INFORMATION EXTRACTION
USING OPTICAL AND RADAR REMOTE SENSING DATA FUSION

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ABSTRACT

Information extraction from multi-sensor remote sensing imagery is an important and challenging task for many applications such as urban area mapping and change detection. Especially for optical and radar data fusion a special acquisition (orthogonal) geometry is of great importance in order to minimize displacements due to an inaccuracy of the Digital Elevation Model (DEM) used for data ortho-rectification and due to the presence of unknown 3D structures in a scene. Final data spatial alignment is performed manually using ground control points (GCPs) or by a recently proposed automatic co-registration method based on a Mutual Information measure. These data pre-processing steps are of a crucial importance for a success of the following data fusion. For a combination of features originating from different sources, which are quite often non-commensurable, we propose an information fusion framework called INFOFUSE consisting of three main processing steps: feature fission (feature extraction for complete description of a scene), unsupervised clustering (complexity reduction and feature conversion to a common domain) and supervised classification realized by Bayesian/Neural/Graphical networks. Finally, a general data processing chain for multi-sensor data fusion is presented. Examples of buildings in an urban area are presented for very high resolution space borne optical WorldView-2 and radar TerraSAR-X imagery over Munich city, Germany in different acquisition geometries including the orthogonal one. Additionally, theoretical analysis of radar signatures of buildings in urban area and its impact on the joint classification or data fusion is discussed.

KEYWORDS: multi-sensor fusion, ortho-rectification, co-registration, classification, change detection

INTRODUCTION

Data fusion is a rapidly developing 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). Different modalities of data can be obtained by different sensors for the same area, and more properties can be revealed on the area structure, contents and properties. Incommensurability of different sources of data (e.g. optical, SAR, and DEM) requires a proper design of fusion process. For example in (Benediktsson, 1990 and 1997) statistical versus neural network approaches for multisensory data fusion and classification are investigated. Linear and logarithmic opinion pools optimized by multilayer neural network are proposed for combination of multisensory data (multispectral, elevation, slope, aspect, and SAR). Several approaches for multisensory data fusion following consensus theory and employing different techniques such as Bayesian networks, neural networks and fuzzy logic approaches were developed e.g. see results of fusion contest (Pacifici, 2008) or urban area classification (Fauvel, 2006).

We approach the joint optical and radar data classification task using a more general view on the whole data fusion problem. Thus data acquisition planning and pre-processing become very important steps for a successful data fusion. Additionally, we discuss some problems of classification arising from different acquisition geometries of data.

The paper is organized as follows. First, in Section 2 we present a general processing chain for multi-sensor data fusion. Then, in Section 3 the data used in this work are described in detail. Moreover, the special (orthogonal) multi-sensor formation geometry for optical/SAR data acquisition is proposed aiming at easier data evaluation/interpretation in further processing steps. One of such examples for WorldView-2 and TerraSAR-X data is illustrated in the following Section. Pros and cons of such acquisition are discussed and consequences for a classification are derived. The Section 5 is dealing with the building signatures in optical and radar imagery, influence of DEM and Digital Surface Model (DSM) used during the ortho-rectification process and consequences for the following feature extraction. The paper ends with conclusions, acknowledgments and references.

PROCESSING CHAIN

A proper preparation of data is a very important prerequisite for a successful data fusion. A general approach for data processing chain is presented in Figure 1.

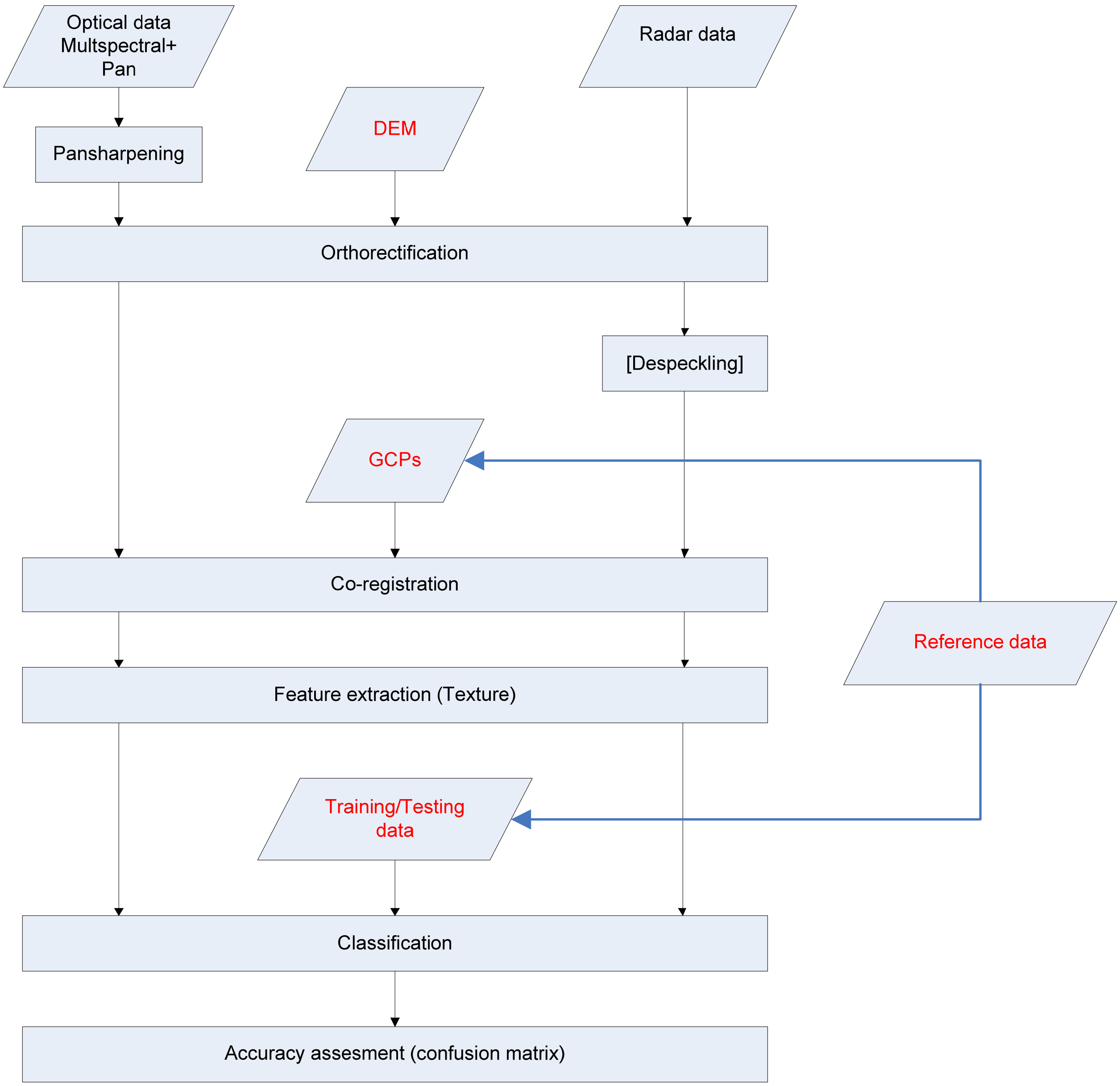

Figure 1. Optical and SAR data processing chain.

Below is the detailed explanation of the separate steps:

- Input image data are of multi-sensor nature. Two acquisition geometries are possible:
  - Accidental acquisition geometry

    - Orthogonal acquisition geometry (Palubinskas, 2010a)
- Pansharpening of optical multispectral data using panchromatic band to enhance pixel resolution simultaneously preserving spectral characteristics (Palubinskas, 2011a)
- Despeckling of SAR data is optional
- Additional data (marked in red) are used:
    - Digital Elevation Model (DEM) for orthorectification
    - Reference data for ground control points (GCPs) und training/test data extraction
- Orthorectification of imagery using available DEM/DSM
- Manual co-registration of multi-sensor images using extracted GCPs (Reinartz, 2011)
- Feature extraction from input images
    - Gabor texture
- Fusion und classification methods:
    - Maximum likelihood (ML)
    - Neural networks (NN)
    - Support vector machines (SVM)
    - INFOFUSE (Palubinskas, 2008)
- Classification accuracy assessment by calculating confusion matrices for test data

Here we have to note that a simple stacking of all available data (e.g. optical and radar) and their features and then applying one of the above mentioned classifiers for the fusion can result in unstable results especially for urban area mapping. For example, sometimes the addition of radar information to optical data increases the classification accuracy, but quite often the quality decrease is observed (Makarau, 2011a and 2011b; Palubinskas 2011b). We try to explain the reasons for such instability or randomness of urban area classification in Sections 4-5.

DATA

For our experiments data over the test site Munich, Germany were selected and acquired. Descending orbit for SAR data is preferable for fusion applications, because optical data are always acquired in descending orbit. Additionally, orthogonal acquisition geometry for optical/SAR data is interesting and is investigated in our experiments.

Orthogonal Acquisition Geometry

In this Section we propose an optimal optical and radar sensor formation for image acquisition compensating and minimizing ground displacement effects of different sensors (Palubinskas, 2010a and 2010b). A sum of look angles should give approximately 90° (Figure 2a). Flight directions should be as parallel as possible and perpendicular to look directions which are opposite for different sensors (Figure 2b). Same flight directions are not required in general e.g. airborne case. This sensor configuration allows e.g. 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 possible sensor formation with a right looking radar and left looking optical sensor can be useful for data fusion too.

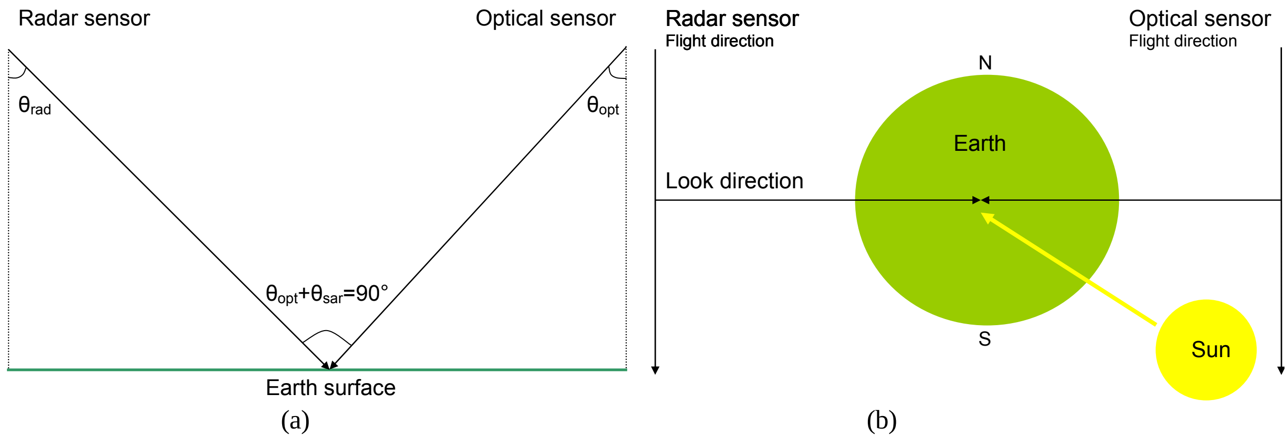

Figure 2. Proposed optical and radar sensor formation is illustrated. A sum of look angles should give 90° (a). Flight directions should be parallel, in same direction and perpendicular to look directions which are opposite for different sensors (b). Sun illumination direction is from an optical sensor to the target on the Earth.

Two pairs of optical and SAR data were investigated in further experiments:
1. TS-X 07-06-2008 and WV-2 12-07-2010 (different years, similar season) and
2. TS-X 30-08-2010 and WV-2 23-09-2010 *orthogonal* (same year, similar season)

Experiment 1

Scene parameters for data of the first accidental acquisition geometry experiment over Munich city are presented in Table 1.

Table 1. Scene parameters of the first experiment over Munich city

Sensor / Parameter	TerraSAR-X	WorldView-2
Image date	07-Jun-2008	12-Jul-2010
Image time (local)	06:17:48	10:30:17
Mode	Spotlight HS	PAN+MS
Look angle	49.95° Right	5.2° Left
Polarization	VV	-
Product	EEC	L2A
Resolution gr x az (m)	1.0 x 1.14	0.47 x 0.47
Pixel spacing (m)	0.5	0.5

Footprints of the both scenes for the first experiment overlaid on Google map are shown in Figure 3.

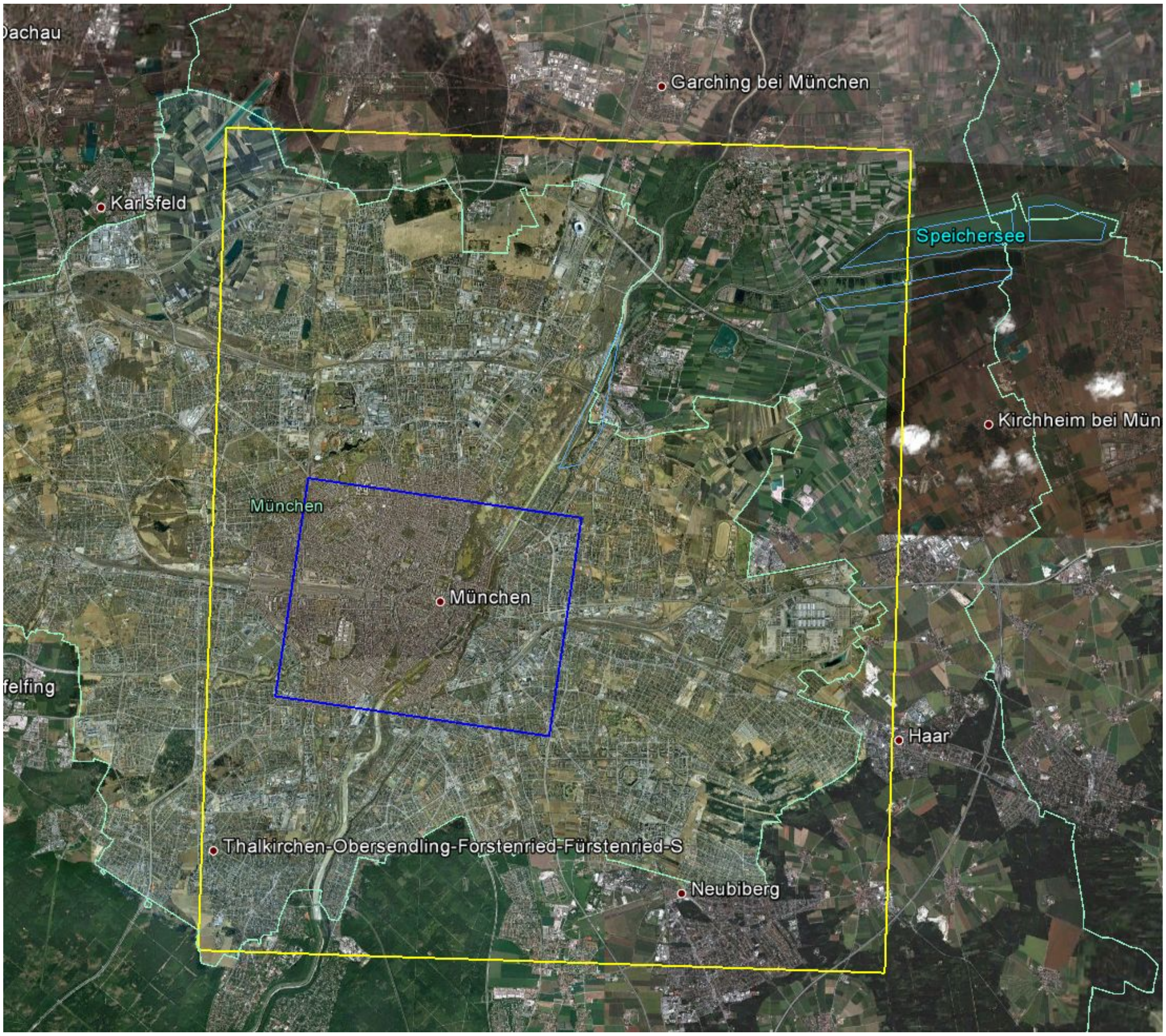

Figure 3. Footprints of the both scenes for the first experiment overlaid on Google map.

Experiment 2

Scene parameters for data of the second orthogonal acquisition geometry experiment over Munich city are presented in Table 2.

Table 2. Scene parameters of the first experiment over Munich city

Sensor / Parameter	TerraSAR-X	WorldView-2
Image date	30-Aug-2010	23-Sept-2010
Image time (local)	06:18:03	11:15:44
Mode	Spotlight HS	PAN+MS
Look angle	50.07° Right	42.8° Left
Polarization	VV	-
Product	EEC	L1B
Resolution gr x az (m)	1.0 x 1.15	0.70 x 1.02
Pixel spacing (m)	0.5	0.5

Footprints of the both scenes for the second experiment overlaid on Google map are shown in Figure 4.

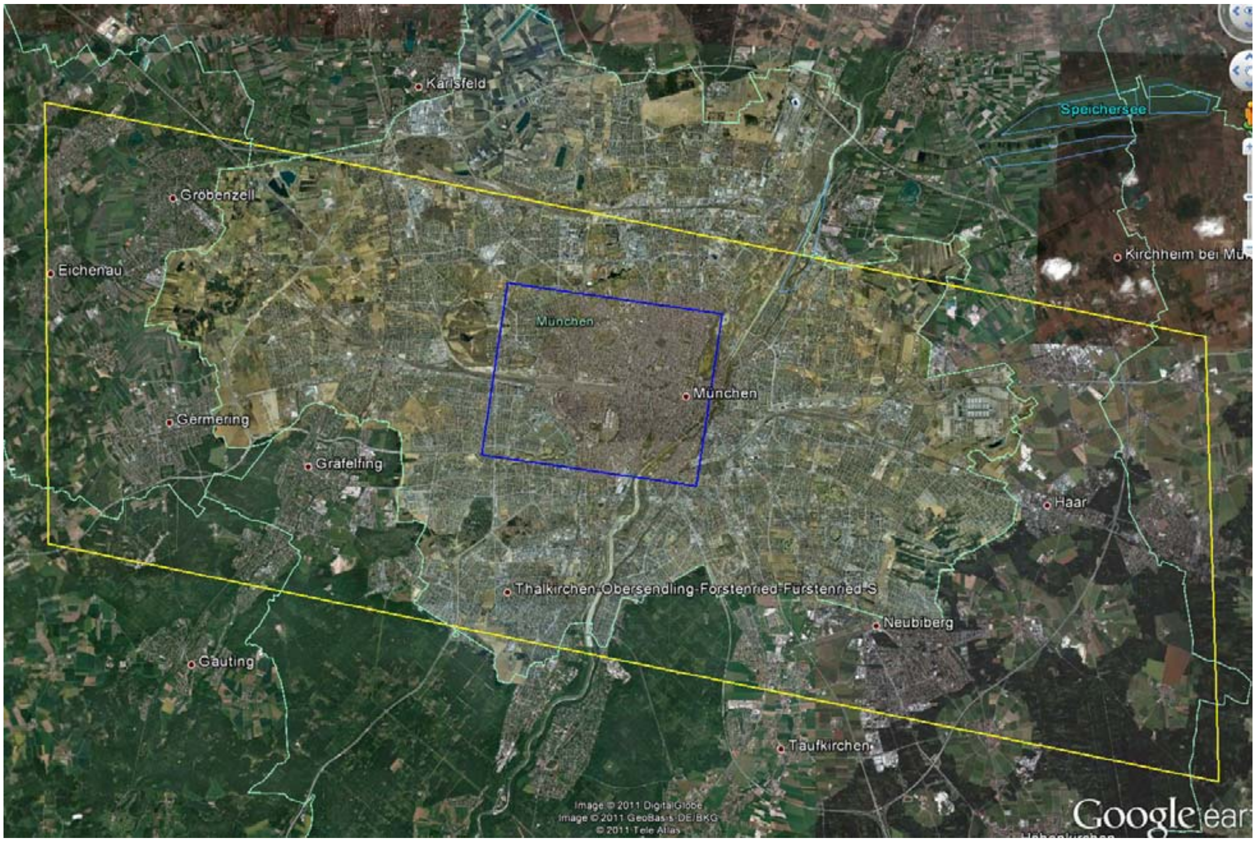

Figure 4. Footprints of the both scenes for the second experiment overlaid on Google map.

Other Processing Parameters

Because it is known that TerraSAR-X imagery exhibit a very accurate geo-location several manually extracted GCPs in corresponding optical and SAR data were applied to enhance the ortho-rectification accuracy of optical imagery (Reinartz, 2011). Thus a quite good co-registration of the multi-sensor data was achieved.

EXAMPLE OF ORTHOGONAL ACQUISITON GEOMETRY

In this Section mainly visual analysis of optical and radar data pairs acquired in different geometries is presented.
In Figure 5 we present an example of two pairs of optical and radar images which shows the influence of acquisition geometry: accidental (a-b) and orthogonal (c-d) for selected buildings in urban area (part of the city Munich). For better understanding we note that the illumination for optical sensor is from left to right and for radar sensor from right to left. We can see clearly, that for the first pair (a-b), roofs of vertical buildings are projected in layover areas (mixed signatures) in the radar image and the vertical street in the middle of the image is projected in the shadow area (no signature) in the radar image. For other orientations of buildings and streets other correspondences between optical and radar data will be observed. Thus the naive classification (simple stack of data) will lead to random results. For the orthogonal projection we can observe a fully different picture. Again, data are not directly usable for classification or mapping applications. Of course, this orthogonal configuration can be useful for 3D model reconstruction purposes because e.g. the building is seen from opposite sides in different images. Both radar images look similar due similar acquisition parameters (compare Tables 1-2).

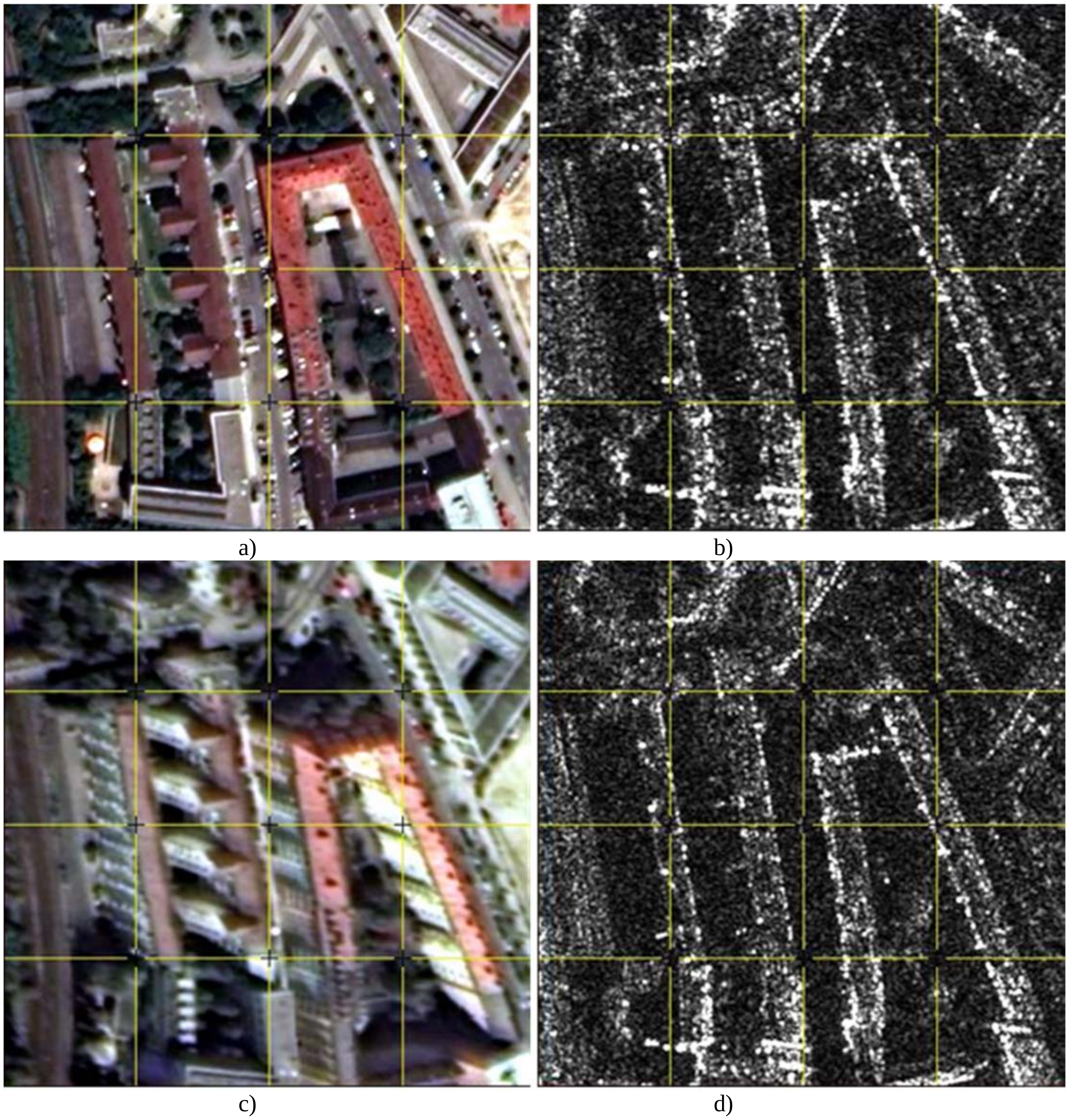

Figure 5. Example of acquisition geometry: accidental (a-b) and orthogonal (c-d) for selected buildings in urban area. Yellow grid is used for better orientation in images.

BUILDING SIGNATURE IN SAR ORTHOIMAGE

In order to understand better e.g. how a building is projected in a radar orthoimage one must look in detail at SAR image formation process as shown in Figure 6. Green box shows the projection of SAR image using DEM whereas orange box – DSM. It is assumed that a building with a gable roof (yellow color) is standing on a flat ground (green line).

Green box shows how parts of a building are projected on the ground. Starting analysis from left to right, first come two layover areas (L1, L2, red color), each composed of three different contributions from building and ground (mixed radar signature). Then follow the right roof (R, blue), which is the only true radar signature but projected in a wrong location. Finally, comes a shadow area (S1, S2), where eventually other neighboring buildings can be projected. So for this type of building only a small part of the roof (right roof) is unambiguously projected on the ground but unfortunately in the wrong place. So the naive fusion of such SAR orthoimage with optical data makes no sense or will deliver random and unstable results for such type buildings. Other objects will produce other patterns thus individual analysis is needed.

Orange box shows how parts of a building are projected on the ground using DSM or 3D model for ortho-rectification. First two layover areas are identical as in the previous case. Then come two interpolated copies of a first layover (L1) and one interpolated copy of a second layover (L2). Layover area is almost two times larger than in the previous case. The roof part is smaller (interpolated) in this case and is only partly projected in the correct location. Shadow areas (S2) are the same. Again, such orthoimage is not much more useful for the classification purposes than in the previous case, only a small part of a roof is displayed in approximately correct location. Illustration is performed for simplicity in 1D case. 2D case will be much more complex to interpret or understand.

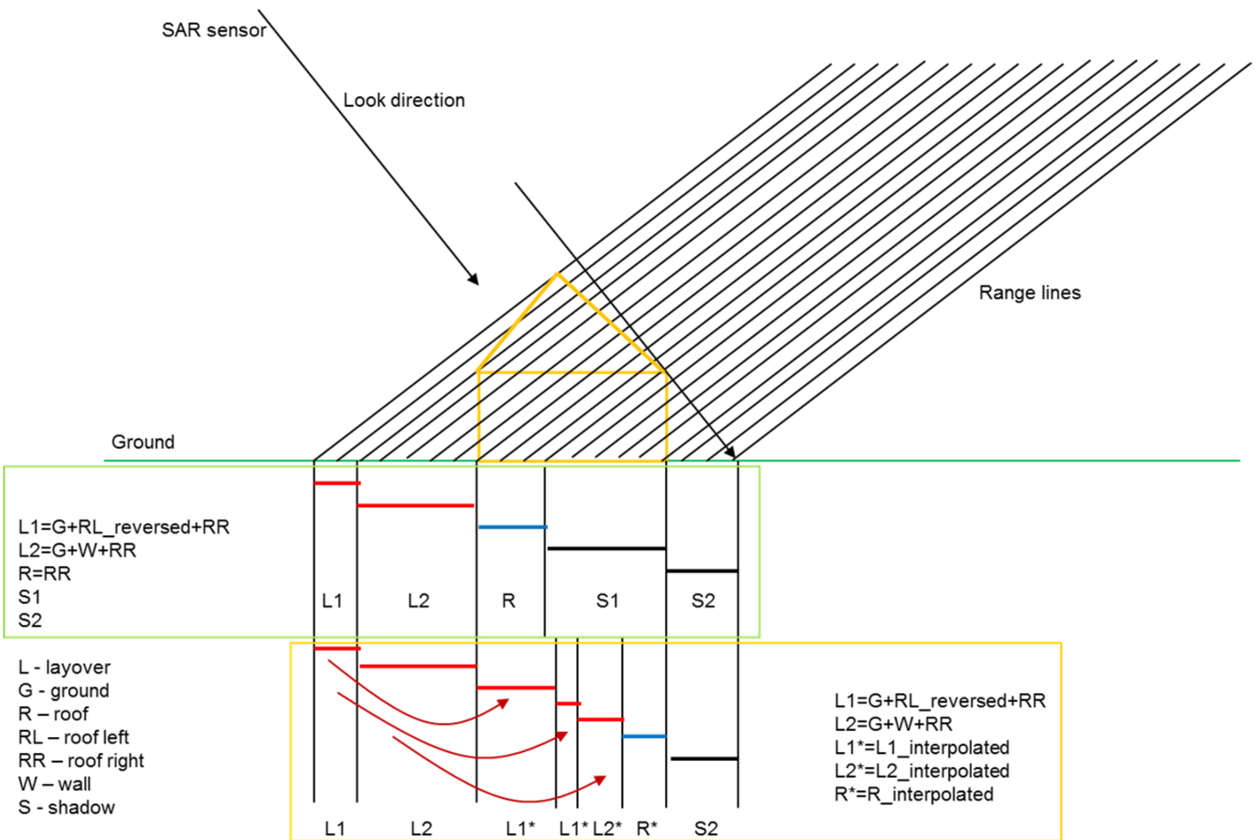

Figure 6. Example of building projection in SAR orthoimage using DEM (green box) and DSM (orange box).

This analysis shows that ortho-rectification of a radar image in urban area should be performed very carefully. DSM or 3D model is necessary to obtain a true othoimage of an object. Image area suitable for a fusion with optical data should be extracted using DSM by simulation tools (e.g. Tao, 2011a and 2011b). This can reduce the amount of data suitable for the fusion drastically. Further research can be devoted towards unmixing layover and resolving shadow areas.

CONCLUSIONS

The approach for the joint optical and radar data classification task using a more general view on the whole data fusion problem is presented. Thus the importance of pre-processing steps such as data acquisition planning, ortho-rectification and co-registration for a successful data fusion is shown. Additionally, some problems of classification arising from different acquisition geometries of data are discussed.

Presented analysis has shown the importance of the availability of a very good DSM for data fusion of different views and acquisition geometries in order to prepare such data (orthorectify and co-register) for the classification and change detection applications. Investigation on the simulation of optical and radar images using various qualities of DSMs is needed in order to exclude ambiguous regions such as layovers and shadows in an orthoimage. Further work can be directed towards unmixing of layover areas e.g. using multi-temporal data acquisitions.

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