CHALLENGES OF REMOTE SENSING IMAGE FUSION TO OPTIMIZE EARTH OBSERVATION DATA EXPLOITATION

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Abstract

Remote sensing delivers multi-modal and -temporal data. Image fusion is a valuable tool to optimize multisensor image exploitation. It has developed into a usable image processing technique to extract information of higher quality and reliability. Due to the availability of many different sensors and operational image fusion techniques researchers have conducted a vast amount of successful experiments. 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 results it is visible 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 its complexity and variability. This paper reports on the findings of an initiative to streamline data selection, application requirements and the choice of a suitable image fusion technique. All this forms the first step into the development a Fusion Approach Selection Tool (FAST). The project aims at collecting successful image fusion cases that are relevant to other users and other areas of interest. From there standards will be developed that apply to these cases that are valuable contributions to further applications and developments. The availability of these standards will help to further develop image fusion techniques, make best use of existing multimodal images and provide new insights on the processes of the Earth.

Keywords: Remote sensing, image fusion, multisensor image exploitation

Introduction

Image fusion has come a long way from experimental processing trials to an operational image exploitation technique. By definition image fusion combines different images from single or multiple sensors at pixel level to produce enhanced images for image visual and computer-based image interpretation (Pohl and Genderen 1998). Image fusion can produce information that is not available in the single data alone.

Remote sensing image fusion is a widely used methodology to make the most of multisensor remote sensing data. It is meant to combine different satellite images on a pixel by pixel basis to produce fused images of higher value. The value adding is meant in terms of information extraction capability, reliability and increased accuracy. Successful image fusion produces data that results in other, better or additional information that cannot be extracted from each single image alone. Starting off as experimental method image fusion has found its way into commercial software packages and many remote sensing applications (Beiranvand and Hashim 2013, Dahiya et al. 2013, Xin et al. 2013). Based on the fact that different applications require different information derived from remote sensing imagery the user is left with a large choice of processing possibilities. The selection of an appropriate image fusion technique has a great influence on the resulting fused product, which again limits its applicability. The outcome of this study contributes to the establishment of processing strategies in image fusion to help other users and researchers to use image fusion appropriately and further develop this established research field.

With the continuous availability of multisensory images fusion has become commonly used image enhancement approach. In particular the combination of multispectral with panchromatic data, the so-called pansharpening is an accepted tool in the remote sensing community (Alparone et al. 2007, Choi et al. 2013, Ehlers et al. 2010). Even though it is widely used by image providers, software vendors and remote sensing data users there is little knowledge on which technique with which parameters delivers optimized results for a certain application. There is a lack of standardization and users have to develop their own processing strategy for each individual case again and again. Pansharpening forms only one example. Looking at the diverse nature of the different images available today (multispectral, panchromatic, hyperspectral, airborne, spaceborne, optical, microwave, etc.), the increase in spatial resolution (Witharana et al. 2013) and the possibility to access multipolarization SAR images, there are many more options to make use of multimodal imagery (Khaleghi et al. 2013, Zhang 2010). The final outcome of the project aims at providing results from existing, successful image fusion cases in a compilation of case studies that are valuable for future applications of image fusion. The compilation will help to standardize processing flows as well as provide a uniform terminology to the user community.

A major constraint of remote sensing for applications in tropical regions is the almost permanent cloud cover. It is very difficult to obtain up-to-date information from remote sensing satellites operating in the optical part of the electromagnetic spectrum. One option that is being studied since active microwave sensors have become operational is the use of synthetic aperture radar (SAR) images which are independent from daylight and weather conditions. However, the information content of these data is complementary rather than substituting the information from optical remote sensing (Su et al. 2013). Still, optical remote sensing plays an important role here.

The intention of the experiment presented in this paper is to exploit available, cloud-free images to a maximum to obtain the most accurate and reliable information. This paper illustrates with the help of this example the challenges that a remote sensing image fusion user faces and underlines the need of standardized processes in terms of image fusion and quality assessment. The remaining paper starts with a description of the data and study area, followed by a definition of image fusion and fusion techniques. Thereafter the results of the experiment are reported in detail, divided into fusion and classification results. The paper finishes with concluding remarks and an outlook for ongoing and future activities.

Materials and methods used

In Malaysia an effort has been taken to launch a satellite with different orbit characteristics compared to the commonly used sun-synchronous polar orbits. The Malaysian RazakSAT is a Near-Equatorial Low Earth Orbit (NEqO) with a low inclination angle of 9°. This orbit allows 14 overpasses per day over the equatorial region which is one of the criteria to increase the possibility of obtaining images with low cloud coverage. The RazakSAT satellite that operated for about a year after its launch in 2009 contributed high resolution optical images acquired by a pushbroom camera with five linear detectors (one panchromatic, four multispectral) to the EO community (Hashim et al. 2013). RazakSAT was launched as a research and development project. In the meantime, the Malaysian space agency ANGKASA in collaboration with Astronautic Technology (M) Sdn Bhd (ATSB) is preparing the next mission, RazakSAT-2 planned for launch in 2015. In order to enhance the range and quality of applications for RazakSAT-2 the study exploited different image fusion techniques and processed the data further to extract thematic information using multispectral image classification. The results form an excellent example to outline the challenges and benefits of image fusion to provide high quality thematic maps.

Table 1. RazakSAT MAC details

RazakSAT MAC	Band	Spectral Range [nm]	Spatial Resolution [m]
Panchromatic	PAN	510-730	2.5
Multispectral	blue	450-520	5
	green	520-600	5
	red	630-690	5
	NIR	760-890	5

For this paper an example of a multispectral and panchromatic image obtained from RazakSAT has been selected to demonstrate the potential as well as the problems that arise when working with remote sensing image fusion. The selected image covers an area on the west coast of Peninsular Malaysia, north of the heritage city Melaka. The medium-sized aperture camera (MAC) of RazakSAT contains four bands multispectral of 5 m spatial resolution and one band panchromatic of 2.5 m spatial resolution as described in table 1. The data is disseminated in 20 x 20 km scenes taken from the original 20 x 500 km swath.

Figure 1. Multispectral and panchromatic image subset used in this study

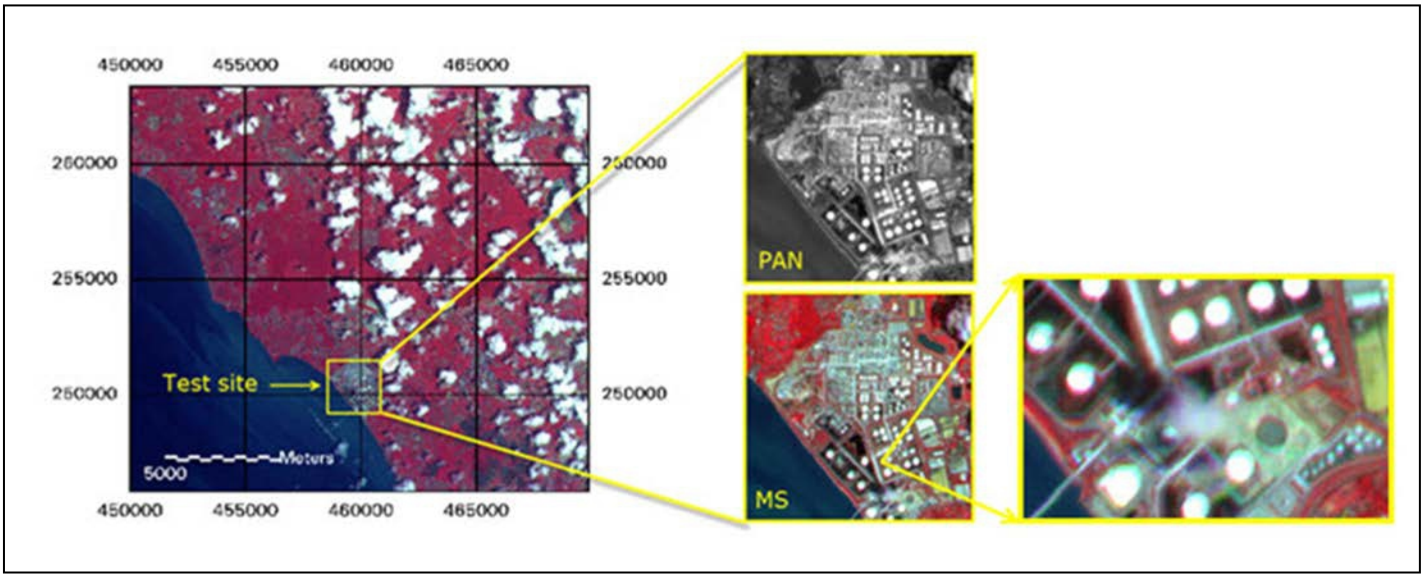

Figure 1 illustrates the location of the RazakSAT scene and the area of the subset taken to produce the fused images and finally the thematic maps. The selected test site for this experiment contains very complex structures of a petroleum storage facility. At the same time the site includes scrub, water bodies, the coastline and parts of the ocean. Due to the complexity of the site the results of these experiments are expected to show abilities and limitations of the various approaches. In addition it is very likely that the approach delivering the best results works for other less complex areas as well.

Prior to image fusion remote sensing images have to be pre-processed to eliminate sensor errors, atmospheric effects and geometric distortions. The image bands that finally enter the fusion process are radiometrically and geometrically corrected and geocoded, meaning that the image pixels in the different bands refer to the same location on the ground. The presented data does not introduce multisensor criteria or problems of multitemporal acquisitions where not only different sensor characteristics influence the images but also the different atmospheric conditions between the two acquisition dates. Regarding the changes on the ground between different dates image fusion can be a useful tool to perform change detection analysis (Zeng et al. 2010).

The issues discussed in this paper exclude influencing factors from the use of multisensor and multitemporal data. Even in this simple single sensor and single date image fusion case the factors that influence the final result are manifold as will be shown from the results.

Image fusion is an established research field that has led to many successful implementations in remote sensing applications. It finds its place amongst the different levels at which fusion of data is possible. The terms commonly used in the remote sensing community vary. Two accepted terminologies are given in table 2. This paper tackles pixel or iconic level fusion issues.

Table 2. Terms commonly used in remote sensing data fusion

Fusion	**Pohl & Genderen 1998**	**Ehlers et al. 2010**
Level	Pixel	Iconic
	Feature	Symbolic
	Decision	Knowledge

In the past 15 years many techniques have evolved to fuse remote sensing images on a pixel level. There is a trend to adaptations of established approaches to account for sensor particularities, local context and image characteristics that are relevant to the information that the user anticipates to extract. In addition the tremendous increase in available image bands and spatial resolution of the imagery demanded a progress in fusion techniques. From the traditional Intensity – Hue – Saturation (IHS) transform that was able to handle three bands, other techniques matured, such as the generalized IHS or Ehlers fusion, the latter using the Fast Fourier Transform (FFT) to extract and enhance the spatial content of the high resolution image to be inducted to the lower resolution image(s). Some of the developments have found their way into commercial software (e.g. Ehlers Fusion - EF, Gram-Schmidt method - GS, University of New Brunswick fusion – UNB); others are used by image vendors or form a product by themselves (e.g. Fuze Go^{TM}, hereafter called Fuzego) (Alparone et al. 2007, Fuze Go 2013, Huang et al. 2013, Karathanassi et al. 2007, Zhang 2010).

The presented example uses optical remote sensing images in five bands (four multispectral and one panchromatic). Therefore the selection of fusion techniques that make sense reduce to pansharpening algorithms. This would be a first step in the definition of a processing flow and a standardization process. The performance evaluation is carried out using two different multispectral image classification algorithms, i.e. the Maximum Likelihood Classifier (MLC) and the Support Vector Machine (SVM). The reason for selecting these two classifiers lies in the fact that the MLC is a widely applied and known classifier, simple and with low computational effort. SVM in contrary is much more complex and computationally intensive. However, it achieves much better results even if only a few training samples are used. So this makes these two classifiers very suitable for this experiment.

For the production of thematic maps using multispectral classification the input images should contain the original spectral response of the land use / land cover. The performance of a spectral classifier improves with the separability of the different classes based on the different radiometric information contained in the different bands of the sensor acquisition. Therefore it is crucial to preserve the spectral information inherent in the image if the further information extraction relies on image classification. As a consequence the selection of suitable fusion techniques should give preference to methods that are proven to maintain spectral integrity while at the same time improving spatial detail. Both aspects describe a high quality pansharpening approach.

Other researchers in this field have conducted a lot of case studies to evaluate the performance of different pansharpening algorithms. Table 3 compiles a list of techniques commonly used. From top to bottom the listed techniques evolve from traditional, generic techniques to more sophisticated hybrid, adaptive and context based methods that naturally lead to better results.

For this publication two fusion techniques for pansharpening have been selected to conduct the experiment. These two techniques, namely Ehlers fusion and Fuzego, show promising results in the literature and from own experiments. They are both following the trend of adaptive and context based approaches that deliver higher quality fused images. Traditional methods had to be developed further with the upcoming new satellite generation providing data at much higher spatial and spectral resolutions, e.g. IKONOS, QuickBird, RapidEye, and others.

Table 3. List of popular pansharpening algorithms (adapted from Zhang 2008)

Pansharpening Algorithm	**Abbreviation**	**Description**
Intensity Hue Saturation	IHS	RGB to IHS, replacement of I by high res. image, reverse IHS
Principal Component Substitution	PCA	PCA, replacement of PC1 by high res. image, reverse PCA
Brovey Transform	BT	Multiplication of multispectral (MS) bands with high res. image, division by sum of MS bands
High Pass Filtering	HPF	HPF on high res. image, adding achieved spatial information to MS bands
Wavelet based methods	MRA	Wavelet transform to decompose high res. image into low res. image with high res. features, replacement of low res. image by bands of low res. MS bands, reverse wavelet transform
University of New Brunswick	UNB	Least square technique plus statistic approach toe create relationship between high res. and low res. bands to fuse
Ehlers	Ehlers	IHS fusion, spatial information extracted in feature space using Fast Fourier Transform
Fuze Go^{TM}	Fuze Go^{TM}	Commercial UNB algorithm

Ehlers fusion is based on a very common image fusion method called Intensity – Hue – Saturation (IHS) transform. Traditionally this method converted three input bands from the Red – Green – Blue (RGB) color space to IHS. In IHS space the Intensity (I) is replaced by the high resolution panchromatic channel. The reverse IHS transform produces the fused image. Ehlers discovered that the traditional use of IHS is not suitable for many applications, in particular if spectral content preservation is required. His research team advanced this method by transferring the panchromatic image (P) and the intensity component of the multispectral input data into the frequency domain using a Fast Fourier Transform (FFT). From the power spectrum of both images an appropriate low pass filter for I and a high pass filter for the high resolution P are designed (Ehlers 2004). The filtering takes place in the frequency domain to extract the spatial detail that is then to be introduced into the low resolution data by replacing I through the sum of the low pass filtered I_{LP} and the high pass filtered P_{HP}. A reverse IHS produces the fused image in RGB space. Within the processing flow bands that are being replaced are adjusted in terms of histogram matching to optimize the result.

Fuzego is a commercialized pansharpening approach that has evolved from an algorithm developed by the University of New Brunswick called UNB (Fuze Go^{TM} 2013). The research group of Zhang realized that new sensors appeared to require new adaptations of existing methods due to the fact that the wavelength of the panchromatic channels extended from the visible to the near infrared range (Zhang 2004). Therefore they developed a new approach that uses statistics to avoid color distortion and the operator and data set dependency, the latter being one of the major issues of the research project of which this experiment forms one example. Fuzego uses the least square technique to find the best fit between the bands being fused and to adjust the weighting of each individual band contribution. It applies a statistic approach to create a grey value relationship of all input bands to avoid redundancy and automate the fusion process.

Obviously there would be many other suitable candidate techniques. However, for the purpose of this study the use of two advanced and up-to-date techniques is sufficient. It should be mentioned that each fusion technique inherits the possibility of fine-tuning its parameters which again multiplies the number of options to produce fused images.

Achievements and discussion of results

The first outcome of the experiments conducted using the above described image fusion techniques is a series of fused images. They contain contributions of the lower spatial resolution multispectral data and the high spatial resolution panchromatic channel. This can be observed in a comparison of the original data with the fused images (see figure 2).

The visual inspection suggests that the Fuzego algorithm disturbs the color content while achieving a very high spatial detail. The Ehlers method on the other hand stays closer to the original spectral information with a little less spatial crispness than the Fuzego method.

Results can only be discussed if the processing allows an objective and comprehensible evaluation. In this respect a visual inspection of the images obtained (be it the fused data or the classified map) can show a potential. The verification of the results requires quality parameters. In the literature many different so-called quality indices for imagery can be found. Also, in the frame of pansharpening many solutions have been suggested. A discussion of the usefulness of the different indices is not subject of this paper. A few researchers have followed the path of investigating the usefulness of a result to a certain application which should be considered a priority in remote sensing image processing. Therefore, it was decided to take the fused images and continue the processing flow using the two different classification algorithms based on the same training samples and control points. The 200 control points to produce an accuracy measure were randomly selected over the entire thematic map.

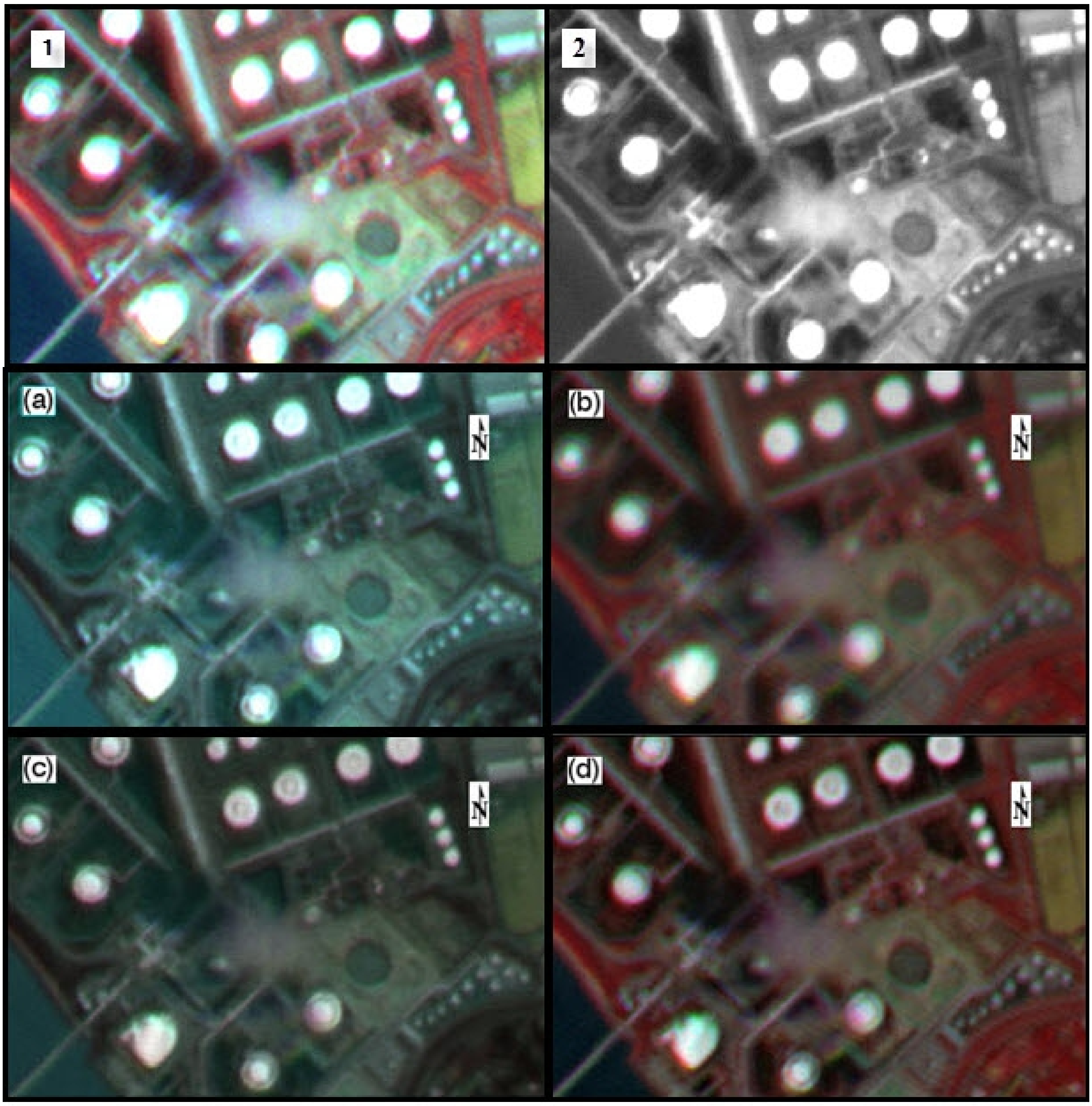

Figure 2. Comparison of original images - (1) multispectral and (2) panchromatic bands with fusion results: (a) Fuzego without emphasis on spatial content (b) Ehlers fusion focusing on spectral content preservation (c) Fuzego with spatial enhancement (d)

Ehlers fusion with emphasis on spatial content

The second stage of results contains the classification results of the different fused images and the results of classifying the original data. Since two different classifiers (MLC and SVM) have been tested the same data set becomes available for both of the classifiers. From the classification process itself, considering the separability of classes in this data set, eight elements were identified: Reservoir, petroleum storage/pipeline, building, pavement, bare soil, water, scrub and road.

The results of the two different classifiers applied to the Fuzego fused images are depicted in figure 3. The statistical evaluation of the classification performance is summarized in table 4.

Obviously, inherent cloud cover in the processed subset of the test site image causes artifacts (lower part of the classification results). The clouds lead to artifacts that influence the different classifiers with a different. An example is the clear picture of the petroleum storage infrastructure (tanks and pipelines) in the MLC image while the SVM classifier provides much too much detail with wrongly classified pixels (petroleum partly classified as building). This is also partly related to the image quality of this particular RazakSAT data set. The original data shows striping effects that are enhanced using image fusion and sophisticated classifier algorithms. The pier leading into the ocean was identified best by the SVM classifier in the spatially enhanced Fuzego image. Logically, different data and applications require different algorithms.

Table 3. Comparison of MLC and SVM classification results of fused images

Image classified	**Overall accuracy MLC [%]**	**Overall accuracy SVM [%]**
Original	84.51	89.37
Fuzego spectral	**92.59**	94.57
Fuzego spatial	38.98	**94.58**
Ehlers spectral	56.12	86.70
Ehlers spatial	65.14	89.70

The statistical evaluation summarized in table 4 provides more insight in the classification results. Apparently Fuzego beats the Ehlers method in terms of overall classification accuracy, i.e. MLC 92.59% vs. 65.14% and SVM 94.58% vs. 89.70%, respectively for the best results achieved by each fusion technique.

If another area of the image is chosen and the focus of the application is oriented towards petroleum storage facility mapping the images show different results (see figure 4). There is no 'negative' influence of clouds and as for the petroleum storage facilities the classification algorithms perform well. The best "visual performance" is the use of Ehlers fusion, tuning its parameters to extra spatial enhancement rather than preserving spectral qualities.

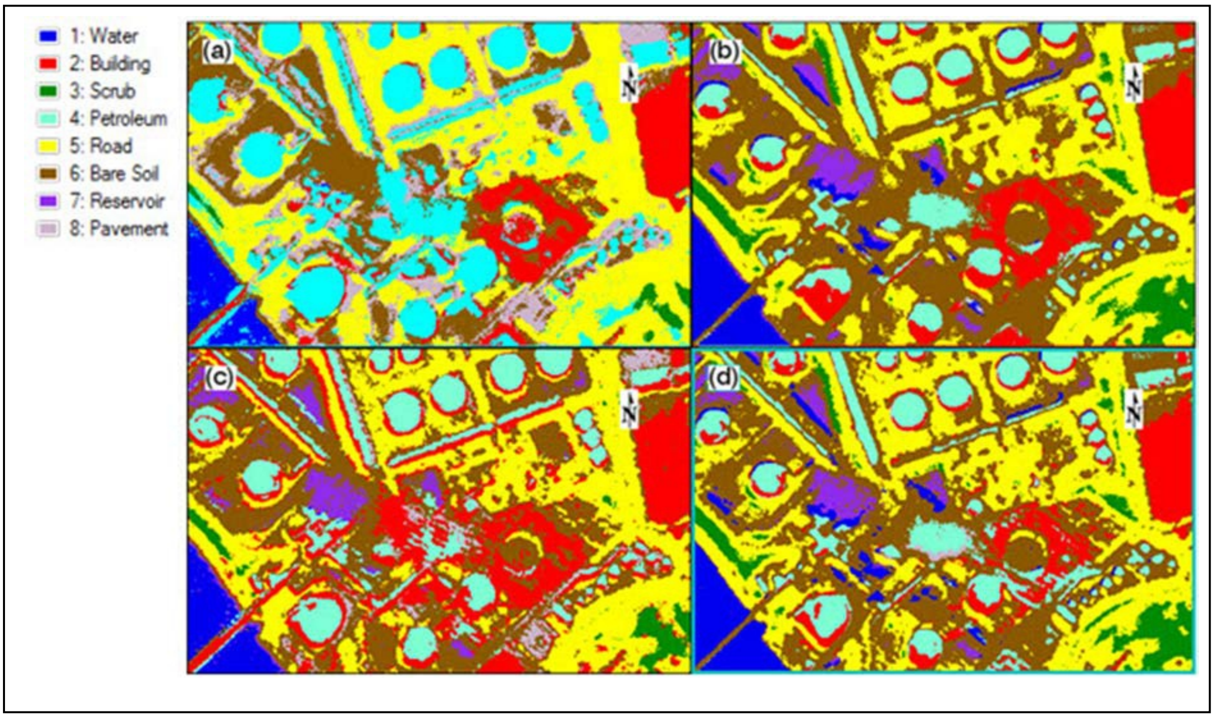

Figure 3. Fuzego classified fused images using MLC and SVM classifiers: (a) Fuzego spectral MLC, (b) Fuzego spatial MLC, (c) Fuzego spectral SVM and (d) Fuzego spatial SVM

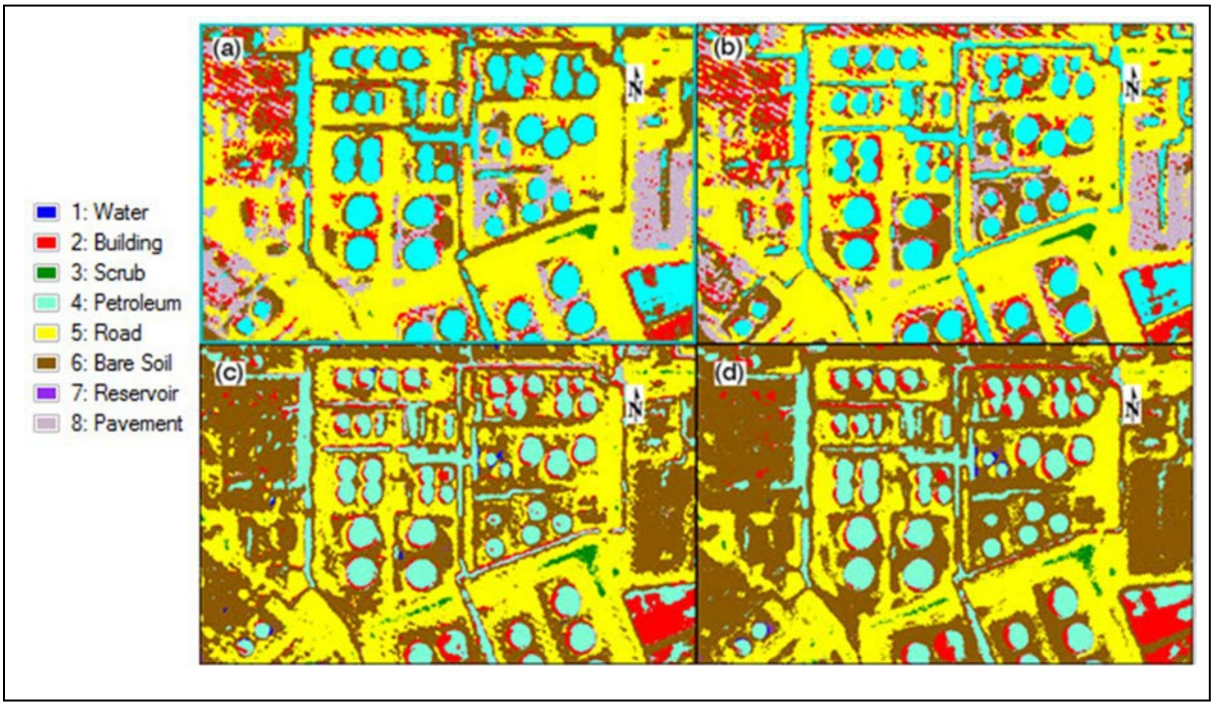

Figure 4. Comparison of Fuzego and Ehlers fusion for Petroleum facility mapping using the SVM classifier: (a) Ehlers spectral, (b) Ehlers spatial, (c) Fuzego spectral and (d) Fuzego spatial

This contradicts the result of the overall accuracy statement discussed previously. This implies that an image fusion technique per se is not generally good or bad. A precise application framework has to be known prior to performing any processing on the images. An awareness of key parameters for the application is essential.

Conclusion

The results of the experiment show that RazakSAT imagery has the potential for map updating applications. Using appropriate image fusion techniques and adequate fine tuning of the individual techniques an enhancement of features can improve the results obtained from the imagery. The cloud cover problem in tropical areas will not be solved but available imagery with little cloud cover can be used to an optimum following this approach.

The lessons learned from this experiment proof that there are many quality influencing parameters that the user of remote sensing image fusion has to be aware of. A professional application of these technologies requires expertise in the sensor characteristics and performance, appropriate pre-processing, image fusion and proper knowledge of the application, in particular with respect to using remote sensing. Only then the resulting data makes sense and can be used by others, i.e. introduced in a geographical information system (GIS) to model the Earth surface. In conclusion there is no such thing as an absolute statement for the performance of a certain fusion technique.

Remote sensing provides a vast amount of Earth observation images that needs to be processed and value-added in order to be useful for the end user (government, industry, university, citizen, etc.). Remote sensing image processing software has integrated in the past decade new tools for multisensor image fusion. In the meantime the user has access to more than 20 commercialized image fusion techniques plus the option to tune the parameters of each individual technique to match the anticipated application. This leaves the operator with an uncountable number of options to combine the remote sensing images, not talking about the selection of the appropriate images, resolution and bands. Image processing and in particular multisensor image fusion is a machine and time consuming endeavor.

Future activities will add further selection criteria to provide an image fusion framework to be discussed internationally. There are two steps for the implementation: 1. Compilation of image fusion atlas to provide guidelines for useful image fusion applications and approaches and 2. Development of a Fusion Approach Selection Tool (FAST) containing a decision feature plus the option to preview fusion results based on different applications. It will be designed to provide the user with a FAST overview of processing flows to choose from to reach the target. The concept of FAST uses the available images, asks for application parameters and desired information and processes this input in order to come out with workflow to quickly obtain the best results. It will optimize data and image fusion techniques and provide an overview on the possible results from which the user can choose the best one by visual inspection. FAST will enable even inexperienced users to use advanced processing methods to obtain better results. The development of FAST is an ongoing research project.

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