# A GEOMETRICAL MODEL FOR A PRECISE REGISTRATION OF SAR AND OPTICAL IMAGERY BY MEANS OF ADJUSTMENT TECHNIQUE

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## 1. ABSTRACT

In this paper, we propose and introduce a novel and automatic technique for a precise fusion of spaceborne SAR and optical imagery. The approach is mainly based on feature extraction techniques which will be separately carried out in both data sets. Features once extracted are commonly described by their imaging attributes and additionally by their location in the object space. The entire geometrical characteristics of the radar and optical sensor, such as the attitude and the orientation data as well as the ground information described in a digital height model, are considered in order to derive a precisely registered optical image to an already precisely geocoded SAR image. Especially the fact of using the three-dimensional geometrical information of the features in combination with their imaging parameters made it possible to apply a three-dimensional adjustment algorithm to minimise remaining residuals between corresponding features. For that reason, the widespread and established adjustment technique is utilised for solving the optimisation problem. By taking the fully geometrically modelling into account, the parameters of the height model as well as the ephemeris of the used sensor orbits, can be introduced into the adjustment calculation. Finally it is our target to estimate and to improve them, too.

Within recent years, the importance of high resolution remote sensing data has grown more and more. Specifically, the combination of multi-modality data like high resolution SAR and optical imagery enables new possibilities for different kinds of approaches and analyses. At this stage, the applications range from the field of change detection [5], monitoring and assessing naturally or man-made influenced catastrophes [9] to techniques dealing with object extraction and 3D reconstruction [6]. For these issues, images acquired by active SAR sensors such as TerraSAR-X and passive optical sensors like RapidEye has the potential to considerably support this development. Still a fusion of both images types allows the use of the complementary and redundant information of a scene. Anyway, images acquired by a SAR sensor have different geometric and radiometric properties as images acquired by an optical sensor [8]. Due to these differences the high-precision fusion of SAR and optical imagery is a great challenge.

In order to combine both kinds of imagery, different researches were done and several approaches were deveoped, recently. But the most of the existing fusion techniques of SAR and optical data are often accomplished on a manually or semi-automatically way [6]. Only a few automatic approaches are existing currently [1, 2]. Nowadays, the image registration can be roughly distinguished into feature-based and intensity-based techniques. In general, the estimation of registration parameters are often based on the question, how well can the so called on ground two-dimensional-features like rivers, streets, etc. be correctly extracted? Since the mentioned features are not much influenced by sensor viewing geometry and because they are appeared in a reasonable size and homogeneous intensity, the intensity based methods are often deployed in order to fuse SAR and optical data [7]. Nevertheless, the outcomes of those approaches mostly suffer a loss in accuracy, because they are only working on a two-dimensional level and does not include any information about the geometry, like the viewing geometry of both sensors or the object geometry. Moreover, the sensor geometry has a huge influence on the appearance of represented objects in the images [7]. For that reason, both data sets are not exactly co-registered on pixel level mostly. Furthermore, the mitigation of the fusion accuracy will be supported by inaccuracies in the sensor orbits, such as the sensor attitude and orientation, as well as some variations included in the digital surface model which is used for geocoding the images. But often these additional geometrical parameters and informations have been never or only seldom integrated into the co-registration approach to fuse SAR and optical data. The approach proposed in [6] shows an example for a successful integration of the sensor geometry.

In order to overcome these difficulties we aim to develop an automatic and feature-based approach for a precise fusion of SAR and optical data by means of a geometric modelling within an adjustment algorithm. The test data consist of SSC images from TerraSAR-X sensor captured in Stripmap mode (3.3 m resolution) and of optical images from RapidEye sensor acquired in nadir direction (6.6 m resolution) over the city Potsdam, Germany. The whole processing chain is decomposed in several parts. The first part deals with the geocoding of both imagery. Here, the SSC data as well as the optical data have to be projected onto a single digital elevation model (DEM), given by the SRTM-X band mission.

The fully-geometric modelling also considers information about the sensor's orbits and attitude, their viewing geometries and their orientations. Particularly, the different viewing geometries of both sensors are accounted for during registration onto the DEM [3, 4]. Hereinafter more precise orbits of the TerraSar-X sensor are calculated by the German Research Centre (GFZ) and are used. During this processing step a pre-process both images before further processing is deployed, in order to reduce the noise level and to treat the speckle effect.

After the ortho-rectification process some residuals are always remaining between the roughly registered and overlaid images. The reasons include different viewing geometries of both sensors, objects not included in the DEM and variations in the orbit parameters. Residuals remaining are treated and refined using feature extraction and optimization algorithms in the following parts. Hence, the line features to be extracted are treated separately. Line features are more comfortable to extract, because projected man-made objects can be often found in large numbers in both images. Also, several useful and established edge detectors, like the Canny edge detector for optical images, already exist. Accordingly, in the field of edge detectors for polarimetric SAR data, similar investigations have been conducted and are promising. The output of the feature extraction step are binary maps showing the extracted ones. Once extracted, they are described by their image parameters and their three dimensional coordinates in the object space. Assuming, if an ideal geocoding has been conducted, every corresponding feature is overlaying onto the DEM in the object space.

According to a final minimization of residuals remaining between already roughly registered and ortho-rectified images, a comparison between extracted features in terms of a correspondence analysis have to be carried out. Such a correspondence analysis calculates a probability for feature correspondence based on similarity measures between each of them and is needed in the following optimisation process. Here, both images are treated jointly for a first time. Image and geometrical parameters of the features as well as the geometric information of both sensor models, such as the sensor attitude and the precise sensor orbits, describe an overdetermined problem. This information builds up a functional model, where the feature parameters are the observations and can be geometrically formulated as functions of the unknowns, which include the object space coordinates and the refined orbit and sensor parameters. Additionally, the functional model can be extended by equations where the observed DEM heights are expressed as the unknown feature heights. This enables the enhancement of DEM heights. All relations are then put into an adjustment algorithm, such as widely used least square method, in order to find an optimal estimated solution for the residual registration errors.

The proposed approach especially the adjustment calculation allows us to comprise geometrical feature and sensor parameters together within the co-registration process. So we expect to determine precisely co-registered and fused orthoimages, more accurately estimated sensor orbits in addition to an improvement in the initially used DEM.

Within the experimental studies, the adjustment calculation, the main component of the feature- and geometrically-based co-registration approach, was tested with the TerraSAR-X and optical RapidEyedata mentioned above. It turned out, that the implementation of the adjustment is feasible and promising together. However, efficient and reliable automated feature extraction and similarity measuring techniques have to be introduced in the next steps. The first results of applying the adjustment calculation for co-registration of SAR and optical data will be reported in the final paper.

## 2. BIBLIOGRAPHY

[1] M. Ali, D., A. Clausi, "Automatic registration of SAR and optical band remote sensing images" *Proceedings of the joint IEEE International Geoscience and Remote Sensing Symposium IGARSS 2002*

[2] P. Dare, I. Dowman, "An improved model for automatic feature-based registration of SAR and SPOT images" *ISPRS Journal of Photogrammetry & Remote Sensing,* Vol.56, pp. 13 – 28, 2001

[3] M. Eineder, N. Adam., (2005), “A maximum-likelihood estimator to simultaneously unwrap, geocode and fuse SAR interferograms from different viewing geometries into one digital elevation model” *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 43, No. 1, pp. 24 – 36, 2005

[4] O. Hellwich, H. Ebner, “Geocoding SAR interferograms by least squares adjustment” *ISPRS Journal of Photogrammetry & Remote Sensing,* Vol.55(4), pp. 277 – 288, 2000

[5] F. Orsomando, P. Lombardo, M. Zavagli, M. Costantini, “SAR and optical data fusion for change detection” *IEEE Urban Remote Sensing Joint Event, Conference Proceedings*, pp. 1 – 9, 2007

[6] H. Sportouche, F. Tupin, L., Denise, “Building extraction and 3D reconstruction in urban areas from high-resolution optical and sar imagery” *IEEE Urban Remote Sensing Joint Event, Conference Proceedings*, pp. 1 - 11, 2009

[7] S. Suri, S. Tuermer, P. Reinartz, U. Stilla, “Registration of high resolution SAR and optical satellite imagery in urban areas” *ISPRS Commissions I2, I4, IV/2, VII/2 Workshop “High resolution Earth Imaging for Geospatial Information”*, 2009

[8] J., D. Wegner, “Automatic fusion of SAR and optical imagery” *Diplomarbeit, IPI, CNES, CS, Hannover*, 2009

[9] S. Yonghua, L. Xiaojuan, G. Huili, Z. Wenji, G. Zhaoning, “A study on optical and SAR data fusion for extracting flooded area” *Geoscience and Remote Sensing Symposium, IGARSS 2007 IEEE International*, pp. 3086 – 3089, 2007