Increasing the potential of Razaksat images for map-updating in the Tropics

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Abstract. The high resolution remote sensing satellite Razaksat is a unique satellite system since it operates in a near-equatorial orbit with a low inclination angle of 9. In a first study scientists have found the images suitable for feature extraction in an urban context to update the road network at a scale of 1:25,000. In a preceding project for land cover mapping the research team used the five available bands of Razaksat imagery. This paper describes a continuation of the former study in which techniques are used to fuse the high resolution panchromatic band with the lower resolution multispectral bands. The study investigates the impact of pansharpening on the spatial and spectral content of the data. It compares various image fusion techniques and their impact on land use classification results. The image fusion techniques investigated are Brovey Transform, High Pass Filtering, Principal Component Analysis, Wavelet Approach and Ehlers Fusion. The images are classified using a maximum likelihood classifier. The results show that the use of an appropriate image fusion technique with adequately tuned parameters can improve quality of the resulting thematic maps.

1. Introduction

Optical remote sensing has its constraints in the humid tropics due to the frequent cloud cover in this region. The Malaysian Near-Equatorial Low Earth Orbit (NEqO) Razaksat launched in 2009 with a low inclination angle of 9° enables 14 overpasses per day over the equatorial region. Designed for high resolution terrain mapping Razaksat is very suitable for land use mapping. The study described in this paper focuses on value adding processing techniques to get the most out of the optical images.

Image fusion and pansharpening in particular has found its place in remote sensing image exploitation. In the case of Razaksat providing high resolution panchromatic and multispectral image data single-sensor pansharpening can be performed. The challenge in image fusion is to choose from countless possibilities of fusing the images not even considering the different pre-processing options and tunable parameters of the individual fusion techniques.

Razaksat data is not well-known yet in the research community. With the upcoming Razaksat-2 to be launched within the next two years there is a need for further research in its potential. Using image fusion to obtain more reliable and accurate information is therefore one issue to be looked at. Exploring existing fusion methods and evaluating land use classification accuracies that can be achieved this research aims at customizing the work flow for optimum information extraction from Razaksat images. This paper describes part of a larger research project in the context of image fusion strategies. It concentrates on the suitability of different image fusion techniques for multispectral image classification. The next section gives an overview on the test site and the data used in this study. Section three introduces the issues in image fusion and the experiments conducted, followed by the land use classification performed. Section four reports the results obtained from image fusion and classification including a detailed accuracy assessment. The paper concludes with a discussion of the results in the context of digital earth.

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2. Test site and data used

The research test site is located in Malaysia, on the west coast of the Malayan peninsular near Sungai Udang, about 10 km north of the cultural heritage town Melaka. This site was chosen because the data was available and already pre-processed for purposes of geometric and radiometric evaluation of the satellite sensor [1]. Using the available research results from that previous project brings up the issues of digital earth in the context of knowledge about the information extraction procedures and the accuracy of the provided information. Data sharing and further advances in the diversity of information as well as the increase of accuracy are only possible if ancillary data is provided with the digital information stored.

2.1. Test site

The test site that has previously been used to evaluate the quality of the Razaksat medium-sized aperture camera (MAC) contains very diverse features and is very challenging. Apart from natural land cover types (water, trees, scrub) it has many man-made features, such as roads, pavement, buildings and many petroleum storage facilities that also extend in height. In addition, petrol pipelines in various dimensions connect the storage facilities, crossing roads that lead to the various facilities and buildings. The area is dominated by the Malaysian Petronas Refinery site Melaka.

2.2. Remote sensing data

The MAC delivers five bands: four bands multispectral (MS: blue, green, red, near-infrared) at 5 m resolution and one panchromatic band (PAN: 510 – 730 nm) at 2.5 m resolution. The radiometric resolution is 8 bit. A full swath covers 20 x 500 km, the scenes are distributed as 20 x 20 km scenes. For this study the subset was taken out of the full scene and covers a 95% cloud-free region of 2.5 x 2.5 km. The location of the study site and an overview of the remote sensing image subsets are given in figure 1.
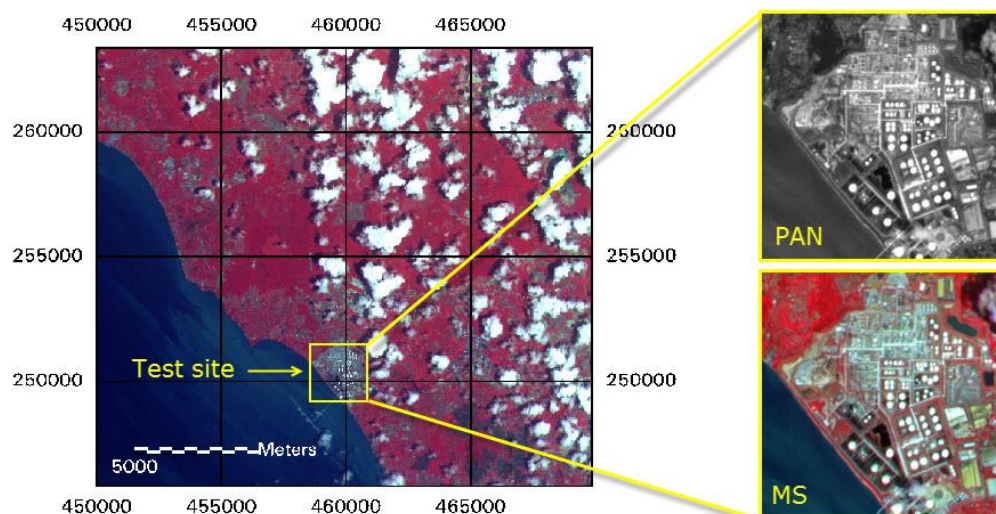

Figure 1. Location of the study site showing the MS & PAN subset.

3. Image fusion and its impact on information extraction

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 [2]. Image fusion can produce information that is not available in the single data alone.

3.1. Pre-processing

For image fusion the two or more original images have to be pre-processed in order to be combined. The images have to be at least co-registered or, more advanced, ortho-rectified, i.e. geometrically

corrected and rectified using a digital elevation model (DEM) [3]. In this research the pre-processing of the subset image containing the four MS and one PAN band comprised of a radiometric correction to eliminate sensor-induced striping effects due to misregistration and an ortho-rectification to provide a geometrically corrected image with the characteristics of an image map. The obtained accuracy lies within sub-pixel accuracy using a third-order polynomial function for transformation [1].

3.2. Image fusion techniques

The variety of image fusion techniques is manifold. In the last fifteen years, since the first publication of an extensive review on image fusion techniques by the first author, the methodologies used move towards adaptive fusion techniques that consider local context and sensor characteristics to obtain best results. Just to provide an example the widely used Intensity – Hue – Saturation (IHS) technique started as a method to perform pansharpening, i.e. increase the spatial resolution of multispectral data using a high resolution panchromatic band, applicable to a maximum of three MS bands. The technique converts three channels (red, green and blue – RGB) into the IHS colour space, replaces the intensity component using the high resolution channel and returns the fused image by an inverse transform back to RGB.

A first variation of this method is to match the high resolution panchromatic band with the intensity of the IHS transformed image and then perform the inverse transformation. Further developments of this technique provide possibilities of using more than three bands as multispectral input to the process. This modified IHS is called GIHS = Generalized IHS and allows the introduction of weights for the various channels [4].

A new technique called the Ehlers Method further developed this idea. One main requirement for the new technique was its effect on the increase in spatial resolution while at the same time maintaining the spectral integrity of the data. The Ehlers method is capable of reaching this goal by using the Fast Fourier Transform (FFT) on the Intensity component (I) and the panchromatic image (PAN). The FFT spatial components are enhanced in low pass filtering I and high pass filtering PAN followed by an addition of I and PAN. The result I^* replaces the original I and the I^*HS is reverse transformed into RGB space to form the fused image [5].

The developments that can be seen regarding the IHS technique also resulted for other previously established common methods in adapted and modified versions, e.g. colour normalization based on Brovey (CN), University of New Brunswick algorithm (UNB) and the adapted multiresolution analysis (MRA) techniques based on wavelets, just to name a few.

For this research five different fusion methods are explored: (1) Brovey transform, (2) high pass filtering (HPF), (3) principal component analysis (PCA), (4) MRA and (5) Ehlers method in three different variations are used. The choice of techniques is a subset of an ongoing research project that explores a wider range of possibilities to provide an image fusion strategy for remote sensing users. The challenge in image fusion is to identify the "right" method for the images and application targeted. This can be quite a demanding task.

3.3. Land use classification for mapping

An example of successful classification of a fused data set using a standard and an expert classification approach has been published by [6]. The previously published work on the data set used in this research conducted a classification experiment using a PCA fused image of MS and PAN. The authors selected six land use classes and applied a combination of both unsupervised and supervised maximum likelihood classification [1]. After thoroughly having studied the test site and the data set for this research project another set of land use classes comprising eight elements is produced. It was decided to use a modified version of land use classes due to the fact that the image fusion techniques used in this study revealed different abilities in the identification of features in the image: Reservoir, petroleum storage/pipeline, building, pavement, bare soil, water, scrub and road.

For the classification of the fused images a supervised maximum likelihood (ML) classifier is applied to all images using the same training areas. A separate set of 200 randomly selected independent control points is identified to assess the accuracy of the obtained results.

4. Image fusion and land use classification results

The set of fused images that enters the classification process is shown in figure 2. The image subsets contained in figure 2 are taken from the processed 2.5 x 2.5 subset described in section 2.2.

4.1. Fusion results

From visual inspection of the fused images compared to the original false colour composite MS, displayed in figure 2a, it is immediately apparent that depending on the pansharpening technique the spectral content of the data is modified. The worst multispectral representation results from the rather traditional Brovey transform. As could be expected the HPF method (figure 2c) provides the highest spatial detail, in particular since the other methods used are directed towards spectral preservation. Best colour representations by visual assessment are wavelet and Ehlers fusion in figures 2e and 2f, respectively.
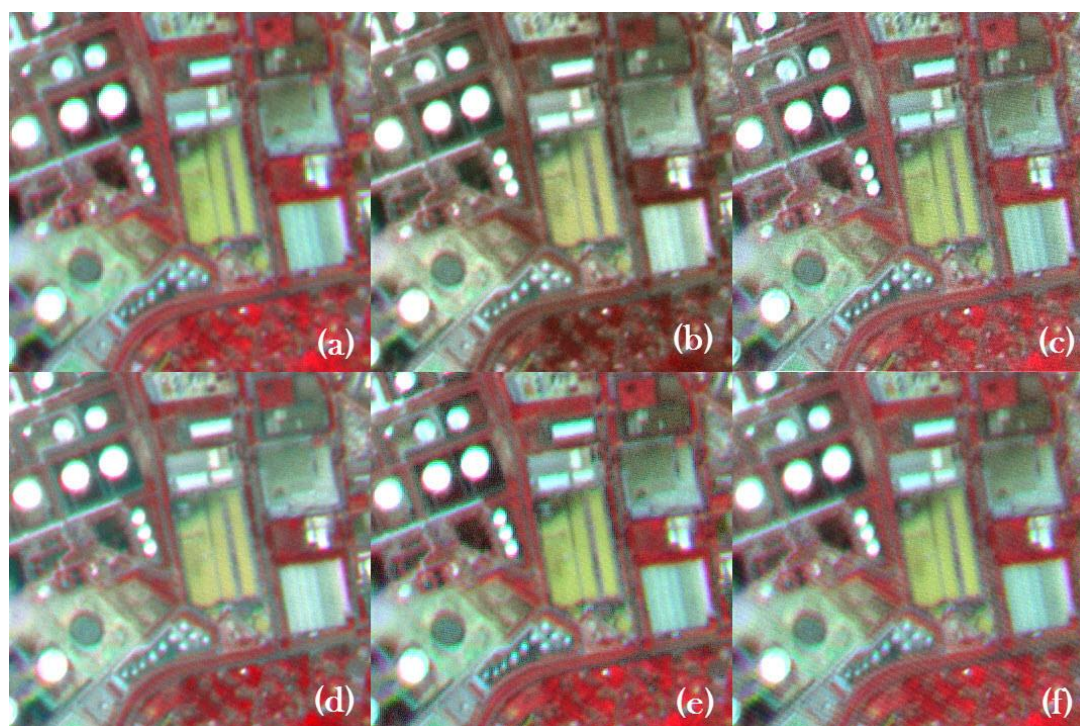

Figure 2. Image fusion results combining MS (a) and PAN using (b) Brovey, (c) HPF, (d) PCA, (e) MRA and (f) Ehlers method.

4.2. Classification for evaluation

In the literature many quality assessment methods have been introduced, ranging from defining the spatial improvement, through assessment of the spectral enhancement achieved to measuring both, spectral and spatial advancement of the data [7], [8], [9] and [10]. For this research a different approach is selected in order to be able to work on automated procedures such as land use classification. Therefore the data is further processed based on the classification approach mentioned in the previous section. Before classification the signature separability using the original and the five fused images is evaluated. The original image provides an average divergence value of 240, the Ehlers fusion method results in the best class separability (286). The worst separability is obtained from Brovey transform (151). This confirms the visual evaluation of the fused images.

For verification and accuracy assessment a set of 200 random points are selected on the classified image. The ground truth is provided from the previous research [1]. The results of the ML classification of the original multispectral bands are summarized in table 1. The classification reached an overall accuracy of 80% with 160 correctly classified pixels. As expected the classes reservoir, water and scrub have the highest classification accuracy (enhanced values in bold). More difficulties are encountered with correctly classifying roads, bare soil, pavement and buildings. In particular the

buildings of this test site (values marked italic) are difficult to classify using this approach because they have very different roof slopes and types: tiles and various types of metal roofs.

Table 1. Results of classifying the original four multispectral bands using ML.

Classes	No. Ref. Pixels	No. Classified Pixels	No. of correctly classified	Producer's accuracy [%]	User's accuracy [%]	Kappa
Reservoir	4	5	4	**100.00**	**80.00**	**0.7959**
Petroleum	27	25	18	74.07	80.00	0.7682
Building	14	16	8	*64.29*	*56.25*	*0.4565*
Pavement	8	10	7	87.50	70.00	0.6875
Bare Soil	40	41	28	70.00	68.29	0.6037
Water	56	56	55	**100.00**	**98.21**	**0.9754**
Scrub	37	33	33	**89.19**	**100.00**	**1.0000**
Road	14	14	7	69.23	64.29	0.4681
Overall	**200**	**200**	**160**	**80%**		**0.7565**

A comparison of the results of the classifications of the fused data is shown table 2. Amongst the classification results of the different fused images the Ehlers method performed best with 82.5% overall accuracy and 165 correctly classified pixels. The worst result is obtained from the Brovey transformed image (68% overall accuracy, 137 correctly classified pixels). This is due to its known impact on spectral content.

Table 2. Comparison of classification results of fused images using ML.

Image classified	No. of correctly classified	Overall accuracy [%]	Kappa
Original	**160**	**80.00**	**0.7624**
Brovey	*137*	*68.00*	*0.6519*
HPF	141	70.50	0.6466
PCA	147	73.50	0.6803
Wavelet	141	70.50	0.6477
Ehlers	**165**	**82.50**	**0.7889**

5. Discussion and conclusion in the context of digital earth

As part of a larger project the results of this study provide a first glimpse on the possibilities and constraints of working with Razaksat imagery using advanced processing methods to improve information flow to digital earth. Working with optical data in the tropics is a challenge in itself due to the cloud cover problem. Having access to Razaksat with its special orbit configuration to increase re-visiting time is only part of the solution. Making most of the existing "cloud-free" data is therefore a must. This research provides ways to exploit the data for land use classification. It was possible to increase the quality of the classes as well as the classification results using an appropriate image fusion technique. In this case the Ehlers fusion method adapted to the type of area (industrial site with natural context) using the tradeoff parameters to focus on spectral enhancement rather than spatial performed best with an overall accuracy of 82.5%. The definition of an appropriate workflow prior to processing the imagery requires knowledge in all related fields: remote sensing, image fusion and land use classification. 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. That is why this project forms part of a larger initiative to streamline data selection, application requirements and the choice of a suitable image fusion technique. In a next step the methodology developed in this research has to be tested on other sensors to enable application guidelines for other researchers. This research is ongoing and will focus in future on the application of more sophisticated classification methods (e.g. support vector machine)

and the use of cloud-independent synthetic aperture radar (SAR) imagery. Apart from its independence of cloud cover SAR images contain complementary information that can help the information extraction process and enrich the resulting data.

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