MULTISENSOR IMAGE MAPS: A CONTRIBUTION TO TOPOGRAPHIC MAP UPDATING IN THE TROPICS

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ABSTRACT

In many Developing Countries, especially in the humid Tropics, frequent cloud cover is a major drawback to topographic map updating using visible and infrared remote sensing. This is one of the main reasons why topographic maps at 1:100,000 scale and larger are often outdated. The study, described in this paper, investigated the possibilities of fusing up-to-date spaceborne microwave data with existing images from optical sensors for topographic map updating. A key issue researched was the influence of geometric distortions and corrections of remote sensing data on the results of pixel based digital image fusion in relation to topographic map updating. After having terrain-geocoded and radiometrically enhanced imagery from Landsat, SPOT, ERS-1 and JERS-1 the data were fused applying colour transformation techniques as well as statistical or arithmetic methods. Initially, the image fusion was implemented in images covering a test site in the north of The Netherlands in order to calibrate specified combinations and techniques in a rather flat area. With the experience gained, the remote sensing data acquired over the research site were processed. The research test site is located in a typical Developing Country in the humid Tropics, on the mountainous south-west coast of Sumatra in Indonesia. The results of the various applied techniques and image combinations were evaluated with reference to their capability to overcome the cloud cover problem and their usefulness to update Indonesian topographic maps at 1:100,000 scale. New combinations of techniques and images were developed as result of an optimisation process with respect to revising existing topographic maps. The research produced two prototypes of annotated 1:100,000 scale image maps containing fused, cloud-free optical/microwave imagery.

KURZFASSUNG

In vielen Entwicklungsländern, jedoch ganz besonders in feuchtropischen Gebieten, ist die Aktualisierung von topographischen Karten mit Hilfe von optischen Fernerkundungsdaten durch die permanente Wolkenbedeckung besonders eingeschränkt. Dieses ist eine der Hauptursachen dafür, daß topographische Karten im Maßstab von 1:100.000 häufig extrem veraltet sind. Die hier beschriebene Studie beschäftigte sich mit der Untersuchung von Möglichkeiten der Radarfernerkundung im Verband mit der digitalen Fusion von Radar- und optischen Bilddaten, um topographische Karten zu aktualisieren. Eine Kernfrage war der Einfluß von geometrischen Verzerrungen und deren Korrektur auf die Ergebnisse der pixel-basierten Fusion mit Hinblick auf die Revision von topographischen Karten. Nachdem die Szenen der Satelliten Landsat, SPOT, ERS-1 und JERS-1 geokodiert und radiometrisch verbessert wurden, sind die Bilder unter der Verwendung von verschiedenen Techniken, wie z. B. Farbtransformationen oder arithmetischen Verknüpfungen von Bildkanälen, kombiniert worden. Zunächst wurden die der aus Literatur bekannten Fusionsmethoden und Bildkombinationen anhand eines flachen Gebietes im Norden der Niederlande kalibriert, für welches ausreichend aktuelles und großmaßstäbiges Kartenmaterial zur Verfügung stand. Die hier gewonnenen Einsichten wurden danach auf ein Forschungsgebiet übertragen. Bei der Region, die für diese Fallstudie ausgesucht wurde, handelt es sich um ein typisches Entwicklungsland in den Tropen, an der gebirgigen Südwestküste von Sumatra in Indonesien liegend. Die Ergebnisse der vielen verschiedenen Bildkombinationen und angewandten Techniken wurden hinsichtlich ihres Nutzens für die Fortführung von Indonesischen topographischen Karten im Maßstab von 1:100.000 untersucht. Ein besonderer Aspekt war ihre Wirksamkeit bezogen auf die Wolkenbedeckung. Mit der Absicht, die bekannten Fusionsmethoden und Bildpaare im Hinblick auf Kartenaktualisierung zu optimieren, wurden neue Kombinationen von Szenen und Techniken entwickelt. Das Endprodukt dieser Forschung bilden zwei Prototypen von Satellitenbildkarten, die mit fusionierten, wolkenfreien, multisensoralen Daten hergestellt wurden.

1. INTRODUCTION

In Developing Countries, topographic maps at scales of 1:100,000 and larger are often outdated, if they exist at all. Topographic mapping and map updating has its major constraint in the heavy and regular cloud cover which disables visible and infrared (VIR) sensors to acquire data from the Earth's surface. According to a study by Gastellu-Etchegorry and Ducros-Gambart (1991), the mean probability of acquiring a remotely-sensed image of Central Sumatra with less than 30% cloud cover is only 7%. An operational topographic mapping programme or monitoring of land cover changes with optical data is therefore almost impossible. Since the launch of remote sensing satellites carrying microwave sensors on board, synthetic aperture radar (SAR) data are continuously available. Independent from weather or daylight the active SAR sensors provide information at any time of the year. Therefore, the combination of up-to-date radar images with existing optical data for topographic map updating in Developing Countries was investigated. The research presented in this paper used the idea of integrating data from SPOT and Landsat with ERS-1 and JERS-1 SAR to overcome the cloud cover problem. Additional benefits of fusing disparate remote sensing data were the increased interpretation capabilities and improved reliability of the results due to the complementary nature of microwave and optical images. While optical data represent the reflectance of ground cover in visible and near-infrared, the radar is very sensitive to the shape, orientation, roughness and moisture content of the illuminated ground objects.

2. RESEARCH OBJECTIVES AND METHODOLOGY

The main objective of the research was to investigate the geometric aspects of image fusion for map updating in the humid Tropics. A relevant factor in this respect was to overcome the cloud cover problem in optical remote sensing data using microwave imagery. The project aimed at the production of digital image maps containing fused image data from different optical and radar remote sensing satellites. The image data were geocoded and projected to the Indonesian map projection system (UTM - ID74). Based on the selected operational remote sensing satellites LANDSAT, SPOT, ERS-1 and JERS-1, the resulting image maps were produced at 1:100,000 scale. It is commonly accepted that the scales between 1:50,000 and 1:250,000 can be achieved with LANDSAT, SPOT and ERS-1 (Albertz and Tauch, 1994; Dowman et al., 1993; Doyle, 1984; Jacobsen, 1992). The research focused on the geometric aspect of image fusion evaluating the impact of various parameters on the fused imagery in terms of geometric accuracy. A second interest was to find the optimum combination of satellite data in terms of spatial and spectral resolution. This included a study on image enhancement possibilities in the frame of pixel-based image fusion. The following list comprises parameters which were of interest to the research:

- Satellite and sensor characteristics;
- Geocoding;
- Time;
- Observed ground.

There is a variety of methods to combine different remote sensing data. The methods identified and selected during the research period are pixel-based and included colour transformation techniques (e.g. Red Green Blue *RGB* colour composites, Intensity Hue Saturation colour transformation *IHS*) as well as statistical/arithmetic methods (e.g. Principal Component Analysis *PCA*, band combinations, ratios). These techniques require a highly accurate, co-registered or geocoded data set. Especially, the geocoding of SAR data played an important role because SAR images are subject to severe geometric distortions based on the steep viewing geometry of the sensor. Figure 1 displays a flow chart that describes the image processing of the remote sensing data to obtain fused image maps (Pohl and Genderen, 1995).

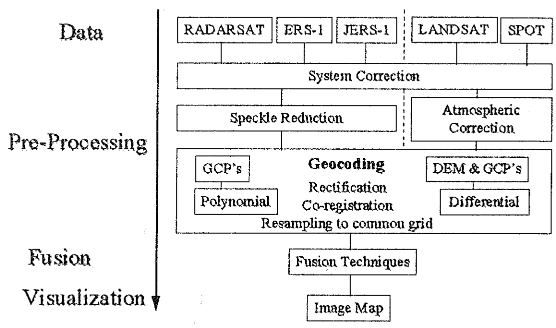

Figure 1: Flow chart for fused image map production

After having acquired the image data, they were pre-processed to remove system induced as well as externally influenced radiometric and geometric distortions in order to provide compatible data as input to the image fusion process. The geocoded data were then introduced to the actual image fusion process. An evaluation of the resulting fused imagery considered the topographic map updating capabilities of the produced fused images. The best results related to map updating (perceptibility of topographic features and geometric accuracy) were printed as image maps including some annotation such as a coordinate grid and a legend.

3. TEST SITES AND DATA DESCRIPTION

The research relied on the processing of data sets from two different test sites. The calibration test site is located in the north of the Netherlands, bordered by geographic latitudes 52°45'-53°30'N and longitudes 5°00'-6°15'E. It consists mainly of agricultural areas, some urban areas, water bodies and a coastal zone including the island of Ameland as shown in Figure 2.

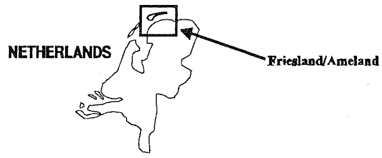

Figure 2: Location sketch of calibration test site in the Netherlands

The actual research test site is located on the south-west coast of Sumatra in the Province of Bengkulu, Indonesia. It extends from 3°15' to 4°45'S and 102°00' to 102° 30'E. Sumatra is an equatorial tropical island with a climate that is characterised by constant high temperatures and extremely abundant rainfall, well distributed over the year. With relief ranging from sea level to 2,400 metres, and complex land forms, tropical forests, and mixed agricultural systems, the research site was selected as a representative, typical problem area which experiences extensive cloud cover. Figure 3 indicates the location of the research test site in the western part of the country.

Figure 3: Location of research test site, Bengkulu - Indonesia

Among the selected sensors that provided the remotely sensed data were ERS-1 SAR, JERS-1 SAR, SPOT HRV and Landsat TM. The sensors, supplying data of different spatial and spectral resolutions, cover areas ranging from 3,600 km^2 (SPOT) to 34,225 km^2 (TM).

For both test sites a full set of images from each sensor was collected. In the case of ERS-1, a multi-temporal data set was requested in order to be able to fulfil the research objectives and test the influence of multi-temporal and multi-orbit ERS-1 SAR data on image fusion. The data of the calibration test site in the Netherlands consisted of multiple ERS-1 SAR scenes acquired during the first half year of 1993. The optical data set contained SPOT XS data from 1986, SPOT PAN dated 1989 and a Landsat TM scene from 1992.

Concerning the research site in Indonesia, it was much more difficult to obtain the remote sensing data due to a number of constraints. It was problematic to find optical remote sensing data from SPOT and Landsat with less than 30% cloud cover. In the case of Landsat TM one scene could be identified in the archive that was not fully covered by clouds collected in 1990. In terms of SPOT XS the only useful scene dated back to 1987. Based on a request, further scenes could be acquired in the summer of 1994. Together with a three dates coverage of ERS-1 SAR and two JERS-1 SAR coverages with a time difference of one year the data set was completed. It was necessary to acquire two JERS-1 SAR scenes per coverage which were used to build a mosaic in order to cover the entire research test site.

4. IMAGE PROCESSING

First, the Dutch data was processed in order to calibrate the image fusion approach and to identify suitable techniques for the cloud removal without having to deal with terrain induced distortions. In addition, up-to-date topographic maps of 1:50,000 and larger scale were available to verify the findings. The experience gained from these experiments was later adapted and applied to the Indonesian area.

4. 1 Radiometric Pre-Processing

An atmospheric correction was applied to the optical remote sensing data in order to remove haze effects from the imagery. Because no ancillary information, necessary for correct atmospheric modelling, were available, only an approximation (histogram modification) for this correction was applied. The optical remote sensing data of the calibration site (Netherlands) was not affected by striping. The Landsat TM scene of the research site in Indonesia contained 16-lines striping. One of the SPOT XS scenes had a striping appearance too. For destriping, each pixel was adjusted based on a comparison of the local mean of the line to an unweighed local mean of those closest neighbouring lines. But it has to be taken into account that this *destriping* is a cosmetic act that should be performed after spectral interpretation or processing of the images (Crippen, 1989). However, the destriping was done prior to image fusion to take into account the radiometric characteristics of the VIR data alone which cannot be separated from SAR in fused imagery.

The SAR data were reduced from 16- to 8-bit applying linear scaling in consideration of the mean and standard deviation of the particular images in order to reduce the data volumes. In addition, a speckle reducing filter (3x3 Gamma MAP) was applied for the spatial enhancement of the data (Shi, 1994).

4. 2 Geocoding

The Dutch data set was geocoded using well-distributed GCP's and polynomial rectification because the terrain height influence on the geometry was negligible. The largest height difference reaches ± 10 m in that region.

This was different for the Indonesian data set where sophisticated sensor models in combination with a DEM were applied to geocode the images (Cheng et al., 1995). The GCP's used in the polynomial model as well as in the sensor model, to improve the model parameters, were identified in existing topographic maps at 1:50,000 scale. This limited the accuracy of the geocoded data to the geometric accuracy of the map material used. As a result of further investigation the Indonesian data set was geocoded to an estimated precision of ± 50-100 m.

4. 3 Multisensor Image Fusion

The techniques considered in the research presented in this paper were pixel based because of the purpose of image map production using multisensor VIR and SAR data. The fusion of only VIR data was not considered for two reasons: 1. The subject has been studied extensively by other researchers (e.g. Carper et al., 1990; Chavez et al. 1991; Cliche et al. 1985; Franklin and Blodgett, 1993; Mangolini et al., 1993; Pellemans et al., 1993; Rothery and Francis, 1987; Shettigara, 1992; Welch and Ehlers, 1987) and 2. VIR image fusion is not very likely to solve the cloud cover problem. The actual implementation of image fusion techniques consisted of colour composites, arithmetic band combinations, IHS colour transformations, mosaics and a mixture of techniques. It was anticipated to optimise image combinations and fusion techniques for the purpose of topographic map updating.

5. RESULTS

This section summarises the scientific findings. They refer to the image fusion environment as well as to the advantages and disadvantages of techniques and image combinations examined.

5. 1 Pre-Processing

All sensor-specific corrections and enhancements of image data have to be applied prior to image fusion since the techniques refer to sensor-specific effects. After image fusion the contribution of each sensor cannot be distinguished or quantified in order to be treated accordingly. A general rule is to first produce the best single sensor geometry and radiometry (geocoding, filter, line and edge detection, etc.) and then fuse the images. Any spatial enhancement performed prior to image fusion is of benefit to the resulting fused image. An advantage is the possibility of filtering and enhancing the data during the geocoding process to avoid multiple resampling. The data has to be resampled to the pixel spacing required for the desired image fusion.

The type of radiometric enhancement required depends on the nature of the area being studied. An example is the high pass filtering, successfully implemented in the processing of the Dutch data set. However, it led to poor results in the case of Bengkulu in Indonesia due to the extreme variations in elevation and the ground cover.

The importance of geometric accuracy to avoid artefacts and misinterpretation should not be underestimated. Pixels registered to each other should refer to the same object on the ground. This implies that the data should be geocoded with an accuracy of < 1 pixel. Therefore the DEM plays an important role in this process. As found for the Indonesian example, the SAR data still contains shifts of one or more pixels as a result of the poor DEM and map quality. The need for DEM's of high quality and appropriate grid spacing is therefore evident.

5. 2 Techniques and image combinations

The following list of statements categorised by technique conclude the findings of the research discussed.

RGB

The following list provides a summary of the main features of image fusion using the RGB method:

- Digital numbers in single images influence the colours in the RGB composite. This implies the following considerations:
    1. Histogram stretching of single channels influences the visibility of features in the final colour composite.
    2. Inversion of image channels might be desirable to assign colour to features.
    3. RGB channel assignment significantly influences the visibility of features and visual interpretation by a human interpreter (blue = water, green = land, etc.).
- The technique is simple and does not require CPU time-intensive computations.
- RGB overlay prevents the contribution of the optical imagery from being greatly affected by speckle from SAR.

Band Combinations

The following conclusions were drawn by visual interpretation from the image fusion using band combinations:

- The fusion of ERS-1 SAR with SPOT PAN data improves the interpretation of the SAR data.
- Subsequently, it helps applications that benefit from the interpretation of up-to-date SAR data (urban growth, coastal zone monitoring, tidal activities, soil moisture studies, etc.).
- The resulting fused image depends very much on the appearance and content of the SAR data.
- As a result, the SAR data have to be selected according to the interest of the application.

- Influence of terrain on SAR backscatter reduces the suitability of the data for recognition of the features, such as roads, cities, rivers and others.
- The fusion of SAR with PAN using this type of band combination is not recommended in tropical areas with mountainous terrain.
- This type of technique does not solve the cloud cover problem because the range of digital numbers corresponding to clouds is preserved and even enhanced if not excluded from the calculation.

Brovey Transform

The images obtained from this special ratioing and multiplication technique (ERDAS, 1995) showed the following important elements:

- It preserves the spectral content of the VIR data while introducing the texture from SAR.
- The resulting image is not quite as sharp as the one produced from multiplication only.
- The water/land boundaries are well defined in the fused images; it allows one to assign colour to the water currents (e.g. tidal inlets).

PCA

PCA processing to fuse optical and microwave image data resulted in the following conclusions:

- Radiometric pre-processing plays an important role in relation to the spectral content of the fused image.
- Appearance of SAR significantly influences fused VIR/SAR image in terms of feature visibility.
- As a consequence, features that are detectable on SAR data can be introduced to the VIR data by image fusion to complement the data (e.g. soil moisture, urban area, oceanographic objects).
- XS/ERS fused imagery shows more details than TM/ERS based on the higher spatial resolution of XS compared to TM.

For SAR combinations using PCA the following remarks are valid:

- Principal component SAR images show a potential for topographic mapping.
- This is valid in particular for the 3D impression of topography and change detection.
- Possibilities have not been fully explored, e.g. combination of principal components with optical data.

IHS

The IHS combinations are characterised by:

- The capability of allocating data from the SAR to cloud covered areas without having to identify the clouds in an earlier stage.
- The speckle is preserved from the SAR data in the fused image.
- Similarities with the Brovey transformation in terms of spectral content of the imagery.
- Reduced spatial detail compared to original optical data.

Mosaic

The mosaic has an important position amongst the image fusion techniques as far as cloud removal from VIR and the replacement of radiometrically distorted SAR data is concerned:

- The result depends very much on the quality of the cloud/shadow mask designed for the mosaic. This is a critical point for the optical imagery. The identification of foreshortening, layover and shadow areas in the SAR is based on DEM calculations and pure geometry. These products are often delivered with the SAR image itself (e.g. GIM* from ESA).
- It is essential to match the histograms of the various input data to each other.
- It can be used in combination with any other image fusion technique.

Combinations of techniques and images

The best combinations of techniques and images were achieved with *'triple sensor image fusion'*. This refers to the fusion of SPOT XS and PAN with ERS-1 SAR. The images were developed during the process of improving published techniques and combinations. Their characteristics are:

- Fused data contains the multispectral information from XS, the spatial resolution from PAN and the texture from SAR.
- The road network is clearly visible, the same is valid for housing structures in the urban area.
- Field boundaries are enhanced, variations inside the fields as well as differences to the field arrangements compared to the XS are visualised.
- Speckle does not dominate the image as seen in other fused examples.

6. CONCLUSIONS

The results of the presented research prove the usefulness of fusing microwave remote sensing data with complementary optical imagery as far as topographic map updating is concerned. From the findings a first image map prototype was designed and printed at BAKOSURTANAL in Indonesia. The image map contains fused, multisensor, multitemporal satellite images from SPOT XS, ERS-1 SAR and JERS-1 SAR covering the research site in Indonesia in which all the clouds have been removed.

The study contributed to operationalize VIR/SAR image fusion in presenting a processing line considering current operational satellite systems delivering images

* Geocoded Incidence angle Mask

on a regular basis as input into a more rapid map updating programme in Developing Countries than is presently utilised. With upcoming improved sensors, the importance of multisensor image fusion and interpretation will increase and open new possibilities in Earth observation for operational applications in the Developing Countries as well as for the protection and development of the Earth's environment.

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Abbreviations:

IJRS ... International Journal of Remote Sensing

PE&RS ... Photogrammetric Engineering and Remote Sensing