

# Multisensor image fusion guidelines in remote sensing

**C Pohl**

Institute for Geoinformatics and Remote Sensing (IGF), University of Osnabrück, Barbarastrasse 22B, D-49076 Osnabrück, Germany

chripohl@uni-osnabrueck.de

**Abstract.** Remote sensing delivers multimodal and –temporal data from the Earth’s surface. In order to cope with these multidimensional data sources and to make the most of them, image fusion is a valuable tool. It has developed over the past few decades into a usable image processing technique for extracting information of higher quality and reliability. As more sensors and advanced image fusion techniques have become available, researchers have conducted a vast amount of successful studies using image fusion. However, the definition of an appropriate workflow prior to processing the imagery requires knowledge in all related fields – i.e. remote sensing, image fusion and the desired image exploitation processing. From the findings of this research it can be seen that the choice of the appropriate technique, as well as the fine-tuning of the individual parameters of this technique, is crucial. There is still a lack of strategic guidelines due to the complexity and variability of data selection, processing techniques and applications. This paper gives an overview on the state-of-the-art in remote sensing image fusion including sensors and applications. Putting research results in image fusion from the past 15 years into a context provides a new view on the subject and helps other researchers to build their innovation on these findings. Recommendations of experts help to understand further needs to achieve feasible strategies in remote sensing image fusion.

## 1. Introduction

Multisensor data from Earth observation missions deliver different views of the Earth’s surface. The information contained in images from different platforms and sensors facilitates a better understanding of processes and the building of a ‘Digital Earth’. In this respect remote sensing image fusion (RSIF) has become an established, advanced processing approach to extract the optimum information from multisensor data. Within the framework of data fusion image fusion takes place on pixel, namely image level [1]. Feature and decision level fusion are higher processing levels. In RSIF the input images are radiometrically and geometrically corrected, geocoded or at least co-registered prior to being fused to obtain a single image for information extraction. RSIF has proven its usefulness and importance in many different applications in the past 30 years. Early experiments were dedicated to understand the complementarity of optical (visible and infrared) and microwave (radar) remote sensing and how to increase spatial resolution while maintaining spectral integrity of optical images alone (pansharpening) [2]. First successful applications were mapping, stereo-photogrammetry, GIS, agriculture, geology and flood monitoring. Pansharpening forms a sub-group in RSIF. It arose with the availability of single platform multisensor images, such as the multispectral and panchromatic channels of the first Système d’Observation de la Terre (SPOT) satellite, launched in 1986. Together with the recognition of the value of combined complementary images, fusion for pansharpening is one of the reasons why image fusion has gained popularity and visibility apart from the fact that more research has gone into this scientific field. The increase in accessible sensors, spatial resolution and



computer power is another contributing factor to the popularity of RSIF. It has boosted the development of new, more advanced and adaptive fusion algorithms. In addition commercial remote sensing image processing software vendors have discovered the benefit of incorporating specialized fusion techniques in their workflows [3]. Image fusion has become feasible for the broad user community. This development is accompanied by the difficulty of identifying suitable processing techniques for multisensor data sets, in particular for inexperienced users. There are choices to be made regarding the ‘right’ images, pre-processing techniques, image fusion approaches and the final interpretation methods of the fused data [4]. This paper aims at providing an overview to RSIF users to facilitate proper choices.

The problem requires the compilation of research results and scientific activities in the field of RSIF. It is necessary to analyze published RSIF findings in various aspects. Therefore two information collection approaches have been performed [5]:

1. Building of a literature database with publications on RSIF in international, peer-reviewed journals. The database contains various categories. Each publication is screened to feed these categories accordingly.
2. Design of a questionnaire on RSIF and its distribution amongst experts in the field [6]. The questionnaire data collected is then examined to support the findings.

Both elements delivered valuable inside in the state-of-the-art in RSIF research and applications. The ultimate goal of this research is the development of a Fusion Approach Selection Tool (FAST) for remote sensing applications [4].

### *1.1. RSIF Literature*

The literature database presently contains around 350 relevant journal papers that have been analyzed. Table 1 provides a summary of the frequency of RSIF publications per journal. Emphasis has been given to the past 15 years to reflect recent developments. The publications were selected based on three components: First, searches in Scopus using keywords, such as remote sensing and image fusion; second, publications citing the remote sensing image fusion review paper from 1998, which summarized the state-of-the-art at that time; and third, references listed in relevant papers leading to further literature on the subject. Journals, which published a minimum of two papers, are listed explicitly. The remaining journal papers are combined in the category ‘others’. It is interesting to observe that journals have a long tradition of high quality papers in remote sensing are also leading the number of papers in RSIF, i.e., the Transactions on Geoscience and Remote Sensing and the International Journal of Remote Sensing. The International Journal of Image and Data Fusion and Geoscience and Remote Sensing Letters closely follow them. Other long established remote sensing journals such as Photogrammetric Engineering and Remote Sensing, Information Fusion and the ISPRS Journal of Photogrammetry and Remote Sensing still reach about 20 papers each.

### *1.2. Questionnaire Results*

The questionnaire was designed to cover all relevant topics required to derive guidelines and standards. There are two sections in the questionnaire: Part A contains questions to extract the acquired knowledge of the expert. It collects information on sensors, applications, fusion techniques, quality assessment, software, major challenges encountered and trends. Part B is related to an actual case study to actually provide successful applications of RSIF. Participants in this data collection so far originate from 10 different countries in North America, Europe and Asia. The valuable information derived from the questionnaire concerns challenges and trends as envisioned by the experts consulted. They will be summarized in the conclusion section of this paper.

The remaining paper reports on the findings. The following section concentrates on commonly used image data. Section three reports on applications that benefit strongly from RSIF. More importantly, section four summarizes successful image fusion techniques and their relationship to

**Table 1.** Journal publications in RSIF between 2000 – 2015<sup>a</sup>.

Journal Name	Number of Papers published
Other	62
Transactions on Geoscience and Remote Sensing	50
International Journal of Remote Sensing	48
International Journal of Image and Data Fusion	29
Geoscience and Remote Sensing Letters	24
Photogrammetric Engineering and Remote Sensing	19
ISPRS Photogrammetry and Remote Sensing	19
Information Fusion	18
Journal of Applied Earth Observation and Geoinformation	10
Journal of Applied Remote Sensing	9
Geocarto	8
Selected Topics in Applied Earth Observation and Remote Sensing	8
Remote Sensing	7
Optical Engineering	5
Sensors	4
Revista Teledeteccion	4
GIScience and Remote Sensing	4
Computer and Geosciences	4
Arabian Journal of Geosciences	4
Remote Sensing Letters	3
Pattern Analysis and Applications	3
Optik	2
Journal of the Indian Society of Remote Sensing	2
International Journal of Digital Earth	2
International Journal of Computer Science and Mobile Computing	2
Computer Vision and Pattern Recognition	2
Advances in Remote Sensing	2

<sup>a</sup> The category 'others' contains journals that published only one paper (based on database)

sensors and applications. Last but not least the discussion in section five reveals communalities and contradictions from existing research results.

## 2. Sensors and image data in RSIF

The top most utilized image data in RSIF literature are from Landsat and IKONOS, closely followed by QuickBird and SPOT (table 2). All these sensors provide optical imagery with multispectral and high-resolution panchromatic channels. These are very suitable for mapping and monitoring, especially with the option of single platform pansharpening.

Taking advantage of complementary information acquired by optical and radar satellites in RSIF and the availability of operational and continuous space programs radar satellites have gained importance. Most popular in this category is the data of the TerraSAR-X mission and Radarsat.

## 2. Applications of RSIF

One quarter of the applications reported on belong to the study of urbanization processes. Change detection is another important applications of RSIF described in the collected journal publications as shown in figure 1. Both applications reflect that the topic is of global interest. The papers mainly focus on anthropogenic aspects, such as the development of Mega-cities and the change in land use, i.e., conversion of natural landscapes into industrial and agricultural areas. RSIF is a major contributor in

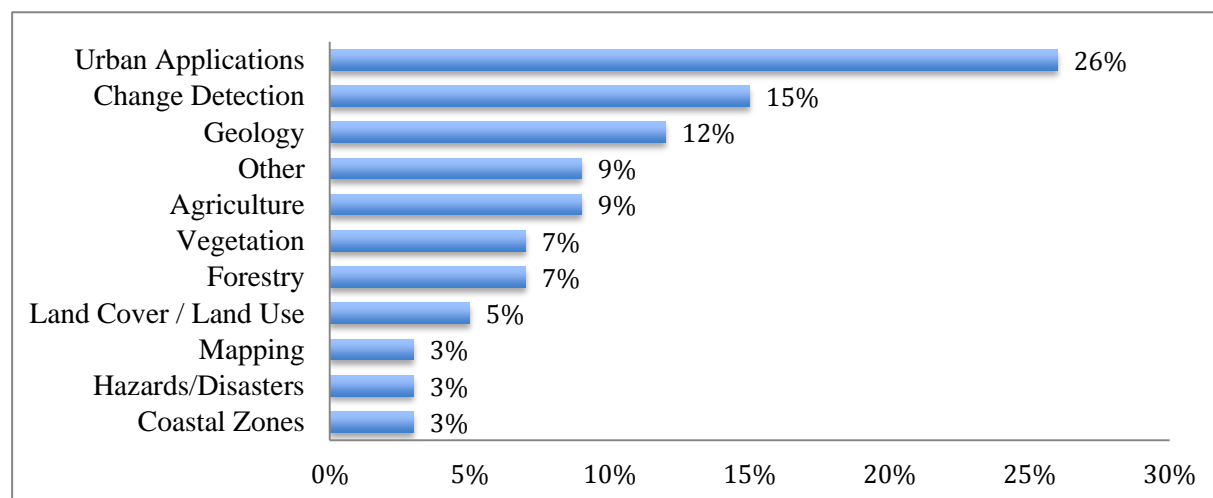
image processing due to the increased spatial resolution of available sensors by pansharpening, which makes urban mapping from space feasible. Both applications are key players in global change studies.

**Table 2.** Popularity of satellite sensors in RSIF<sup>a</sup>.

Sensor	Number of Occurrence	Sensor	Number of Occurrence
Landsat	106	ERS	15
IKONOS	103	GeoEye	12
QuickBird	86	IRS LISS	8
SPOT	69	RapidEye	6
WorldView	31	ENVISAT	6
Other	25	Pleiades	5
TerraSAR-X	23	Kompsat	4
Hyperspectral Sensors <sup>b</sup>	22	Formosat	4
Radarsat	19	COSMO-SkyMed	4
MODIS	18	ZY	3
ALOS VIR/SAR	16		

<sup>a</sup> Derived from the literature database.

<sup>b</sup>The group of hyperspectral sensors contains information on airborne platforms.



**Figure 1.** Applications of RSIF in journal publications

### 2.1. Urbanization

The monitoring of the urbanization process plays a central role in urban pollution, energy consumption and risk reduction in natural/anthropogenic hazards as well as climate change studies [7]. RSIF is an important contribution to this type of applications since the availability of very high-resolution sensors. However with the necessity of proper object discrimination and mapping the trend leads from fusion at image level to feature level to take advantage of object-based analysis. Pansharpening is an essential player in urban growth monitoring. Many RSIF techniques are used in this domain [8].

### 2.2. Land use / land cover change detection and mapping

Multi-temporal remote sensing provides the means of the necessary coverage and repetition for

monitoring land use / land cover changes. These studies often cover several decades of development. Optical as well as radar data serve the purpose of identifying the developments. Advanced methods have been developed to automate the process using, e.g. unsupervised classification [9]. The impact of rapid urbanization and industrialization can lead to environmental problems. Fusing VIR and SAR images can improve classification results for large areas [10]. Principal component analysis (PCA) is a popular approach in RSIF for change detection [11]. VIR/SAR image fusion for mapping is important in tropical areas where frequent cloud cover can cause problems in optical data acquisition [12].

### *2.3. Geology and Geomorphology*

Geology was one of the first applications to apply RSIF. The richness of interpreting a combination of multispectral information from optical sensors with surface roughness and texture from radar imagery has been appreciated with the upcoming availability of spaceborne sensors. VIR/SAR image fusion provides comprehensive geological information, e.g., for metallic deposits even if they are obscured by dense vegetation in the tropics [13]. Integrating multi-temporal images from optical sensors it is possible to derive high-resolution mineral information even though the individual image does not have enough spectral resolution [14]. In geomorphological applications VIR/SAR fusion is a recognized tool, in particular to map sub-surface structures. Component substitution techniques enable the mapping of sand-buried arid landscapes [15].

### *2.4. Agriculture*

Yield prediction has become relevant to investigate improvements in food production. Monitoring using remote sensing is indispensable due to the large coverage needed [16]. The combination of multiple sensors allows the identification of the best periods for grain yield estimations [17]. Another example of RSIF applications in agriculture is the mapping of crops for resource management in terms of crop types, vegetation health, etc. [18].

### *2.5. Vegetation monitoring*

Especially in the context of carbon budget calculation, soil monitoring and climate change due to land use / land cover changes vegetation mapping is crucial. Other applications include growing cycles and phenology changes. Multispectral, multi-temporal images along with microwave remote sensing data provide valuable input to the calculations. Using joint classification [19] and image fusion [20] lead to higher accuracy than using the single data alone.

### *2.6. Forestry*

Large-scale mapping of forest, deforestation and forest degradation studies heavily rely on remote sensing. Again the combination of active and passive sensor data lead to an increased reliability of the results and help the discrimination of different tree types [21]. Other studies utilize pansharpening of single platform sensors data to create high resolution, high accuracy of the classification results [22]. In the context of carbon stock estimation tropical above ground biomass receives increased attention. This is closely related to forest degradation and deforestation. VIR/SAR image fusion can contribute to the development of high quality models if appropriate techniques are chosen [23].

### *2.7. Disaster and hazard monitoring*

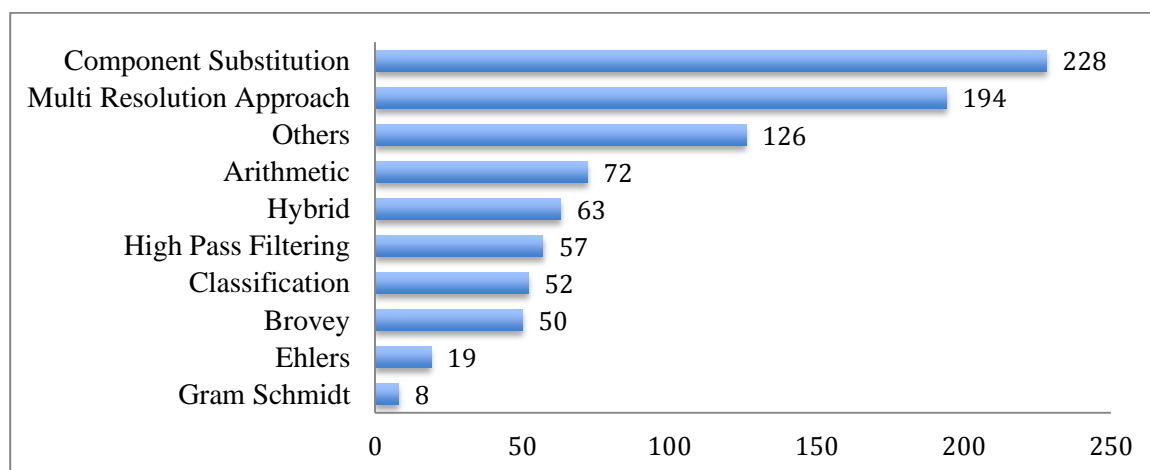
Natural hazard and disaster monitoring benefit from high spatial and spectral resolution RSIF (pansharpening). The information is needed for large areas in great detail [24]. Based on the increased resolution by image fusion spaceborne data can replace costly airborne surveys. Derived multi-temporal products from radar sensors allow operational volcano monitoring and feed information into decision support systems followed by advanced interpretation techniques [25].

## 2.8. Coastal zone management

Coastal ecosystems are under threat due to climate change and anthropogenic activities. Their monitoring and management is important to preserve and restore the habitats for coral reefs, mangroves and other structures, protecting the coast and influencing environmental health. These complex structures and processes need sophisticated data integration and hybrid fusion strategies [26]. Pansharpening techniques support the delineation of coastlines using the Normalized Difference Water Index (NDWI) [27].

## 3. Common RSIF techniques

The new development and improvement of image fusion techniques are strong research fields and are on-going [4]. The evaluation of journal papers to identify the most popular image fusion techniques is displayed in figure 2. Most popular and established since the beginning of RSIF experiments is still the group of component substitution (CS) techniques. It converts the image channels into another data space. Then one of the channels in the new data space is replaced by an additional image. The resulting fused image is created by a reverse transform, converting the data back into the original image space. The most popular and well-known CS is the intensity – hue – saturation (IHS) transform [28]. Other group members are the principal component substitution (PCS) [29] and the Hyperspherical Colour Space (HCS) transform [30].



**Figure 2.** Fusion techniques in number of occurrence in journal publications

Multi Resolution Approaches (MRA) caught up in popularity due to the increase in computer power and the availability in commercial software. MRAs comprise all fusion techniques based on wavelets, curvelets, contourlets or similar decomposition processing. The idea behind it is to decompose the input image into various pyramid levels. Then a high spatial resolution image is either substituted or added to inject spatial detail. The reverse transform returns the fused image. It is a very powerful approach with fusion results of higher quality than ‘simpler’ techniques such as the pure IHS transform or arithmetic fusion. Further information on the categorization and broad description of fusion techniques can be found in [31].

## 4. Discussion and recommendations for further research in RSIF

Observing the continuous publication of new results in RSIF it is obvious that it forms an active, evolving research field. With more and more sensors, providing higher spatial and spectral detail the need for new solutions in handling the volume of data efficiently. Therefore the movement towards feature and decision fusion plus the implementation of hybrid fusion systems including all processing levels becomes inevitable. Based on the questionnaire the identified future challenges in RSIF are

integrating diverse information from sensors, such as multispectral, Light Detection and Ranging (LiDAR) and thermal data at very different resolutions (from less than 1m to 30 m). It is necessary to consider the time difference in data acquisition, which sometimes covers several months to years. There is a need for uncertainty estimation using error propagation. It would be desirable to unify data formats and transformations implemented in different commercial software for a proper integration in a Digital Earth concept. The next logical step on the basis of the research findings presented in this paper is the implementation of guidelines and rules that serve as input for a spatial decision support system.

## 5. References

- [1] Pohl C and Van Genderen J 1998 Review article multisensor image fusion in remote sensing: concepts, methods and applications *International Journal of Remote Sensing* **19** 823-54
- [2] Aiazzi B, Alparone L, Baronti S, Garzelli A and Selva M 2012 *Signal and image processing for remote sensing*, ed C H Chen (Boca Raton, FL, USA: CRC Press) pp 533-48
- [3] Zhang Y and Mishra R K 2014 From UNB PanSharp to Fuze Go – the success behind the pan-sharpening algorithm *International Journal of Image and Data Fusion* **5** 39-53
- [4] Pohl C and Zeng Y 2015 Development of a fusion approach selection tool. In: *International Workshop on Image and Data Fusion*, ed R S a I S International Archives of the Photogrammetry (Kona, Hawaii, USA: ISPRS) pp 139-44
- [5] Pohl C and Yen T L 2014 Compilation of a remote sensing image fusion atlas. In: *35th Asian Conference of Remote Sensing (ACRS)*, (Nay Pyi Taw, Myanmar pp 1-6
- [6] Pohl C 2014 Questionnaire - Compilation of a remote sensing image fusion atlas.
- [7] Gamba P 2014 Image and data fusion in remote sensing of urban areas: Status issues and research trends *International Journal of Image and Data Fusion* **5** 2-12
- [8] Dahiya S, Garg P K and Jat M K 2013 A comparative study of various pixel-based image fusion techniques as applied to an urban environment *International Journal of Image and Data Fusion* **4** 197-213
- [9] Celik T and Kai-Kuang M 2011 Multitemporal Image Change Detection Using Undecimated Discrete Wavelet Transform and Active Contours *Geoscience and Remote Sensing, IEEE Transactions on* **49** 706-16
- [10] Balik Sanli F, Kurucu Y and Esetlili M 2009 Determining land use changes by radar-optic fused images and monitoring its environmental impacts in Edremit region of western Turkey *Environ Monit Assess* **151** 45-58
- [11] Deng J S, Wang K, Deng Y H and Qi G J 2008 PCA-based land-use change detection and analysis using multitemporal and multisensor satellite data *International Journal of Remote Sensing* **29** 4823-38
- [12] Pohl C 1996 *Geometric aspects of multisensor image fusion for topographic map updating in the humid tropics*: International Institute for Aerospace Survey and Earth Sciences)
- [13] Pour A B and Hashim M 2014 Integrating PALSAR and ASTER data for mineral deposits exploration in tropical environments: a case study from Central Belt, Peninsular Malaysia *International Journal of Image and Data Fusion* **6** 170-88
- [14] Langford R L 2015 Temporal merging of remote sensing data to enhance spectral regolith, lithological and alteration patterns for regional mineral exploration *Ore Geology Reviews* **68** 14-29
- [15] Rahman M M, Tetuko Sri Sumantyo J and Sadek M F 2010 Microwave and optical image fusion for surface and sub-surface feature mapping in Eastern Sahara *International Journal of Remote Sensing* **31** 5465-80
- [16] Amorós-López J, Gómez-Chova L, Alonso L, Guanter L, Zurita-Milla R, Moreno J and Camps-Valls G 2013 Multitemporal fusion of Landsat/TM and ENVISAT/MERIS for crop monitoring *Int. Journal of Applied Earth Observation and Geoinformation* **23** 132-41
- [17] Wang L, Tian Y, Yao X, Zhu Y and Cao W 2014 Predicting grain yield and protein content in wheat by fusing multi-sensor and multi-temporal remote-sensing images *Field Crops Research* **164** 178-88
- [18] Johnson B A, Scheyvens H and Shivakoti B R 2014 An ensemble pansharpening approach for finer-scale mapping of sugarcane with Landsat 8 imagery *International Journal of Applied Earth Observation and Geoinformation* **33** 218-25
- [19] Kuria D N, Menz G, Misana S, Mwita E, Thamm H-P, Alvarez M, Mogha N, Becker M and Oyieke H 2014 Seasonal vegetation changes in the Malinda wetland using bi-temporal, multi-sensor, very high resolution remote sensing data sets *Advances in Remote Sensing* **3** 33-48

- [20] Lu D, Li G, Moran E and Kuang W 2014 A comparative analysis of approaches for successional vegetation classification in the Brazilian Amazon *GIScience & Remote Sensing* **1**-15
- [21] Sheldon S, Xiao X and Biradar C 2012 Mapping evergreen forests in the Brazilian Amazon using MODIS and PALSAR 500-m mosaic imagery *ISPRS Journal of Photogrammetry and Remote Sensing* **74** 34-40
- [22] Arenas-Castro S, Julien Y, Jiménez-Muñoz J C, Sobrino J A, Fernández-Haeger J and Jordano-Barbudo D 2013 Mapping wild pear trees (*Pyrus bourgaeana*) in Mediterranean forest using high-resolution QuickBird satellite imagery *Int. Journal of Remote Sensing* **34** 3376-96
- [23] Basuki T M, Skidmore A K, Hussin Y A and van Duren I 2013 Estimating tropical forest biomass more accurately by integrating ALOS PALSAR and Landsat-7 ETM+ data *International Journal of Remote Sensing* **34** 4871-88
- [24] Nichol J and Wong M S 2005 Satellite remote sensing for detailed landslide inventories using change detection and image fusion *International Journal of Remote Sensing* **26** 1913-26
- [25] Meyer F J, McAlpin D B, Gong W, Ajadi O, Arko S, Webley P W and Dehn J 2015 Integrating SAR and derived products into operational volcano monitoring and decision support systems *ISPRS Journal of Photogrammetry and Remote Sensing* **100** 106-17
- [26] Henderson F M, Hart Jr T F, Chasan R and Portolese J 1998 Analysis of optical-SAR data fusion and merged data set procedures in highly developed urbanized coastal ecosystems. In: *International Geoscience and Remote Sensing Symposium (IGARSS)*, pp 1131-3
- [27] Maglione P, Parente C and Vallario A 2015 High resolution satellite images to reconstruct recent evolution of domitian coastline *American Journal of Applied Sciences* **12** 506-15
- [28] Tu T-M, Su S-C, Shyu H-C and Huang P S 2001 A new look at IHS-like image fusion methods *Information Fusion* **2** 177-86
- [29] Yin N and Jiang Q-g 2013 Feasibility of multispectral and synthetic aperture radar image fusion. In: *Image and Signal Processing (CISP), 2013 6th International Congress on*, (Hangzhou, China: IEEE) pp 835-9
- [30] Padwick C, Deskevich M, Pacifici F and Smallwood S 2010 Worldview-2 Pan-sharpening. In: *ASPRS Annual Conference*, (San Diego, California
- [31] Pohl C and van Genderen J 2015 Structuring contemporary remote sensing image fusion *International Journal of Image and Data Fusion* **6** 3-21

## 6. Acknowledgment

This work was supported by the Universiti Teknologi Malaysia under grant Q.J130000. 2709.00K71.