**PFG 2016 / 1, 005–015**
Stuttgart, February 2016

**Article**

# Automatic Generation of Orthorectified High Resolution Satellite Imagery – a Case Study for Saudi Arabia

Muhamad Alrajhi, Riyadh, Saudi Arabia & Christian Heipke, Hannover

**Keywords:** Orthophotos, satellite imagery, high resolution, image matching

**Summary:** The Ministry of Municipal and Rural Affairs (MOMRA) is responsible for the production, maintenance and delivery of accurate geospatial data for all urban and rural settlements in the Kingdom of Saudi Arabia. The fast urbanization requires up-to-date information, which is a major challenge. High resolution satellite imagery presents a novel and promising data resource for geospatial data update. It is well-known that a satellite image, if georeferenced using the vendor-provided rational polynomial coefficients (RPC), often displays X- and Y-coordinate biases of several pixels. Ground control points (GCP) are typically required to achieve an accuracy at pixel level. The collection of the 3D coordinates of GCP and their corresponding image coordinates is a time consuming and cost intensive manual process.

The primary objective of this research is to use image matching between existing orthophotos and the satellite images, georeferenced with RPC instead of GCP, in order to automate and speed up the orthorectification process. Based on a series of practical experiments using imagery from GeoEye and IKONOS, the potential of automated matching between aerial and satellite images using the well known Speeded-Up Robust Features (SURF) algorithm for the described task is investigated. The matched points serve as a basis for transforming the satellite orthophoto to the aerial orthophoto using a 2D affine transformation.

This research has led to the development of a simple and efficient tool for satellite imagery with a ground sampling distance of 50 cm to 1 m to be used for updating geospatial information that meets MOMRA accuracy standards for 1:10,000 scale mapping. The process completely eliminates the need for GCP. About 12 to 15 satellite images are routinely being processed on a workstation in a single day. The implementation of this tool at MOMRA greatly enhances its ability to quickly respond to urgent needs for updated geospatial data.

**Zusammenfassung:** *Automatische Erzeugung orthorektifizierter hoch aufgelöster Satellitenbilder – Pilotprojekt für Saudi Arabien*. Das Ministry of Municipal and Rural Affairs (MOMRA) ist für die Erstellung, Laufendhaltung und Bereitstellung von genauen Geoinformationen für alle städtischen und ländlichen Siedlungen des Königreichs Saudi Arabien verantwortlich. Die schnelle Urbanisierung erfordert aktuelle Informationen, was eine große Herausforderung darstellt. Hoch aufgelöste Satellitenbilder stellen eine neue, viel versprechende Datenquelle für die Aktualisierung räumlicher Daten dar. Bekanntlich zeigen Satellitenbilder, die mit Hilfe der von den Satellitenbetreibern bereitgestellten Rationalen Polynomkoeffizienten (RPC) georeferenziert wurden, oft Systematiken in den X- und Y-Koordinaten im Bereich mehrerer Pixel. Typischerweise werden Passpunkte benötigt, um eine Genauigkeit im Bereich eines Pixels zu erzielen. Die Bestimmung der Passpunktkoordinaten im Bild- und Objektraum ist ein zeitaufwändiger und kostspieliger manueller Prozess.

Das wesentliche Ziel der hier vorgestellten Arbeiten ist die Nutzung von Bildzuordnungsverfahren zwischen existierenden Orthophotos und den mit RPC georeferenzierten Satellitenbildern anstelle der Passpunkte, um die Orthoprojektion zu automatisieren und zu beschleunigen. Auf der Grundlage einer Reihe praktischer Experimente mit Daten der Satelliten GeoEye und IKONOS wird das Potenzial des bekannten Speeded-Up Robust Features (SURF) Algorithmus für die gestellte Aufgabe untersucht. Die zugeordneten Verknüpfungspunkte dienen als Eingangswerte für eine 2D Affintransformation zur Verbesserung der Position des Satellitenbildes.

Die Forschungen haben zur Entwicklung einer einfachen und effizienten Software für die Orthoprojektion von Satellitenbildern mit einer Bodenauflösung im Meterbereich geführt. Die Software wird für die Aktualisierung räumlicher Daten genutzt, die die Anforderungen von MOMRA an Kartierungen im Maßstab 1:10,000 erfüllt. Der


DOI: 10.1127/pfg/2016/0285 1432-8364/16/0285 $ 2.75

Prozess benötigt keinerlei Passpunkte. 12 bis 15 Satellitenbilder können pro Tag routinemäßig auf einem Arbeitsplatz prozessiert werden. Die Implementierung in MOMRA verbessert die Möglichkeit, schnell auf dringende Bedürfnisse im Hinblick auf aktuelle räumliche Daten reagieren zu können, erheblich.

## 1 Introduction

Up-to-date geospatial data play a key role in decision making, planning and sustainable development of any geographic region. A most essential need is to provide timely supplements to existing data. Rapid development of infrastructure, high rate of growth and fast changes in urban and rural areas are the major challenges to maintaining currency in a national geospatial database. These developments call for alternative procedures for economic, accurate and rapid geospatial database updating. As a case study Saudi Arabia presents an example which can provide sufficient material to analyse and develop general updating procedures, which can be used globally.

If the existing topographic maps are not very old and only about 10% to 15% of the features have changed, it is uneconomical to map the entire area through a new aerial survey. In such a case, an alternate methodology that allows the incorporation of only the changes into the existing database is faster and, consequently, more economic. Hence, satellite image based mapping can be considered as an alternative to ground and aerial survey.

The objective of this research is to devise, implement and test a methodology for rapid mapping from recent high resolution satellite imagery (HRSI) which eliminates manual work. The first step consists in georeferencing the images based on vendor-provided rational polynomial coefficients (RPC) and height information. In this article, *georeferencing* only refers to a transformation of satellite images using vendor-provided RPC and a DTM. *Orthorectification* denotes the more precise process including either ground control points or the described matching procedure. Since RPC are typically not accurate enough, control is needed to refine the results. This control is established by image matching between the georeferenced satellite images and existing aerial orthophotos.

The remainder of the paper is organised as follows: section 2 discusses prior work; section 3 contains a detailed description of the devised methodology. In section 4 we present the test data used in our study and report the experimental results. Section 5 concludes the paper.

## 2 Related Work

### 2.1 *Georeferencing and Orthorectifying High Resolution Satellite Images*

A review of the literature can be summarized as follows:

- The feasibility of topographic mapping using currently available HRSI has been clearly demonstrated (Gianinetto 2008, Li & Batchvarowa 2008, Holland et al. 2006).
- The basic challenge of sensor orientation of HRSI has largely been solved in previous research (Di et al. 2003, Tao & Hu 2002).
- It has been shown (Fraser & Yamakawa 2004, Grodecki & Dial 2003) that GCP are needed to supplement the vendor-provided RPC to achieve sub-metre positional accuracy required for mapping at large scales from HRSI. Some isolated studies (e.g. Fraser et al. 2002) attempt to establish some correlation between the number of GCP and the resulting map accuracy.
- It is widely recognized that the collection of 3D coordinates for the GCP and their identification in the imagery are the most arduous and time consuming steps in the whole process. Consequently, efforts have been undertaken to automate image orientation using database information. For aer-

ial images, only the contribution by Läbe (1999) using the system AMOR (Automatic Model-based Orientation) reported success. Others (e.g. Karjalainen & Kuittinen 1999, Jedryczka 1999, Pedersen 1999) describe semi-automated interactive solutions, which had less success in operational environments.

More recently, aerial images have been oriented using positioning and attitude information from systems like GPS and inertial measurement units (Blázquez & Colomina 2012). There is, however, a need for seeking alternative methods for the automatic orthoprojection of HRSI.

## 2.2 *Image Matching of Aerial and Satellite Images*

Image matching has been widely investigated over the last decades and is currently an operational tool for image orientation and the derivation of digital terrain and surface models in photogrammetry and remote sensing (Heipke 1997). In the context of this paper image matching can be employed to substitute the needed GCP by matching the satellite image to an aerial orthophoto.

For image orientation, procedures based on distinctive invariant features, have been reported to be considerably successful in recent

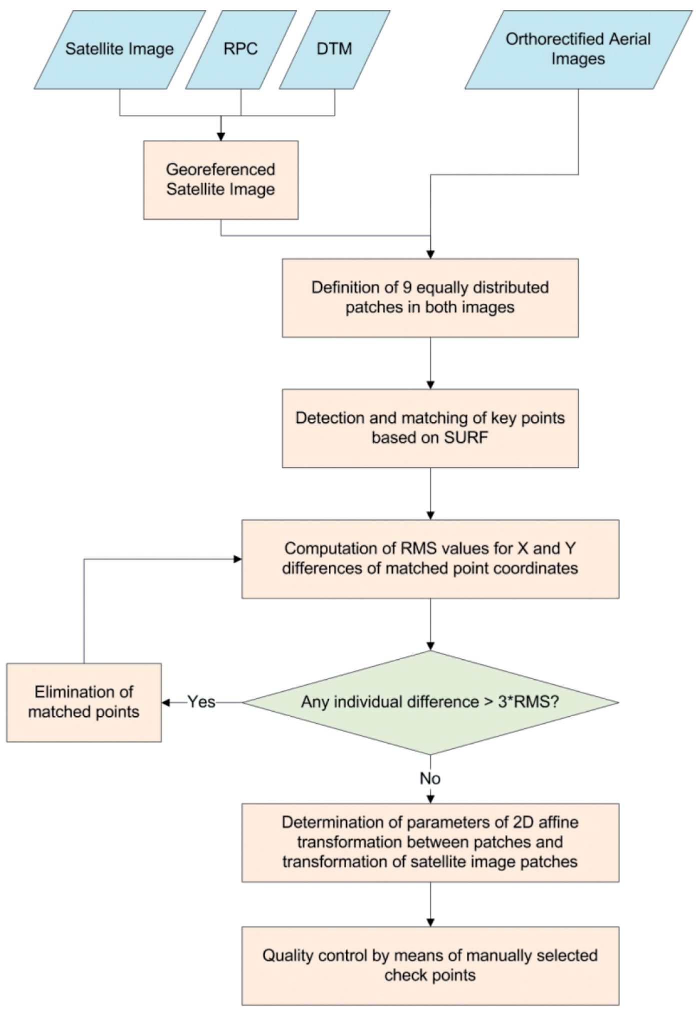


**Fig. 1:** Workflow diagram.

years. These features need to be invariant to image scale and rotation, limited changes in 3D viewpoint, noise, and changes in illumination. Examples for such routines include the Scale Invariant Feature Transform (SIFT – Lowe 2004) and the Speeded-Up Robust Features (SURF – Bay et al. 2008). Both detectors consist of three steps: feature detection, feature description, and feature matching. As shown in many investigations (e.g. Juan & Gwun 2009), SIFT and SURF are equally robust, but SURF is computationally much faster. Consequently, SURF has been selected for this research.

## 3 Methodology

As mentioned it is highly desirable that the need for establishing ground control points for mapping from satellite imagery should be entirely eliminated. To serve this purpose, the most useful data in Saudi Arabia are existing digital orthophotos with 50 cm ground sampling distance (GSD) derived from 1:45,000 scale aerial imagery (Alrajhi 2013). The orthophotos have a geometric accuracy in the range of the GSD. Although this is less than desired, it can still be expected that the orthophotos provide effective control to refine the RPC orientation of the HRSI, if enough matched points are available.

For matching of the GeoEye and IKONOS imagery with the orthophotos, we face the combined challenge of multi-sensor and multi-scale image matching. The images were typically also acquired at different times, and thus in principle multi-seasonal effects come to play. However, our test sites only varied slightly within the year which eliminated the need to cope with such seasonal alterations.

First, the HRSI are georeferenced based on the vendor-provided RPC and a digital terrain model (DTM). In order to refine this approximate result, SURF is used to locate and match key points on these satellite and overlapping aerial orthophotos. As the coverage of an IKONOS scene is $11 \times 11$ km$^2$ and that of GeoEye imagery is $10 \times 10$ km$^2$, it is rather resource consuming to determine key points in the whole satellite scene and the overlapping orthophoto, respectively. To speed up the process, we only use nine equally distributed sub-windows of $800 \times 800$ pixels extracted from the corresponding pairs of satellite and aerial images. In each sub-window, the number of key points is restricted to a maximum of 200. Then, the matching procedure is applied in the neighbourhood of some $10 \times 10$ pixels for each key point extracted in the aerial orthophoto. The coordinates of the matched point pairs are subsequently compared to eliminate gross matching errors: The RMS values for the X-coordinate and the Y-coordinate differences are calculated and pairs showing a difference larger than 3 times the RMS value are rejected.

Next, the satellite image is precisely transformed to the geometry of the orthophoto. Even though the differences in the two coordinate datasets are likely to be dominated by X- and Y-coordinate shifts (Fraser & Yamakawa 2004, Dowman et al. 2012), a 2D affine transformation with six parameters is used in this step. The large number of matched key points, if well distributed over the image, results in a strong least squares based adjustment solution. In addition, the adjustment residuals provide further information regarding the image matching success. A final check based on manually selected check points ensures a high quality of the final product. The described procedure is shown in Fig. 1.

## 4 Experimental Results

### 4.1 *Test Sites*

The proposed automated orthoprojection process was tested over the different landscapes of Saudi Arabia visible in the IKONOS and GeoEye satellite images. Three separate sites were selected for this purpose. Test area 1 contains a densely urbanized part of southwestern Riyadh as well as the adjoining suburban area which is undergoing rapid new development. Test area 2, Al Muzahimiyah, is located about 25 km to the south-west of Riyadh along an escarpment. It includes several cultivated farm parcels and shows a significant variation in topography in a rural landscape. Test area 3, Huraymila, is a small city located about 90 km from Riyadh, surrounded with old style farms with a lot of palm trees. The landscape in the test site ranges from acacia covered wadis to pronounced escarpments and wide plains. The HRSI available for the test are described in Tab. 1. In all cases pan-sharpened images were used.

## 4.2 *Results*

Tests were conducted for all three test sites and for all images listed in Tab. 1. To illustrate the results, we present details of the test site Riyadh for the GeoEye and IKONOS images of 2010 (see Figs. 2 to 5); the other results look rather similar.

**Riyadh, GeoEye 2010 imagery:** Fig. 2 depicts a thumbnail view of the GeoEye image. The nine equally distributed 800 × 800 pixel image patches are highlighted in yellow colour. Fig. 3 contains the distribution of the automatically selected points for three selected patches of Fig. 2 (left patch of upper row, centre patch of middle row, centre patch of lower row). It has to be noted that radiometric differences are taken into account within SURF. It can be seen that in all cases a large number of well distributed points was found. The second

**Tab. 1:** GeoEye (left) and IKONOS (right) images used in the study.

| Area | Date of Imaging |
|---|---|
| Riyadh | 20 Nov 2009 |
| Riyadh | 01 May 2010 |
| Al Muzahimiyah | 26 Nov 2009 |
| Al Muzahimiyah | 09 Jan 2010 |

| Area | Date of Imaging |
|---|---|
| Riyadh | 09 Aug 2008 |
| Riyadh | 01 May 2010 |
| Al Muzahimiyah | 25 Nov 2008 |
| Huraymila | 28 Dec 2009 |

**Tab. 2:** Number and distribution of matched points, GeoEye 2010 image.

| Image patch | Area type | No. of matched points |
|---|---|---|
| Upper left | Open | 77 |
| Upper centre | Open | 38 |
| Upper right | Open | 33 |
| Middle left | Agriculture | 125 |
| Middle centre | Built-up | 184 |
| Middle right | Built-up | 174 |
| Lower left | Built-up | 140 |
| Lower centre | Built-up | 182 |
| Lower right | Agriculture | 147 |
| **SUM** | | **1100** |

**Fig. 2:** Riyadh, GeoEye image 2010; location of nine image patches.

**Tab. 3:** RMS values for check points, GeoEye 2010 image.

| Area type | No. of check points | RMS_X (m) | RMS_Y (m) |
|---|---|---|---|
| Total satellite image | 20 | 0.61 | 0.75 |
| Open area | 7 | 0.48 | 0.57 |
| Built-up area | 8 | 0.75 | 0.76 |
| Agriculture area | 5 | 0.57 | 0.89 |

**Fig. 3:** Distribution of matched points for three selected image patches (left GeoEye image, right orthophoto) shown in Fig. 2: left patch of upper row (open), centre patch of middle row (built-up), centre patch of lower row (built-up).

and the third patch, which depict urban areas with comparatively high texture, show more points, which is not surprising.

Numerical results are presented in Tabs. 2 and 3. Tab. 2 characterises each patch and lists the number of matched points. For all terrain types, numerous points are found. In total, 1,100 matching points were available, which is of course more than enough for the 2D subsequent affine transformation. Tab. 3 contains the RMS values at independent check points for different area types and shows that an accuracy in the range of about 1.2 pixels was reached, which is reasonable, since the image coordinates of the check points were digitised in the 50 cm orthophotos. The mean differences vanish for both the X- and the Y-axis, indicating a fit between satellite and aerial orthophoto without any systematic errors.

**Riyadh, IKONOS 2010 imagery:** Results are displayed for the IKONOS 2010 image of test site Riyadh which has a GSD of 1 m. Fig. 4 contains a thumbnail of the image with the location of the nine patches used for matching. For two examples Fig. 5 shows the detailed distribution of the matched points, again it can be seen that a large number of well distributed points was found. Numerical results are contained in the following tables. Tab. 4 characterises each patch and lists the number of matched points; in total more than 1,200 points were used, which is nearly 10% more than for the GeoEye image. The reason is probably the larger proportion of built-up area in the image patches, exhibiting stronger image texture. Tab. 5 contains the RMS values at the check points and in general confirms the findings for the GeoEye image. Again an accuracy of about 1.2 pixels was reached in most cases, although the differences in Y are a little higher for open and agricultural area, probably due to poor texture. The mean differences again vanish, which means that the observations do not contain any systematic errors.

Tab. 6 contains the RMS values derived at check points, differentiated according to the

**Tab. 4:** Number of matched points, IKONOS image.

| Image patch | Area type | No. of matched points |
|---|---|---|
| Upper left | Built-up | 108 |
| Upper centre | Built-up / agricult. | 116 |
| Upper right | Built-up/ open | 187 |
| Middle left | Built-up / agricult. | 30 |
| Middle centre | Built-up | 162 |
| Middle right | Built-up / agricult. | 134 |
| Lower left | Open | 101 |
| Lower centre | Open | 168 |
| Lower right | Open | 196 |
| **SUM** | - | **1202** |

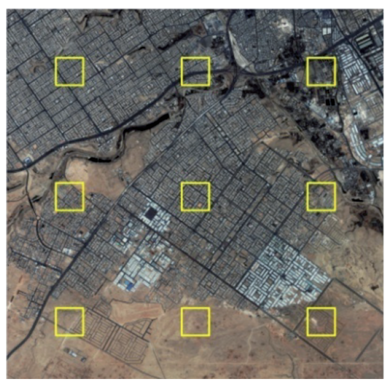

**Fig. 4:** Riyadh, IKONOS image 2010; location of image patches.

**Tab. 5:** RMS values for check points, IKONOS image.

| Area | No. of check points | RMS_X (m) | RMS_Y (m) |
|---|---|---|---|
| Total satellite image | 20 | 1.17 | 1.61 |
| Open area | 6 | 1.20 | 1.85 |
| Built-up area | 9 | 1.15 | 1.32 |
| Agriculture area | 5 | 1.17 | 1.64 |

area types built-up, agricultural and open for all eight images listed in Tab. 1. All values range from 1 to 1.5 GSD which again confirms the findings already discussed. In units of the GSD the values for the IKONOS images were smaller than those for the GeoEye images; this points to the fact that, as expected, the matching procedure delivers sub-pixel accuracy. The lower accuracies for GeoEye images reported in Tab. 6 (GSD) is mainly a result of the manual digitisation of the check points in the aerial orthophotos which negatively influenced geometric accuracy. Again, the mean differences all vanish.

The test results have convincingly demonstrated that SURF provides a very effective image matching approach for multi-scale and multi-sensor image matching. As pointed out

**Fig. 5:** Distribution of matched points for left (built-up) and right (built-up/open) image patch of the upper row shown in Fig. 4 (left IKONOS image, right: orthophoto).

**Tab. 6:** RMS values for check points, all test images.

| Satellite Image | Built-up | | Agricultural | | Open | |
|---|---|---|---|---|---|---|
| | RMS_X (m) | RMS_Y (m) | RMS_X (m) | RMS_Y (m) | RMS_X (m) | RMS_Y (m) |
| GeoEye, Riyadh 2009 | 0.71 | 0.81 | 0.61 | 0.85 | 0.56 | 0.68 |
| GeoEye, Riyadh 2010 | 0.75 | 0.79 | 0.58 | 0.91 | 0.46 | 0.58 |
| GeoEye, Al Muzahimiyah 2009 | 0.68 | 0.75 | 0.54 | 0.83 | 0.52 | 0.65 |
| GeoEye, Al Muzahimiyah 2009 | 0.73 | 0.85 | 0.63 | 0.87 | 0.59 | 0.63 |
| IKONOS, Riyadh 2008 | 0.94 | 1.22 | 0.98 | 1.29 | 1.09 | 1.38 |
| IKONOS, Riyadh 2010 | 1.05 | 1.27 | 1.15 | 1.57 | 1.14 | 1.42 |
| IKONOS, Al Muzahimiyah 2008 | 1.25 | 1.31 | 1.18 | 1.34 | 1.17 | 1.46 |
| IKONOS, Huraymila 2009 | 1.32 | 1.29 | 1.07 | 1.24 | 1.21 | 1.34 |

earlier, the use of the vendor-provided RPC data often results in systematic georeferencing errors. These are effectively corrected by the two shift parameters of the affine transformation that have the dominating influence on the transformation. In fact, it may often be sufficient to simply apply these two shift parameters. The 2D affine transformation also presents another opportunity to filter out poorly matched key points. A threshold of 3 times the RMS_X and RMS_Y values, respectively, was used for rejecting poorly matched points in this study, which due to the large number of matched points provided sufficiently accurate and reliable results.

## 5 Conclusions

Maintenance and delivery of geospatial information by MOMRA serves the needs of a large number of national and regional government agencies in Saudi Arabia. Line maps and orthophoto maps produced at scale 1:10,000 are most commonly used for regional planning, they must meet accuracy standards of 1.25 m in both planimetric coordinates at the 1-$\sigma$ level. Accordingly, any conclusions about the impact of this research study on the enhanced capability of MOMRA for rapidly updating with the use of recently acquired high resolution satellite imagery should be drawn in the light of the information needs mentioned.

Based on the analysis of the results obtained with the experiments reported in this paper, the following conclusions can be drawn:

- The existing aerial 50 cm resolution orthophoto database can effectively be used as control for the orthorectification of satellite imagery of 50 cm to 1 m GSD in order to generate updated 1:10,000 scale line maps and orthoprojected 50 cm and 1 m resolution images that meet MOMRA map accuracy standards.
- In order to generate these products, coordinates for 15 or more control points that are well distributed across the image, may be obtained through manual measurements on the existing orthophotos and the new satellite images and combined with the RPC and DTM data for the orthoprojection of the satellite image. About 4 to 5 hours of a trained operator time is required to complete this process.
- A more efficient alternative for orthorectifying of the new satellite images is based only on the vendor-supplied RPC and DTM data, a process which can usually be completed within one hour. The resulting georeferenced satellite image is then matched with the corresponding existing aerial orthophoto using the proposed SURF-based matching that generates a large number of matched points. These points are subsequently used to transform the satellite image to the orthophoto geometry via a 2D affine transformation. SURF matching and

coordinate transformation only takes a few minutes and results in an orthorectified satellite image that meets MOMRA map accuracy standards for 1:10,000 scale mapping.

- The orthoprojection of a new satellite image can be carried out at a production rate of 12 to 15 satellite images per day without the need for neither field control nor measurement of image coordinates by a skilled human operator. Hence, a viable solution for orthophoto generation in MOMRA's map production environment is now available, in complete fulfilment of the primary objective for this research.
- Based on the currently available 50 cm resolution orthophotos the proposed procedure can be used for generating orthophotos that meet the MOMRA accuracy standard for 1:10,000 map scale. However, if aerial orthophotos of higher positional accuracy become available for control, the proposed procedure will be applicable for generating up-to-date satellite orthophotos of correspondingly higher accuracy.

There are several uses of geospatial information where the completeness and the validity of the map data is of primary interest while the geometric accuracy is of secondary importance. For example, due to the rapid pace of urbanization in Saudi Arabia, the planning for continued urban development requires frequent updating of the land use map that is most commonly compiled from the 1:2,500 scale map database of MOMRA. Such land use planning can be greatly facilitated if MOMRA can rapidly deliver geospatial information that has been updated using recently acquired satellite imagery. Hence and despite not meeting MOMRA's geometric map accuracy standards for land use mapping at the 1:2,500 scale, the up-to-date satellite images can be of paramount importance for spatial planning in Saudi Arabia, as they represent topologically correct current information.

## References


Alrajhi, M., 2013: A Semi-Automated Procedure for Orthophoto Generation from High Resolution Satellite Imagery. – Wissenschaftliche Arbeiten der Fachrichtung Geodäsie und Geoinformatik der Leibniz Universität Hannover Nr. 307.

Bay, H., Ess, A., Tuytelaars, T. & van Gool, L., 2008: SURF: Speeded-Up Robust Features. – Computer Vision and Image Understanding **110** (3): 346–359.

Blázquez, M. & Colomina, I., 2012: Relative INS/GNSS aerial control in integrated sensor orientation: models and performance. – ISPRS Journal of Photogrammetry and Remote Sensing **67:** 120–133.

Di, K., Ma, R. & Li, R., 2003: Rational functions and potential for rigorous sensor model recovery. – Photogrammetric Engineering and Remote Sensing **69** (1): 33–41.

Dowman, I., Jacobsen, K., Konecny, G. & Sandau, R., 2012: High Resolution Optical Satellite Imagery. – Whittles Publishing, Caithness, UK.

Fraser, C., Hanley, H.B. & Yamakawa, T., 2002: Three-dimensional geopositioning accuracy of IKONOS imagery. – Photogrammetric Record **17** (99): 465–479.

Fraser, C. & Yamakawa, T., 2004: Insights into the affine model for high-resolution satellite sensor orientation. – ISPRS Journal of Photogrammetry and Remote Sensing **58:** 275–288.

Gianinetto, M., 2008: Updating Large Scale Topographic Databases in Italian Urban Areas with Submeter QuickBird Images. – International Journal of Navigation and Observation: 116–124.

Grodecki, J. & Dial, G., 2003: Block adjustment of high-resolution satellite images described by rational polynomials. – Photogrammetric Engineering and Remote Sensing **69** (1): 59–70.

Heipke, C., 1997: Automation of interior, relative and absolute orientation. – ISPRS Journal of Photogrammetry and Remote Sensing **52** (1): 1–19.

Holland, D., Boyd, D. & Marshall, P., 2006: Updating topographic mapping in Great Britain using imagery from high-resolution satellite sensors. – ISPRS Journal of Photogrammetry and Remote Sensing **60:** 212–223.

Jedryczka, R., 1999: Contribution to OEEPE-test on automatic orientation of aerial images. – Task A-Semi-Automatic Exterior Orientation Using Existing Vector Map Data, OEEPE **36:** 133–137.

Juan, L. & Gwun, O., 2009: A comparison of SIFT, PCA-SIFT and SURF. – International Journal of Image Processing **3** (4):143–152.

Karjalainen, M. & Kuittinen, R., 1999: Contribution to OEEPE-test on automatic orientation of aerial images. – Task A-interactive Exterior Orientation Using Linear Features from Vector Maps, OEEPE **36:** 127–131.

Läbe, T., 1999: Contribution to OEEPE-test on automatic orientation of aerial images. – Task A-Experiences with AMOR, OEEPE **36:** 119–126.

Li, A. & Batchvarova, T., 2008: Topographic mapping and terrain modeling from multi-sensor satellite imagery. – International Archives of Photogrammetry, Remote Sensing and the Spatial Information Sciences **XXXVI**, Part 1: 809–814.

Lowe, D., 2004: Distinctive image features from scale-invariant keypoints. – International Journal of Computer Vision **60** (2): 91–110.

Pedersen, B., 1999: Contribution to OEEPE-test on automatic orientation of aerial images. – Task A-Solution from Alborg, OEEPE **36:** 139–144.

Tao, V. & Hu, Y., 2002: 3D reconstruction methods based on the rational function model. – Photogrammetric Engineering and Remote Sensing **68** (7): 705–714.

Addresses of the Authors:

Prof. Dr.-Ing. Muhamad Alrajhi, Ministry of Municipal and Rural Affairs (MOMRA), Deputy Minister for Land & Surveying, P.O.Box 89936, 11692 Riyadh, Saudi Arabia.

Prof. Dr.-Ing. habil. Christian Heipke, Leibniz Universität Hannover, Institut für Photogrammetrie und GeoInformation, Nienburger Str. 1, 30167 Hannover, Germany, e-mail: heipke@ipi.uni-hannover.de

Manuskript eingereicht: Juni 2015
Angenommen: Dezember 2015