Accuracy Assessment of Vegetation Height Mapping Using Spaceborne Ikonos as well as Aerial UltraCam Stereo Images

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Keywords: stereo mapping, Ikonos, UltraCam, surface model, vegetation heights

ABSTRACT: High resolution space-borne remote sensing image data show a high level of detail and provide manifold opportunities to be integrated into remote sensing applications. In particular, surface mapping from stereo data sets becomes feasible with a height accuracy in the meter range. Following the focus on forest applications of the Institute, the feasibility to determine tree heights from high resolution space-borne Ikonos stereo data but also from airborne stereo image data acquired by the digital UltraCam camera was investigated. A comparative quality assessment of the achieved results was made with respect to those achieved from laser scanning and with respect to in-situ field measurements.

1 INTRODUCTION

As an alternative to air-borne systems, like laser scanners or aerial photographs, space-borne stereo images with very high spatial resolution are getting more and more used for surface mapping applications, where high accuracy and level of detail is required. As shown in previous investigations elaborated at the Institute of Digital Image Processing (Raggam et al., 2004; Gutjahr et al., 2005), Ikonos image pairs for instance promise a height accuracy in the range of 1 to 2 meters, depending upon the geometric disposition of the stereo pair.

Recent activities at the Institute are related to the utilization of stereo mapping techniques applied to space-borne Ikonos stereo pairs in order to extract vegetation heights, in particular forest stand heights. As known from traditional photogrammetry, 3D mapping of outstanding objects like buildings or trees in general is ambitious, specifically if it is to be done widely automatically. This is due to the perspective distortions inherent to imaging systems, which make such objects appear extremely dissimilar in stereo images. These activities are embedded into the EU 6th framework project “FIREGUARD” (Monitoring Forests at the Management Unit Level for Forest Fire Prevention and Control) and aim at the implementation and feasibility demonstration of a remote sensing based technology to determine tree heights and – subsequently – timber volume and biomass with acceptable accuracy (Stelzl et al., 2005). In this concern, the remote sensing based approach is assumed to assure increased continuity and economic efficiency in comparison to alternative approaches like airborne laser scanning or extensive field work.

Detailed investigations to assess the feasibility of tree height mapping from space-borne stereo data as well as the related accuracy potential were carried out for a well-mapped study area in south-eastern Styria (Austria), which was in general designated as a long term reference test site for various forest applications of the Institute. The area is covered by different types of forest stands and shows agricultural and built-up areas as well. For the investigations being intended a comprehensive set of image as well as reference data was compiled as described in section 2. For 3D surface mapping and consecutive extraction of vegetation heights a space-borne Ikonos image pair was used according to the objectives of the FIREGUARD project. Besides, an airborne campaign with the digital UltraCam camera led to a sequence of digital aerial images which were used for the mapping investigation as well.

For the selected test site an overall objective was to derive digital surface models using the various stereo image data sources, and to extract vegetation heights from these surface models subsequently. The vegetation height extraction as well as the assessment of resulting accuracies and conclusions on the applicability of this remote sensing based approach were based on the following global processing steps:

- Sensor modelling
- Stereo matching and generation of surface models
- Analysis of surface mapping accuracy
- Generation of vegetation height models
- Analysis of vegetation height accuracy

The paper provides a comparative discussion of these processing steps, which have been applied to the space-borne Ikonos as well as the airborne UltraCam stereo images in order to extract vegetation heights. For quality analysis, laser scanner derived tree heights, but also in-situ measurements were used.

2 STUDY AREA AND IMAGE DATA

2.1 *Study area*

The test site represents a rather flat area with an elevation range between 258 and 411 meters above sea level, and is mainly covered by forest and agricultural fields. This is documented in Figure 1 and Figure 2, which show a grey level coded digital elevation model generated from 1 : 50.000 topographic maps and an Ikonos ortho image, respectively. This image was acquired and generated in 2000, and is shown in a false colour presentation. In this figure also the coverage of the laser scanner over-flight as well as of some of the aerial UltraCam images acquired for this test site is shown. A detailed study area as indicated in these figures was selected, where the required field measurements were collected and the basic investigation on vegetation/tree height mapping and its accuracy assessment was performed.

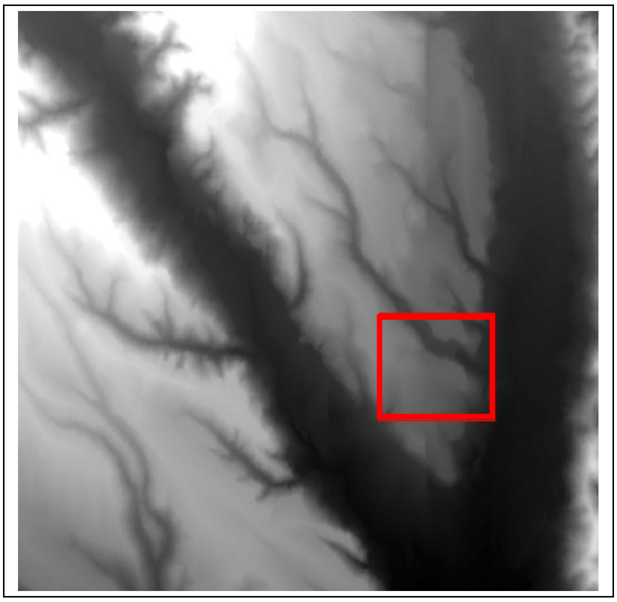


Figure 1: Digital elevation model

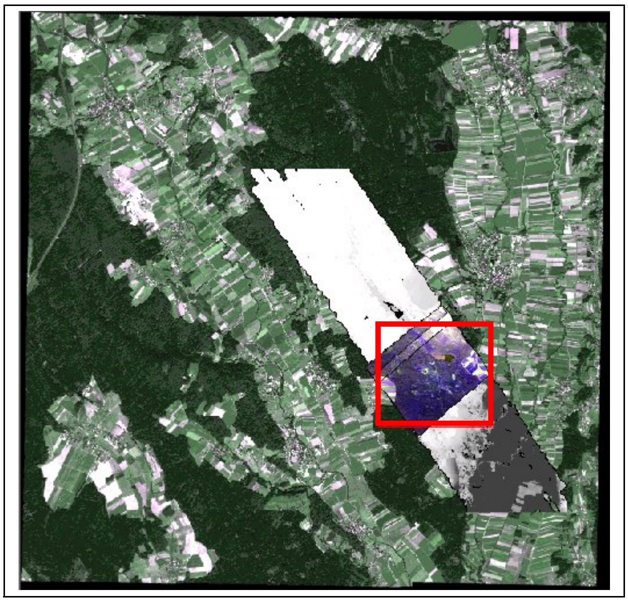


Figure 2: Ikonos ortho image

2.2 *Ikonos stereo images*

An Ikonos map projected stereo pair was acquired for this study area on 13th of September 2004. An anaglyph presentation of this stereo pair is shown in Figure 3 (left) for the detailed study area. For these map projected stereo images, the main parallax can be found in vertical direction due to the flight direction of the satellite. The azimuth and elevation angles of Ikonos data acquisition are given in Table 1 for forward and backward image and result in a stereo intersection angle of about 31°, or a base-to-height ratio of approximately 0.55.

A so-called bundle data set was acquired, comprising 1 meter panchromatic as well as 4 meter multi-spectral stereo images. A pan-sharpening was applied to the multi-spectral stereo images, and the near-infrared spectral band 4 was used for stereo mapping, as this shows comparatively the highest contrast from a radiometric point of view. More details on Ikonos products can be found at the Space Imaging web site (http://www.spaceimaging.com).

Table 1: Ikonos acquisition parameters

	Forward	Backward
Azimuth	9.73°	246.72°
Elevation	60.74°	86.56°

2.3 *UltraCam digital stereo images*

A series of aerial images acquired by the UltraCamD large format digital camera of Vexcel Imaging was acquired in a north-west to south-east over-flight. These images have a forward overlap of about 90% and hence provide stereo combinations in different geometric dispositions, i.e. base-to-height ratios. The main acquisition parameters of the UltraCam over-flight are summarized in Table 2. An anaglyph presentation of one selected image pair comprising the acquisitions 524 and 528 in red and green, respectively, and covering the detailed study area is shown in Figure 3 (right). The anaglyph presentation is coarsely rotated with respect to north for matters of comparability. This image pair skips 3 intermediate acquisitions and shows a forward overlap of about 60% and a base-to-height ratio of 0.23.

The Vexcel UltraCamD comprises 8 individual cameras, 4 each allowing panchromatic and multi-spectral acquisitions, respectively. Image formation as well as pan-sharpening of the multi-spectral images is done in a post-processing step. More details on this digital camera can be found e.g. in Kremer et al. (2004).

Table 2: UltraCam technical specifications and acquisition parameters

Panchromatic image size	11500*7500pixels
Physical format of the focal plane	103.5*67.5mm
Panchromatic Lens focal distance	100mm
Physical pixel size	9µm
Colour	RGB + NIR
Colour image size	4008*2672pixels
Colour lens focal distance	28mm
Acquisition date	21.07.2004
Forward overlap	Up to 90%
Sensor flying height	2080meters
Ground sampling distance	15cm

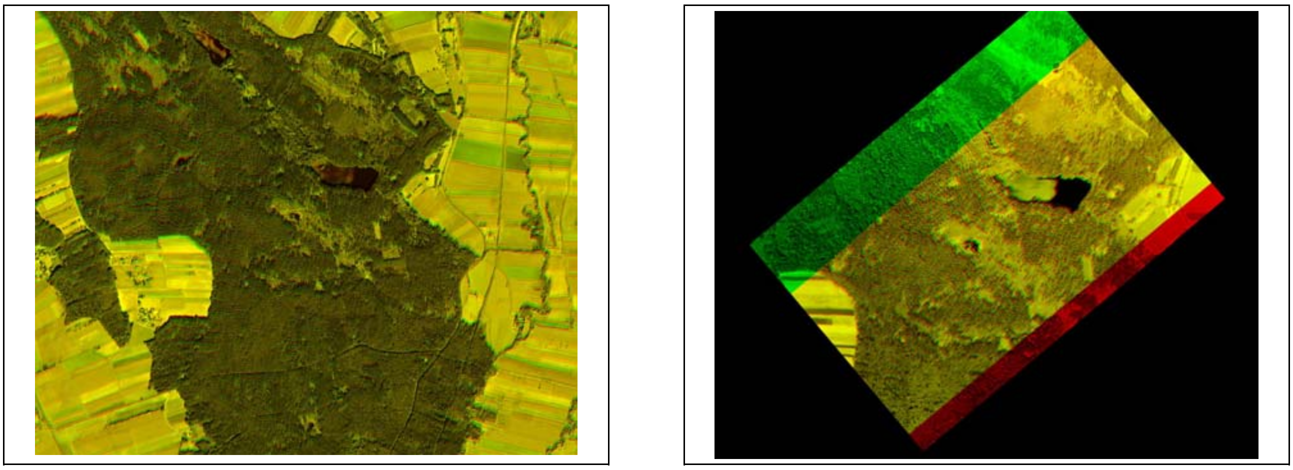


Figure 3: Anaglyph presentations of stereo pairs for detailed study area (left: Ikonos; right: UltraCam)

2.4 *Reference data*

For the investigation the following reference elevation data, geo-located image data and in-situ field measurements were available:

- the DEM mentioned above, providing coarse height reference information.
- a laser scanner data set acquired by the Toposys FALCON1 instrument, which provides reference information concerning surface as well as ground elevations (see Figure 4).
- digital ortho-photo maps with a pixel size of 0.5 meters, which served to measure ground control points for the Ikonos stereo images.
- DGPS-based ground control point measurements, which were collected to perform the orientation of the digital UltraCam images;
- In-situ field measurements of location and height of selected (clusters of) trees.

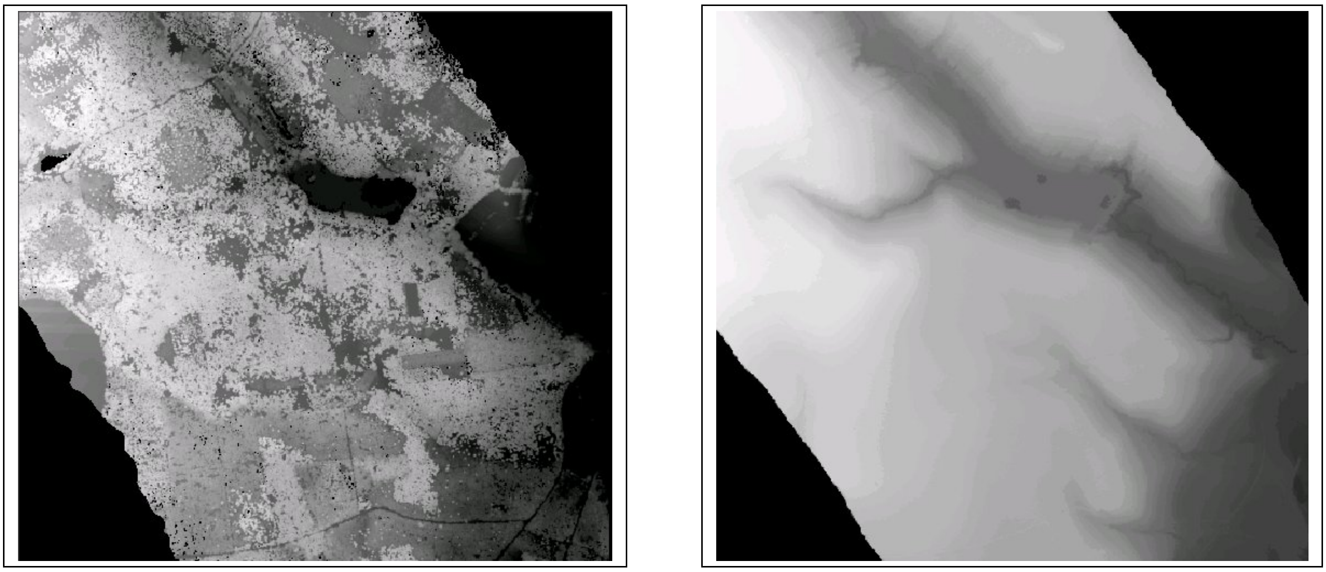


Figure 4: Laser scanner surface model (left) and laser scanner ground model (right)

3 3D MAPPING

3.1 *Geometric Modeling*

The Ikonos map projected stereo images are modeled by means of rational polynomials in a manner adequate to standard stereo or other Ikonos products. The rational polynomials were optimized using linear add-on polynomials being determined from control points, which were measured in the panchromatic Ikonos images and the digital ortho-photo maps. On the other hand, the exterior orientation elements of the UltraCam images, i.e. position and orientation of the camera, were determined from control points, which were measured by DGPS in the field. Due to the forested nature of the test site and the small coverage of the UltraCam images, limited options for control point measurement are available for these data.

RMS, minimum and maximum values of point residuals, resulting from a backward transformation of control points into the image, are used to conclude on the performance of rational polynomial optimization and camera orientation. These are summarized in Table 3 and Table 4 for the Ikonos and the selected UltraCam image pair, respectively. For Ikonos RMS residual errors in the sub-pixel range, i.e. of less than 1 meter are clearly achieved. Apparently, the RMS accuracy is a bit worse for the UltraCam images. However, taking into account the high image resolution of about 15 centimeters it becomes obvious that the metric equivalent of the RMS residuals is some 20 centimeters on ground only, and is in general limited by the location and identification accuracy of the DGPS measured ground control points.

3D point residuals in East, North and Height are determined from spatial point intersection of stereo control points and comparison with given ground coordinates and give an estimate on the potential (a-priori) stereo mapping accuracy. The statistics of the 3D residuals achieved for the Ikonos and the UltraCam stereo pair are summarized in Table 5 and Table 6, respectively. An RMS height accuracy of about 1.5 meters is achieved for the Ikonos stereo model, while the one for the UltraCam stereo pair is about 0.5 meters.

Table 3: Ikonos point residual statistics achieved after rational polynomial optimization.

34 GCPs		**Along**	**Across**	**Length**
Ikonos-Fwd	RMS	0.49	0.59	0.77
	MIN	-0.91	-1.44	0.19
	MAX	1.02	1.23	1.59
Ikonos-Bwd	RMS	0.52	0.51	0.73
	MIN	-0.88	-0.86	0.24
	MAX	1.02	0.93	1.06

Table 4: UltraCam point residual statistics achieved after exterior orientation.

6 GCPs		**Along**	**Across**	**Length**
524	RMS	0.75	0.98	1.24
	MIN	-0.71	-1.32	0.42
	MAX	1.18	1.61	1.77
528	RMS	0.87	1.26	1.53
	MIN	-1.73	-1.52	0.86
	MAX	1.33	1.78	1.87

Table 5: Ikonos a-priori stereo mapping accuracy.

	East	**North**	**Height**	**Length**
RMS	0.5	0.5	1.4	1.6
MIN	-1.0	-0.9	-2.6	0.6
MAX	0.8	0.9	3.7	3.8

Table 6: UltraCam a-priori stereo mapping accuracy.

	East	**North**	**Height**	**Length**
RMS	0.1	0.1	0.5	0.5
MIN	-0.1	-0.2	-0.7	0.1
MAX	0.2	0.2	0.8	0.8

3.2 *Image Matching*

For matching of the stereo images an extended version of the “feature vector” matching method developed at the Institute was used (Paar et al., 1992; Caballo-Perucha, 2004). The components of the “feature vectors” are in general represented by various convolution and variance filters or other suchlike features. One essential feature is the cross correlation coefficient, which formerly used to be applied for image matching as such. Back-matching was used in order to get a reliability feedback for the individual matching results. For part of the detailed study area the matching results (disparity maps) are shown in Figure 5. The UltraCam disparity map is again coarsely rotated with respect to north for matters of comparability. The main disparities are shown in red and green, adding up to yellowish colours. Due to the image arrangement used for stereo matching, the Ikonos and the UltraCam disparities are oppositional, i.e. in the Ikonos disparity map forests appear in bright yellow and open areas in dark yellow, whereas it is the other way round in the UltraCam disparity map.

The back-matching distance is superimposed in blue, indicating unreliable matching areas which appear mainly along forest borders. There, matching is not possible or not reliable due to occlusion effects and associated dissimilarity of the stereo images. These effects are less severe in the case of the UltraCam result, where steeper looking conditions (smaller base-to-height ratio) were used.

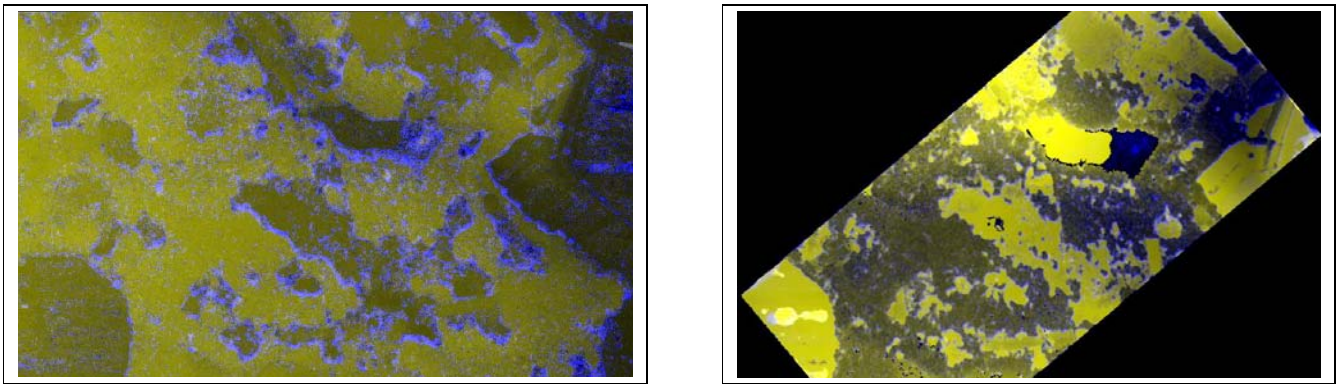


Figure 5: Disparity maps achieved from Ikonos (left) and UltraCam (right) stereo matching

3.3 *Surface model generation*

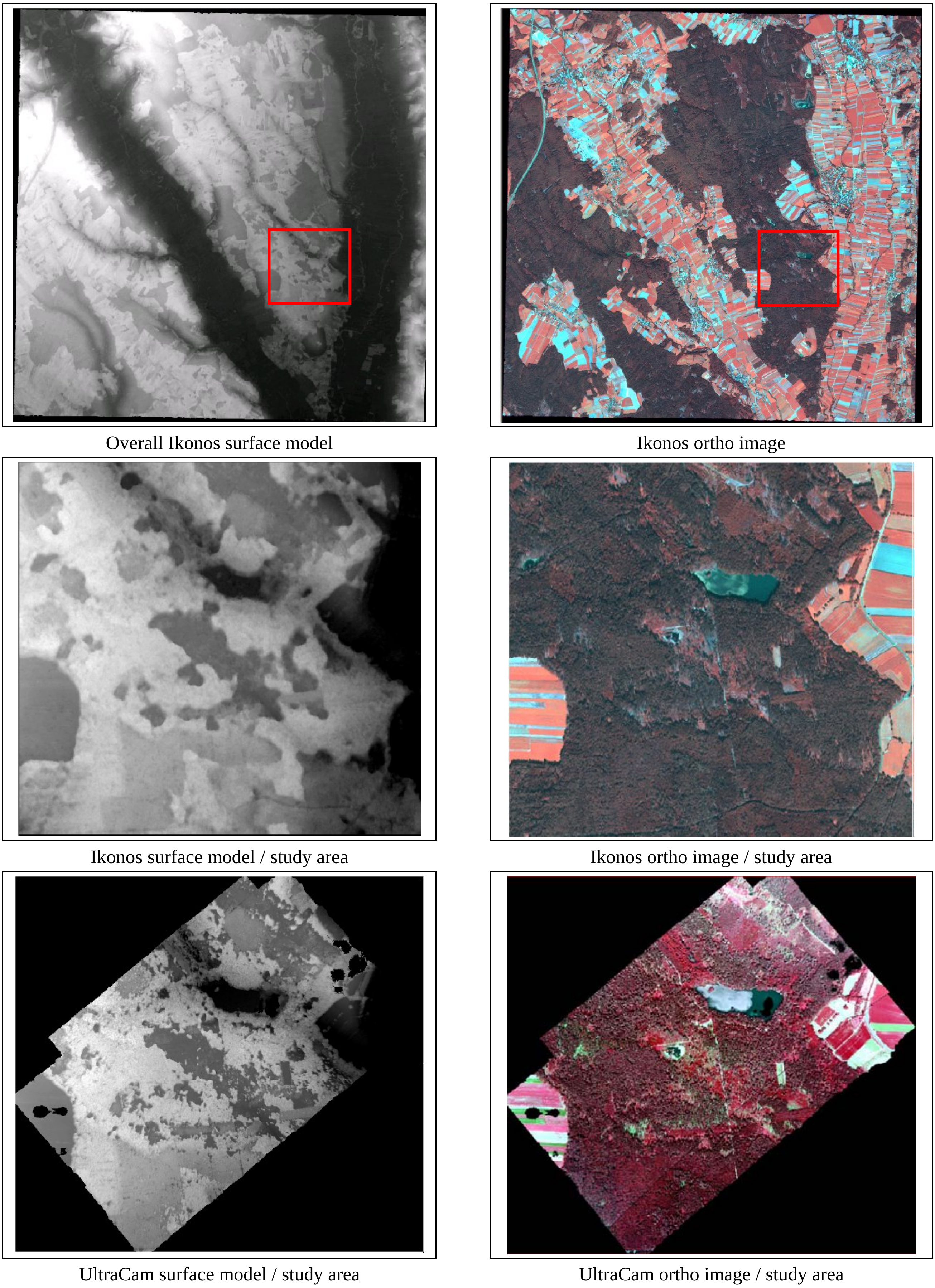
Based on the results of the image matching, digital raster surface models were generated. These are achieved via 3D point intersection of the projection rays defined by the matched image points. In this step, unreliable matching results, which presumably will lead to wrong ground coordinates can be rejected. Subsequently, a regular raster surface model is interpolated. The gaps which may still be inherent to this raster model due to unreliable point rejection are interpolated using a versatile interpolation mechanism.

Surface models were generated in this way from the Ikonos as well as the UltraCam matching results. These are shown in Figure 6, along with respective Ikonos and UltraCam ortho-photos (in the near-infrared false colour composition) for the detailed study area.

3.4 *Surface model accuracy assessment*

A straightforward quality feedback for the stereo-derived surface model can be achieved in comparison to the laser scanner surface model, which is known to be accurate in the decimetre range and thus is considered as the “absolute” reference. Difference models between Ikonos-derived surface model and UltraCam-derived surface model were calculated with respect to the laser scanner surface model. These are shown in Figure 7 in a colour coded presentation along with the colour table which was used for colour coding. The presentations show, that the majority of height differences is in the range of a few meters only.

The accuracy assessment, however, is complicated by (a) the forest coverage of the terrain – specifically of the detailed study area and (b) the time difference and temporal change of vegetation state between the laser scanner surface model (1999) and the stereo-derived surface models (2004). Therefore, an immediate conclusion is neither possible over agricultural areas due to land cover change (e.g. maize fields), nor over forested areas due to forest growth over the years. Yellow and light blue agricultural fields in the difference elevation models for instance indicate elevation differences of some 3 meters (positive/negative) and lead to the conclusion of e.g. maize field presence for one epoch, whereas it is absent in the other.



Overall Ikonos surface model — Ikonos ortho image

Ikonos surface model / study area — Ikonos ortho image / study area

UltraCam surface model / study area — UltraCam ortho image / study area

Figure 6: Ikonos and UltraCam surface mapping results

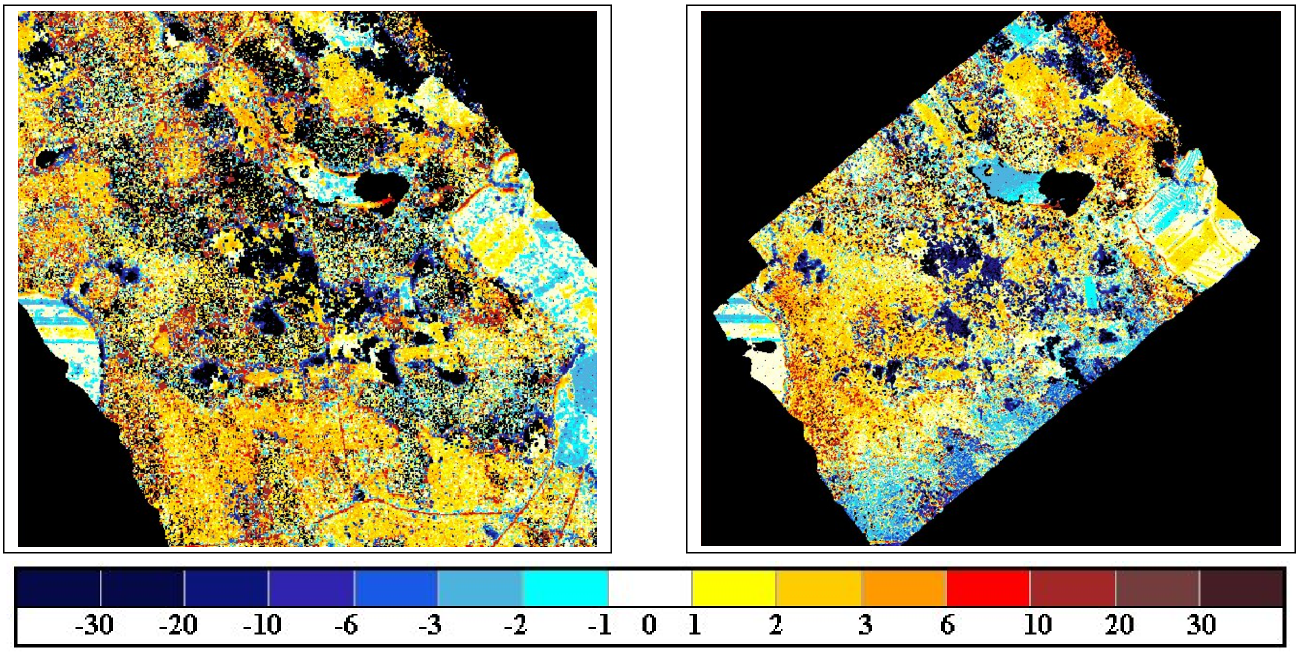


Figure 7: Colour coded elevation differences for Ikonos (left) and UltraCam (right).

Height accuracy assessment was therefore purposely done for reliable and obviously non-vegetated areas of interest (AOI) in laser scanner as well as stereo-derived surface models. The height difference statistics achieved for such areas are summarized in Table 7. Besides, the table shows respective statistical values for AOIs covering streets, forested areas and areas inherent to vegetation change. The positive mean values indicate a systematic height difference over forested areas due to forest growth, while the negative mean values in case 4 indicate the presence of vegetation like maize fields in the laser scanner acquisition of 1999, but no vegetation in 2004.

Table 7: Height difference statistics (1: no vegetation change; 2: streets; 3: forest; 4: vegetation change)

	Ikonos				**UltraCam**			
	Mean	Std.D.	Min	Max	Mean	Std.D.	Min	Max
1	-0.1	0.9	-6.8	6.5	0.2	0.6	-6.9	6.8
2	-0.2	1.3	-12.8	10.0	0.0	0.6	-5.2	4.5
3	1.5	3.7	-18.7	20.6	2.1	5.0	-31.1	34.1
4	-2.7	0.9	-8.8	4.9	-1.4	0.7	-15.0	6.5

4 VEGETATION HEIGHT MAPPING

4.1 *Extraction of vegetation heights*

Vegetation and building heights are straightforward achieved as the difference between the stereo-derived surface models and a ground model. The vegetation height models resulting through subtraction of the laser scanner ground model from the Ikonos as well as the UltraCam surface model are illustrated in Figure 8 in a colour coded presentation. Here, the forested areas are shown in the reddish/brownish colours.

Alternatively, vegetation height models were also derived using the coarse map-derived reference DEM as ground model. This allows to conclude on its applicability for vegetation height mapping. The statistical height differences between laser scanner ground model and the coarse reference DEM for the detailed study area amount to a mean value of 1.5 meters, a standard deviation of 3.2 meters and minimum/maximum height differences of -10 and 18 meters, respectively.

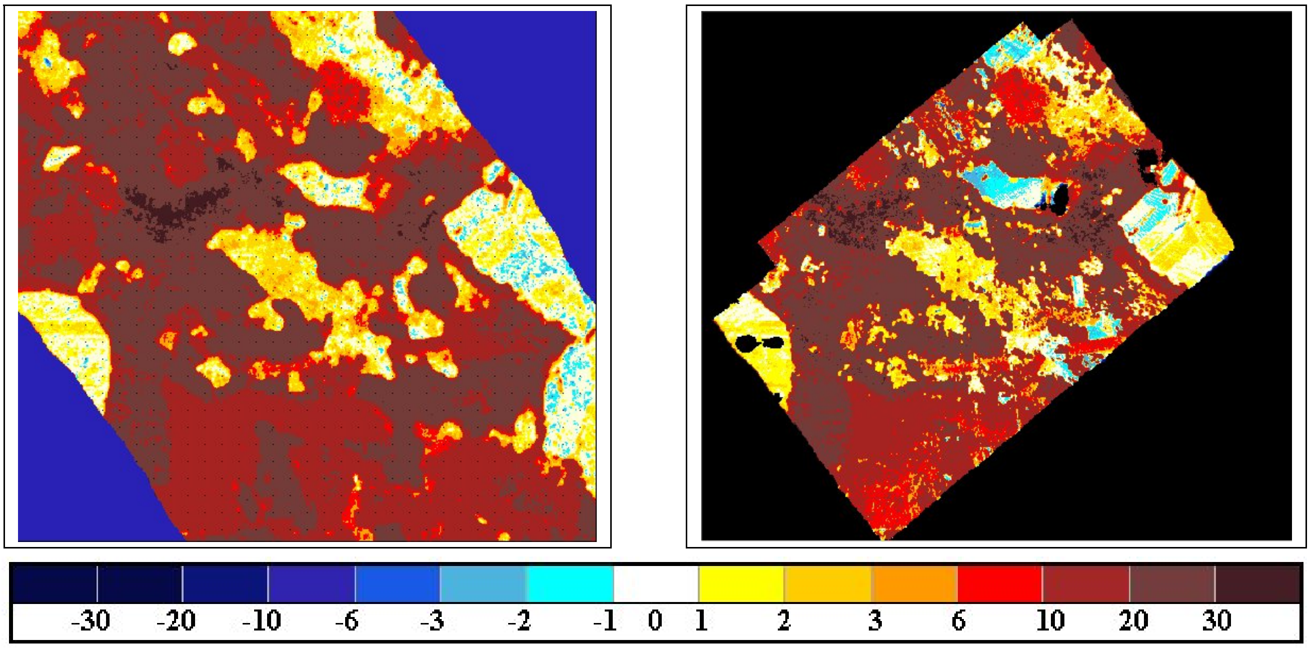


Figure 8: Colour coded vegetation height models for Ikonos (left) and UltraCam (right).

For selected areas of interest, statistical parameters of the vegetation heights were determined in order to check whether major differences are induced by Ikonos versus UltraCam derived surface model on the one hand, and by the laser scanner versus the coarse reference ground model on the other. These statistical parameters are summarized in Table 8. As the test site as such and the selected areas of interest in particular represent flat terrain, the vegetation heights derived via the coarse DEM are more or less equivalent to those derived via the laser scanner ground model. The differences in the mean value are for instance in the sub-meter range.

Table 8: Statistics on vegetation heights

Ground model	**Surface model**	**Mean**	**Std.D.**	**Min**	**Max**
Laser scanner	Ikonos	19.7	6.1	-0.1	33.5
	UltraCam	18.6	6.5	-13.3	38.6
Coarse DEM	Ikonos	19.3	5.5	-3.4	32.9
	UltraCam	18.2	5.6	-15.3	35.9

4.2 *Estimation of Vegetation Growth*

The laser scanner data set dates from 1999, while the stereo results were generated from data being acquired in 2004. With respect to surface model accuracy analysis the amount of tree growth over these 5 years was therefore to be investigated. In-situ measurements of the position and height of several clusters of trees were made in the detailed study area and utilized in this concern. The laser scanner derived vegetation/tree heights were compared to (i.e. subtracted from) the tree heights measured in the field at their respective location. Statistical tree height differences resulting from this comparison are summarized in Table 9, and are given for all trees measured in the field as well as only for those being located in the mid of forests (excluding border areas).

The differences include also several outliers, which are due to incorrect tree location and incorrect tree height mapping, which specifically may happen in forest border areas, where the stereo-derived surface models are affected by interpolation effects. Besides, single trees may just disappear in the stereo-derived surface models due to matching failures caused by the oppositional perspective imaging effects.

The average value of the height differences of the trees amidst the forest can be considered to be more reliable and to represent the tree growth for this time period. This yields a tree growth of about 2 meters and also justifies the mean height differences of 1.5 and 2.1 meters, which were achieved for the Ikonos and UltraCam derived surface models in comparison to the laser scanner surface model over forested areas (see Table 7).

Table 9: Estimation of tree growth

	Mean	**Std.D.**	**Min**	**Max**
All trees	-0.4	6.1	-24.0	10.5
Mid forest only	2.1	3.4	-11.8	10.5

4.3 *Tree height accuracy assessment*

For the trees measured in the field the heights were extracted from the stereo-derived vegetation height models (based on laser scanner as well as coarse ground reference model) and compared to the in-situ measurements in order to assess the accuracy of stereo-based tree height mapping. Statistical parameters of the tree height differences resulting there from are summarized in Table 10, which gives the values separated for all tree measurements as well as for those located in the midst of forested areas only. Again, the statistics, i.e. standard deviation and minimum/maximum height differences, for all trees are worse, as major tree height errors are caused by the same effects as mentioned above in the context of the tree growth analysis. Hence, areas in the midst of forests are favoured for quality assessment. When using the laser scanner ground model , the tree height differences show a standard deviation between 3 and 4 meters, while mean values of 1.8 and 0.4 meter are achieved for Ikonos and UltraCam, respectively. This small bias is due to the cutting of tree vertices in the stereo mapping procedure, resulting in tree heights which tend to be smaller than reality, specifically in case of Ikonos. When using the coarse reference ground model, the mean values become worse in the range between 0.8 and 1.3 meters.

Table 10: Statistics of tree height differences

Ground model	**Stereo data**		**Mean**	**Std.D.**	**Min**	**Max**
Laser scanner	Ikonos	All trees	0.3	8.1	-24.7	31.7
		Mid forest only	1.8	3.8	-15.5	11.4
	UltraCam	All trees	-1.0	7.7	-25.6	30.8
		Mid forest only	0.4	3.4	-13.7	10.3
Coarse DEM	Ikonos	All trees	1.5	8.3	-25.7	32.7
		Mid forest only	3.1	4.1	-13.5	13.8
	UltraCam	All trees	0.2	7.7	-20.6	31.8
		Mid forest only	1.2	5.2	-14.6	15.3

The larger value for Ikonos is presumably due to the fact, that the crown surface as such is pretty well reconstructed, but that areas in between of trees are partly lifted due to interpolation and because the imaging instruments do not permit to view onto the real surface due to off-nadir viewing conditions. These effects are illustrated in Figure 9, which shows the laser scanner as well as the Ikonos and UltraCam derived surface of a selected profile in midst of a forest. The crown surface is well reconstructed by both Ikonos and UltraCam. For areas in between of trees the UltraCam result is superior to Ikonos because image acquisition was made with smaller base-to-height ratio and closer to nadir, thereby causing less severe perspective imaging effects. Moreover, tree tops are frequently slightly cut in the Ikonos derived surface model due to the lower pixel resolution and the larger perspective distortion between the stereo images.

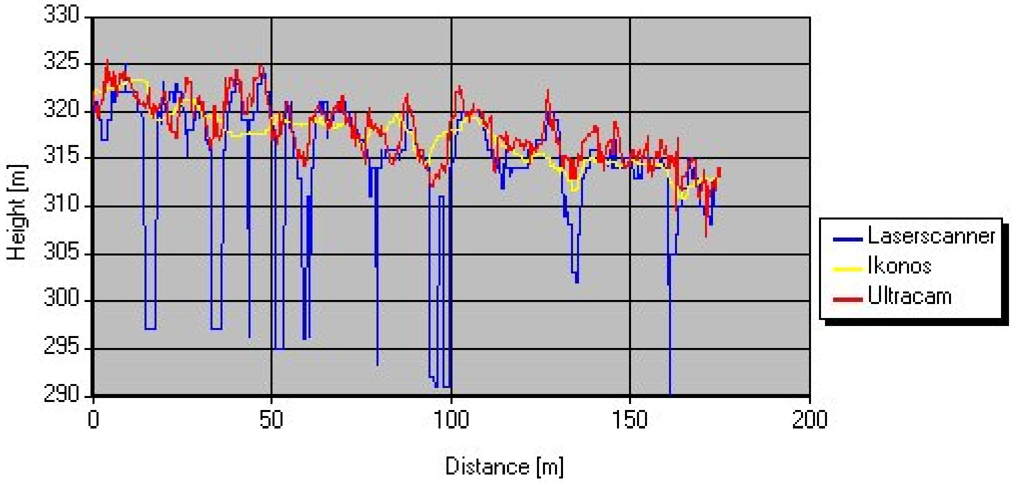


Figure 9: Profile analysis

5 CONCLUSION AND OUTLOOK

For the investigation applied to the selected study area, the remote sensing approach to extract vegetation heights using space-borne and airborne stereo images has proven to be feasible in general and resulted in quite promising results. In comparison to field measurements, the average height differences for trees located in mid forest areas were slightly systematic and in the order of 1.8 meters for the Ikonos derived tree heights and 0.4 meters for the UltraCam derived tree heights. This is due to the cutting of tree vertices in the stereo mapping procedure. Standard deviations in the order of 3 to 4 meters are further achieved in either case. When using the coarse ground reference model, this bias was 3.1 and 1.2 meters and hence worse by a factor equivalent to the shift between laser scanner and coarse ground model.

One bottleneck of this approach is due to the availability of precise ground models. For this test site, a laser scanner ground model could be used. This is however not always available, and might be expensive in case of larger area applications. Alternatively, large area coarse elevation models as widely available might be used. However, this is limited to its utilization in flat areas only, where it might lead to still reasonable and acceptable results as shown in this investigation.

Future work will be related to the feasibility to discriminate a reliable ground model from the stereo-derived surface model. Therefore, thematic information like forest/tree segmentation and classification which also can be extracted from the remote sensing data sets might be utilized. The main problem is that a ground view is not provided by the stereo images in between the forested areas due to off-nadir viewing disposition usually inherent to them. Such locations would have to be detected and used in order to discriminate and extract the ground model.

Therefore, steeper image acquisitions should be used, and optionally the combination of multiple stereo pairs with smaller base-to-height ratio and their treatment as bundle of image acquisitions should be envisaged. The steeper look angles and smaller intersection angles, respectively, assure the achievement of increased ground view, while the multiple stereo pair approach preserves an optimum 3D mapping accuracy as usually inherent to stereo pairs being acquired at larger base-to-height ratios. The benefit of this approach was tentatively shown in an investigation related to a bundle of Spot 5 images, comprising forward, nadir and backward view (Raggam, 2004).

6 REFERENCES

(1) Caballo-Perucha M. (2003): Development and analysis of algorithms for the optimisation of automatic image correlation. Master thesis, Post-graduate University Course Space Science, Karl-Franzens-Universität Graz, Dezember 2003

(2) K. Gutjahr, H. Raggam, and M. Franke (2004): Herleitung digitaler Oberflächenmodelle aus hoch-auflösenden Stereo-Bilddaten im alpinen Gelände. Österreichische Zeitschrift für Vermessung und Geoinformation (VGI), submitted for publication, March 2005.

(3) J. Kremer, and M. Gruber (2004): Operation of the UltraCamD together with CCNSa/Aerocontrol – first Experiences and Results. International Archives of Photogrammetry and Remote Sensing, XXth ISPRS congress, Istanbul, 12 – 23 July 2004, published on DVD, 6 pages.

(4) Paar G. und Pölzleitner W. (1992): Robust disparity estimation in terrain modelling for spacecraft navigation. Proc. 11th ICPR, International Association for Pattern Recognition, 1992

(5) H. Raggam, M. Franke and K. Gutjahr (2004): Surface Model Extraction from High Resolution Stereo Data over Alpine Terrain. 24th Earsel Symposium "New Strategies for European Remote Sensing", Dubrovnik, May 25 – 27, 2004.

(6) H. Raggam, 2004. Accuracy Analysis and Surface Mapping Using Spot 5 Stereo Data. International Archives of Photogrammetry and Remote Sensing, XXth ISPRS congress, Istanbul, 12 – 23 July 2004, published on DVD, 6 pages.

(7) Space Imaging (2005): Homepage published at http://www.spaceimaging.com

(8) H. Stelzl, A. Wimmer, H. Raggam, O. Sacherer, A. Almer and C. Banninger (2004): Monitoring Mediterranean Wildlands with Very High Spatial Resolution Satellite Imagery for Fire Prevention and Control. "IEEE International Geoscience and Remote Sensing Symposium (IGARSS)", Anchorage, 20-24 September 2004, published on CD-ROM.