FUSION OF OPTICAL AND RADAR REMOTE SENSING DATA: MUNICH CITY EXAMPLE

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ABSTRACT:

Fusion of optical and radar remote sensing data is becoming an actual topic recently in various application areas though the results are not always satisfactory. In this paper we analyze some disturbing aspects of fusing orthoimages from sensors having different acquisition geometries. These aspects are errors in DEM used for image orthorectification and existence of 3D objects in the scene. We analyze how these effects influence a ground displacement in orthoimages produced from optical and radar data. Further, we propose a sensor formation with acquisition geometry parameters which allows to minimize or compensate for ground displacements in different orthoimages due the above mentioned effects and to produce good prerequisites for the following fusion for specific application areas e.g. matching, filling data gaps, classification etc. To demonstrate the potential of the proposed approach two pairs of optical-radar data were acquired over the urban area – Munich city, Germany. The first collection of WorldView-1 and TerraSAR-X data followed the proposed recommendations for acquisition geometry parameters, whereas the second collection of IKONOS and TerraSAR-X data was acquired with accidental parameters. The experiment fully confirmed our ideas. Moreover, it opens new possibilities for optical and radar image fusion.

1. INTRODUCTION

Data fusion is an extremely emerging topic in various application areas during the last decades. Image fusion in remote sensing is one of them. However fusion of different sensor data such as optical and radar imagery is still a challenge. In this paper the term ‘radar’ is equivalent to Synthetic Aperture Radar (SAR). Though the data fusion is well spread over different communities there are quite few attempts of its definition. The first one is the so called JDL information fusion definition (U.S., 1991) popular in military community. This definition is based on the functional model including processing levels and full control on sensors thus making it difficult to transfer to other communities. Another data fusion definition more suitable for a broader community is introduced in (Pohl, 1998) mainly emphasizing (and thus simultaneously limiting to) methods, tools and algorithms used. A more general definition is proposed in (Wald, 1999; Data Fusion Server) as a formal framework in which are expressed the means and tools for the alliance of data originating from different sources. According this definition an alignment of information originating from different sources now becomes a part of the fusion process itself.

There exist numerous remote sensing applications e.g. image matching and co-registration (Suri, 2008), pan sharpening (Klonus, 2008), orthoimage generation, digital elevation model (DEM) generation, filling data gaps, object detection, recognition (Soergel, 2008), reconstruction (Wegner, 2009) and classification (Palubinskas, 2008), change detection, etc which are already profiting or can profit significantly from a data fusion.

For the fusion of data from sensors exhibiting different acquisition geometries such as optical and radar missions it is important to understand their influence on a fusion process and to optimize it if necessary. Of course having not a full control on sensors as in a military community it is not so easy but is still possible to influence some acquisition parameters. In this paper we analyze the effect of ground displacements in orthoimages of optical and radar sensors due to the height error in the DEM used during orthorectification process and 3D objects characteristics (height) for various data acquisition parameters such as sensor look angle (elevation) and look direction, satellite flight direction and sun illumination direction.

The paper is organized in the following way. First, the methodology used for the proposed approach is presented in detail. Then, data used in experiments are described, followed by the presentation of experimental results, conclusion, acknowledgments and finally references.

2. METHOD

In this section we analyze two effects: height error in DEM used during orthorectification process and 3D object height and their influence on ground displacements in orthoimages from optical and radar sensors. The study results in a proposal of several data acquisition parameters: sensor look angle (elevation) and look direction, satellite flight direction and sun illumination direction leading to an optimal sensor formation for the following optical and radar data fusion.

2.1 Effect of DEM height

Ground displacement Δx due the height error Δh in the DEM for an optical and a radar sensor orthoimage is shown in Figure 1.

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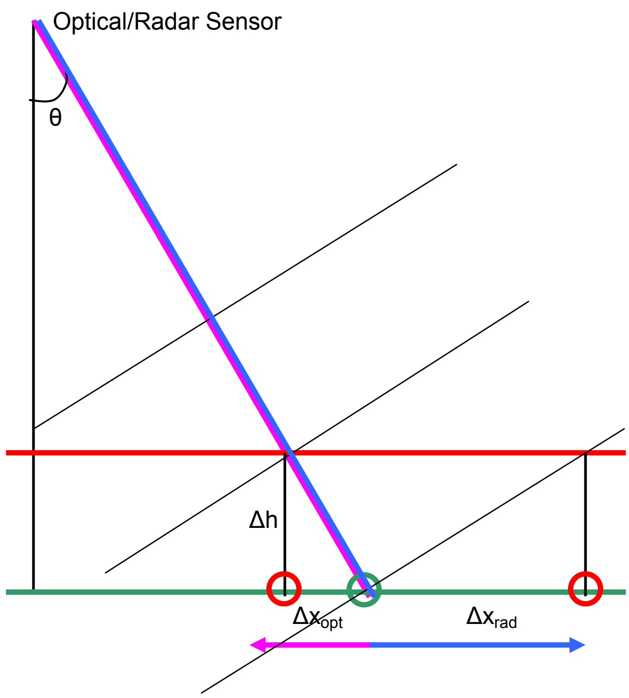

Figure 1. Ground displacement Δx due the height error Δh (positive and negative) in a flat DEM for an optical and radar sensor orthoimage. Look directions: pink line for an optical sensor, blue line – radar sensor. The green horizontal line stands for a true DEM, whereas the red line stands for an error in the DEM (same for both sensors). Similarly, the green circle stands for a true ground position of a 2D point, whereas the red circle – a displaced position. Thin black lines perpendicular to blue line show approximately the radar wave propagation. Flight track is into plane.

Ground displacements are equal to

$$\Delta x_{opt} = \Delta h \cdot \tan \theta_{opt} \qquad (1)$$

for optical sensors and

$$\Delta x_{rad} = \frac{\Delta h}{\tan \theta_{rad}} \qquad (2)$$

for radar sensors. We have to note, that ground displacements are towards the sensor for the optical case and opposite for the radar case (sign of displacement is ignored in formulae). For details on radar geometry see e.g. (Oliver, 1998).

2.2 Effect of 3D object height

Ground displacement Δx for a 3D object of Δh height for an optical and a radar sensor orthoimage is shown in Figure 2.

Formulae for ground displacements are the same as in the previous sub-section: for optical case equation (1) and radar case - (2). The only difference is a displacement direction: it is away from sensor for the optical case and opposite for the radar case.

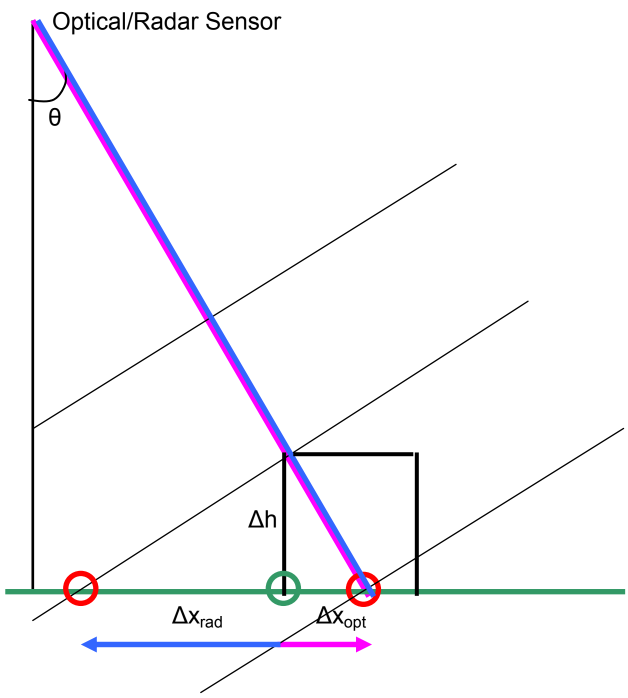

Figure 2. Ground displacement Δx for a 3D object of Δh height for an optical and radar sensor orthoimage. Look directions: pink line for optical sensor, blue line – radar sensor. The green horizontal line stands for a flat DEM, which doesn't include height information of objects. The green circle stands for a true ground position of a 3D point, whereas the red circle – a displaced position. Thin black line perpendicular to blue line shows approximately the radar wave propagation. Flight track is into plane.

2.3 Equality of displacements

We have seen in the previous sub-sections that sizes of ground displacement are different (different formulae) for optical and radar sensors and, moreover, displacement directions are opposite for different sensors. The size equality of ground displacements

$$\Delta x_{opt} = \Delta x_{rad} \qquad (3)$$

is fulfilled for the following sensor look (elevation) angles

$$\theta_{opt} + \theta_{rad} = 90° \qquad (4)$$

We have to note, that smaller ground displacements are obtained in case of

$$\theta_{opt} < \theta_{rad} \qquad (5)$$

In order to compensate opposite displacement directions for different sensors the look directions of different sensors should be opposite. Under the conditions of (4) or (5) structures in optical and radar images appear almost in the same positions thus leading to an easier interpretation and further processing of joint data.

2.4 Optimal sensor constellation

In this sub-section we propose an optimal optical and radar sensor formation for an image acquisition compensating/minimizing ground displacement effects of different sensors (see Figures 3, 4). A sum of look angles should give approximately 90° (Figure 3).

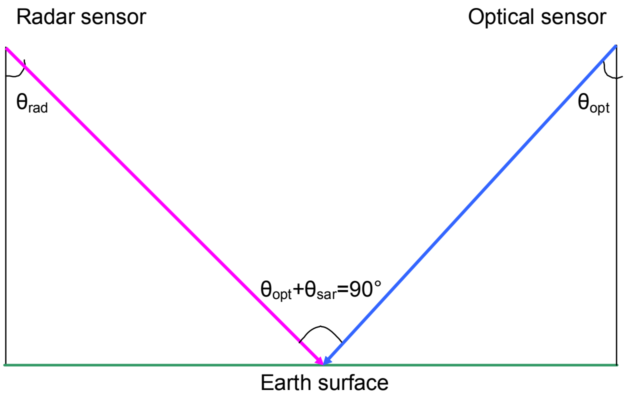

Figure 3. Proposed optical and radar sensor formation is illustrated. A sum of look angles should give 90°.

Flight directions should be as parallel as possible and perpendicular to look directions which are opposite for different sensors (Figure 4). Same flight directions are not required in general e.g. airborne case. A sun illumination direction is from an optical sensor to the target on the Earth in order to see a side of a 3D object which is in shadow in radar image and thus enable full reconstruction of a 3D object. This sensor configuration allows a recovery of 3D object shadows during further data fusion, except a case when the Sun illumination direction is the same as for SAR look direction. Displayed left looking radar and right looking optical sensor formation can be preferable due to the Sun illumination direction which is from an optical sensor to the target on the Earth in order to see that side of a 3D object which is in shadow in the radar image and thus enable full reconstruction of a 3D object. Of course, the second sensor formation with a right looking radar and left looking optical sensor can be useful for data fusion too.
Our approach could be applied in both airborne and space remote sensing. As an example we consider the latter one.
Currently, most space optical remote sensing satellites are acquiring data in descending mode, so a radar satellite should also acquire in a descending orbit. Thus both satellites would fly in the same direction (quasi-parallel orbits). The requirement of opposite look angles and a special sun illumination direction result in a left looking radar sensor and a right looking optical sensor what is achievable with current radar missions though not in a nominal mode (left looking radar). Additionally, larger look angle of SAR sensor than look angle of optical sensor allows minimizing the sizes of ground displacements.

3. DATA

The German Aerospace Center DLR and DigitalGlobe have been engaged in a modest R&D project to investigate complementary uses of Optical and Radar data. Coordinated collections of high resolution TerraSAR-X (TS-X) and WorldView-1 (WV-1) data during July-August 2009 have been acquired. For this experiment one scene of WorldView-1 over Munich city, Germany has been acquired. For more detail on TS-X see (Eineder, 2005). Other scenes of the same urban area of TerraSAR-X and IKONOS have been ordered from existing archives.

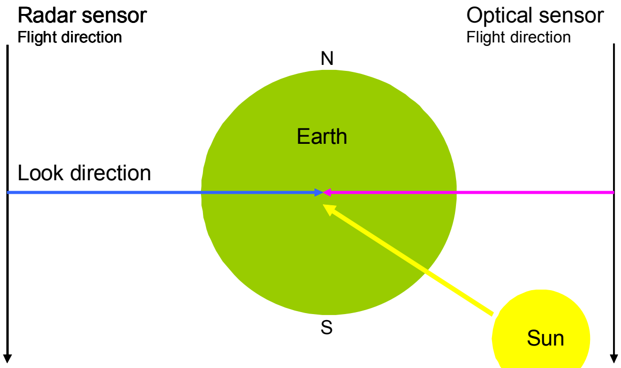

Figure 4. Proposed optical and radar sensor formation is illustrated. Flight directions should be parallel, in same direction and perpendicular to look directions which are opposite for different sensors (right drawing). Sun illumination direction is from an optical sensor to the target on the Earth.

4. EXPERIMENTS

Two experiments, one with a proposed sensor formation and one with an accidental sensor formation were performed to show the potential of our approach. The optical image has been corrected for absolute position by ground control, which yielded a global shift value of approximately 10 m in x-direction for the WV-1 data and 6 m in x-direction and 2 m in y-direction for the IKONOS data in comparison to image rectification without ground control. TS-X data Enhanced Ellipsoid Corrected (EEC) product can be used without ground control, since absolute positioning Root Mean Square Error (RMSE) for the Spotlight mode is in the order of 1 m (Bresnahan, 2009).

4.1 Proposed sensor formation

Scene parameters for the proposed sensor formation experiment are presented in Table 5.

Sensor / Parameter	TS-X	WV-1
Image data	7-Jun-2008	18-Aug-2009
Image time (UTC)	05:17:48	10:50:42
Mode	Spotlight HS	PAN
Look angle	49.45° Right	38.3° Left
Polarization	VV	-
Product	EEC	L2A
Resolution gr x az (m)	1.0 x 1.14	0.89 x 0.65

Table 5. Scene parameters of the first experiment over Munich city

Part of Munich city acquired by WV-1 (upper image) and TS-X (lower image) using the proposed satellite formation is shown in Figure 7. Yellow grid lines are for better orientation between the two images. Ground objects like streets and plazas as well as structures e.g. buildings and trees can be easily detected in both images and are found at the same geometrical position in both images. Only the feet of the buildings, which are differently projected in the radar image due to foreshortening are found at different positions. The roofs and tree crowns are well in place and can be overlayed correctly for any further processing. Groups consisting of 2, 5 and 6 buildings are highlighted in blue color in both images to show a good correspondence.

4.2 Accidental sensor formation

Scene parameters for the accidental sensor formation experiment are presented in Table 6.

Sensor / Parameter	TS-X	IKONOS
Image data	25-Feb-2008	15-Jul-2005
Image time (UTC)	16:51:15	10:28:06
Mode	Spotlight HS	PAN
Look angle	22.75° Right	5.0° Right
Polarization	VV	-
Product	EEC	Orthoimage
Resolution gr x az (m)	1.6 x 1.3	0.8 x 0.8

Table 6. Scene parameters of the second experiment over the city of Munich

Again, part of Munich city acquired by IKONOS (upper image) and TS-X (lower image) using the accidental satellite formation is shown in Figure 8. Yellow grid lines are for better orientation between two images. For this case it is quite difficult to find corresponding structures in the two images. Only ground objects like streets can be found at similar places but buildings are represented in very different geometry and can be hardly allocated to each other. Also from a radiometric point of view the differences are higher than in Figure 7 probably due to different shadow properties. The same groups consisting of 2, 5 and 6 buildings as in sub-section 4.1 are highlighted in blue color in both images again. In this case it is quite difficult to identify the same number of buildings in both images.

5. CONCLUSIONS

In this paper we address a problem of fusion of optical and radar remote sensing imagery. Alignment of information coming from different sources is an important prerequisite for the following fusion in various applications. Especially for a rapid fusion of optical and radar data a specific imaging is of advantage. We propose an optical and radar sensor formation which accounts for different acquisition geometries and minimizes displacements for ground and 3D-objects in orthoimages of optical and radar sensors. The preferred sensor formation is a perpendicular viewing from the two sensor systems due to the complimentary nature of their viewing geometries. For this case the image geometries are nearly independent to errors in the underlying DEM and especially to buildings or other 3D objects, not represented in the DEM. A fast and consistent overlay of the two data sets for on ground and other surfaces is reached. As an example two pairs of high resolution optical (WorldView-1 and IKONOS) and radar (TerraSAR-X) images have been acquired over the urban area - Munich city in Germany – for different sensor formations. Results show a great potential of the proposed approach for further applications of data fusion with optical and radar instrumentation since the geometric positions of the objects can be observed at the same absolute position.

REFERENCES

Bresnahan, P., 2009. Absolute Geolocation Accuracy Evaluation of TerraSAR-X Spotlight and Stripmap Imagery – Study Results. In: *Proceedings of Civil Commercial Imagery Evaluation Workshop, 31 March – 2 April 2009, USGS, Fairfax Virginia, USA.*

Eineder, M., Schättler, B., Breit, H., Fritz, T. and Roth, A., 2005. TerraSAR-X SAR products and processing algorithms. In: *Proc. of IEEE International Geoscience and Remote Sensing Symposium (IGARSS'05), 25-29 July, 2005, Seoul, Korea*, IEEE, vol. VII, pp. 4870-4873.

Klonus, S., 2008. Comparison of Pansharpening Algorithms for Combining RADAR and Multispectral Data. In: *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. Volume XXXVII, Part B6b, Beijing, China, pp. 189-194.

Palubinskas, G. and Datcu, M., 2008. Information fusion approach for the data classification: an example for ERS-1/2 InSAR data. *International Journal of Remote Sensing*, vol. 29(16), pp. 4689-4703.

Pohl, C. and van Genderen, J. L., 1998. Multisensor image fusion in remote sensing: concepts, methods and applications. *International Journal of Remote Sensing*, 19(5), pp. 823-854.

Oliver, C. and Quegan, S., 1998. *Understanding Synthetic Aperture Radar Images*. Artech House, Boston.

Suri, S. and Reinartz, P., 2008. Application of Generalized Partial Volume Estimation for Mutual Information based Registration of High Resolution SAR and Optical Imagery. In: *Proc. of 11th International Conference on Information Fusion (FUSION'2008), June 30 – July 3, 2008, Cologne, Germany*, pp. 1257-1264.

The Data Fusion Server. Available from: http://www.data-fusion.org/ (Accessed 24 February 2010)

U.S. Department of Defense, Data Fusion Subpanel of the Joint Directors of Laboratories (JDL), Technical Panel for C3, "Data fusion lexicon," 1991.

Wald, L., 1999. Some terms of reference in data fusion. *IEEE Transactions on Geosciences and Remote Sensing*, 37, 3, pp. 1190-1193.

Wegner, J.D., Auer, S., and Soergel, U., 2009. Accuracy Assessment of Building Height Estimation from a High Resolution Optical Image Combined with a Simulated SAR Image. In: *Proc. of ISPRS Hannover Workshop 2009 - High Resolution Earth Imaging for Geospatial Information, 2-5 June, 2009, Hannover, Germany*, ISPRS, vol. XXXVIII-1-4-7, part W5.

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Figure 7. Part of Munich city acquired by VW-1 (upper image) and TS-X (lower image) using the proposed satellite formation. Yellow grid lines are for better orientation between two images. Red arrows show flight (az) and look (rg) directions.

Figure 8. Part of Munich city acquired by IKONOS (upper image) and TS-X (lower image) using the accidental satellite formation. Yellow grid lines are for better orientation between two images. Red arrows show flight (az) and look (rg) directions.