correlation Coefficient index used for checking correlation between PAN image and fused image. In addition, visual analysis have been done by visual observing all output fused images. This investigation found that protocol proposed by Zhou in 2004 in some cases it is not suitable, because in this research the result of visual analysis and applied quantitative index as Correlation Coefficient is not matching. In order to one of research questions about, which method may help for quantitative assessment of image fusion results the present research work based on comparing output values and visual analysis found that ERGAS index has been accurate and reliable method for accuracy assessment in image fusion processing. In note may say that for to be sure, which method is much suitable for accuracy assessment of fused image need more than one pair of input images and for confirming result of image fusion quality need to apply more than one method of quantitative assessment.

In order to last research question of present work about, how image fusion may help for object identification as well as measurements in cadastral applications?. The present research work found that image fusion may be very helpful for identification of land cadastral object such agricultural, forest, urban and other, because fused image have not only rich spatial information but also contain spectral information and example to this may see by observing part of airport, as shown in Figure 5-1.

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