EVENT-DRIVEN CHANGE-DETECTION IN URBAN ENVIRONMENTS USING SAR

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ABSTRACT:

SAR sensors are able to operate under nearly all weather conditions, at daylight or in the night. This is especially beneficial for event-driven applications, like time-critical change-detection for disaster management. Unfortunately, SAR systems suffer from occlusions and ambiguities, especially in urban areas. Additionally, due to layover and foreshortening effects, the geo-referencing of SAR images, which is a prerequisite for a change detection, is problematic in urban areas. The initial geo-referencing of the SAR data can be automatically improved using street vectors. By comparing image chips from the SAR image, to the transformed street data, correspondences can be found, which can be used for geo-referencing. Change-detection, combining newly acquired SAR images with other types of data, should use 3D-groundtruth, due to the side-looking property of SAR sensors. The result of the SAR simulation, based on 3D-data, is compared to the real SAR image. It is possible to even use simple models and assumptions for the simulation, like for example lambertian reflection.

1. INTRODUCTION

Urban environments are very unfavourable for remote sensing purposes, due to the dense placement of buildings and man-made structures. This requires a good resolution, to distinguish between these structures. Nowadays, modern high-resolution airborne SAR systems reach resolutions up to 10cm (Ender & Brenner, 2003), which is more than enough for remote sensing applications in urban areas.

Urban areas are important for remote sensing, because they are of the utmost importance for human society. In 2001, around 50% of the human population lived in cities and these numbers are rising (UNCHS, 2001). Urban environments are mostly fast changing environments and therefore change-detection is always an important applications there, especially during special events, i.e. disasters.

Under these circumstances, using SAR has some advantages. SAR is an active system and is hence able to operate at day and night, under smoke and almost all weather conditions, which is crucial for time-critical applications. But beside the advantages, there are also a lot of disadvantages, especially while using SAR in urban environments. The run-time geometry and side-looking properties of the SAR system are leading to occlusions and ambiguities, especially in the dense inner city areas.

Because of these disadvantages normally SAR is not used for data collections in urban environments. Buildings can, for example, be more conveniently reconstructed using LIDAR (Haala & Brenner, 1999), although it is possible to reconstruct buildings from InSAR (Soergel, 2003). But in event-driven time-critical applications, the weather independence of the SAR sensor is decisive.

2. SAR PRINCIPLE

SAR systems are using different wavelengths than optical systems. But that is not the only difference. The different geometrical properties are also important. Both make it difficult to combine optical and SAR images. Since SAR systems are run-time systems, the position of a pixel in the image depends on the distance between the sensor and the imaged object.

In Figure 1, the SAR geometry is shown schematically in range direction, which is normally perpendicular to the flying direction of the sensor.

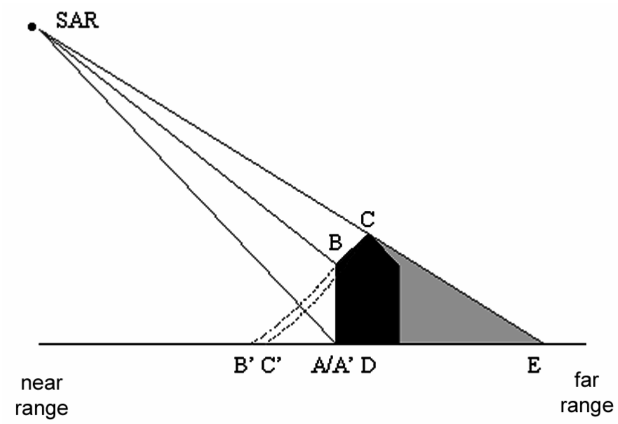

Figure 1. SAR geometry in range

Point A is imaged correctly in A', whereas the points B and C are imaged in B' and C', closer to near range, as their real position. This so-called layover-effect is caused by the run-time geometry of the SAR sensor. The range between A and E is the shadow area. Because of the displacement of point C in C' the shadow is starting at point A and not at point D.

The brightness of the pixel in a SAR image is determined by the backscattered energy. Thus, the SAR image intensity depends on the roughness and the dielectric constant of the depicted material. Additionally, the shape of the depicted object has a major influence on the brightness. Therefore, especially if an object consist of similar materials, the appearance in a SAR image mainly depends on the shape as well as the sensor and platform parameters.

3. EVENT-DRIVEN SAR DATA ACQUISITION

The oblique SAR illumination limits the visible area in a SAR image, especially in urban areas. Because of this limitation, the mission planning is very important for any event-driven SAR data acquisition. The area of interest should, of course, be visible in the SAR image and should be as less disturbed, by shadows and occlusions, as possible. This requires some forward planning. Having a terrain model and a 3D-city model of the area of interest, the best data acquisition parameters can be determined by SAR simulating this data. The impact of the SAR phenomena on the visibility of the objects in the area of interest can be simulated for any flight and illumination direction (Soergel et al, 2003). Using this simulations, the optimal flight parameter can be chosen. Sometimes it will be necessary to use multiple flights from different aspect, viewing and squint angles. Still it will be possible, that some regions in dense inner city areas, will not be visible at all.

For time-critical applications, it is important to get fast results. The whole time span, between identifying the area of interest until the final data delivery, is important. Modern SAR systems are equipped with on-board quick-look SAR processors (Hoffmann & Fischer, 2002), allowing a first look on the acquired data, which is especially beneficial for analysing the visibility of the area of interest during data acquisition. If the area of interest is not clearly visible, the data can be acquired again, using different parameters.

Using an UAV as sensor platform, instead of an airplane, could reduce the time-to-information even more, due to the long-time on-duty capabilities of some UAVs. The Northrop Grumman Global Hawk, for example, can stay up to 32 hours on station and could, using the direct data downlink, nearly constantly deliver data from the area of interest (Stacy et al, 2002).

4. SAR-SIMULATION

For the presented approach, the SAR simulator is the key element, because a SAR simulator helps the human operator understanding SAR images by simplifying the reality. Although a SAR simulator does not simulate all SAR phenomena, SAR simulators are often used for training purposes. Additionally SAR simulators are also very useful for automated target recognition applications.

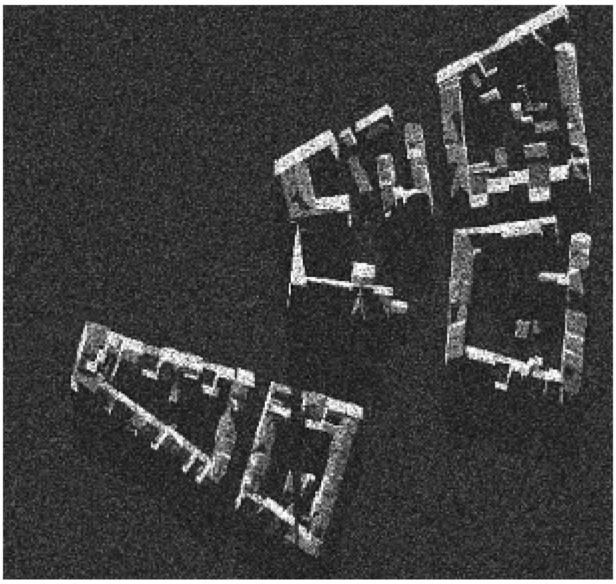

Figure 2. Simulated SAR image

In Figure 2, a simulated SAR image is visible. The simulation is based on a 3D-city model of Karlsruhe, automatically generated using LIDAR data and ground plans (Haala & Brenner, 1999). The 3D-city model was simulated using the SARView Light SAR simulator (basis version) of the EADS Dornier GmbH. In Figure 3, the corresponding real DOSAR image is visible. DOSAR is the multifrequency polarimetric airborne SAR system of the EADS Dornier GmbH (Hoffmann & Fischer, 2002). The flight direction is 90.05°, the off-nadir angle is 70°, the pixel resolution is 0.26m and the 3dB-resolution is about 0.57m.

Figure 3. Subset of a DOSAR image of Karlsruhe

There are large differences between the real SAR image and the simulation, but most of the difference are related to the incompleteness of the 3D-city model used for the simulation. But beside the missing objects, the appearance of buildings is quite similar. The results of the SAR simulation can be used to analyse the differences between the real SAR image and the 3D-city model.

5. AUTOMATED GEO-REFERENCING

The prerequisite of a change-detection, is a reliable geo-referencing of the data. The data analysed for changes and the newly acquired data must be co-registered. The co-registration of data, acquired by different sensor types, is not a trivial task. It requires attention to the specific sensor properties.

For the automated geo-referencing of SAR data, 3D-data as ground-truth is most beneficial. But 3D-city models are not widely available. In the approach, described in this paper, street data is used as ground-truth. GDF-street vectors are commonly available and are covering a huge area. These standard datasets are e.g. provided for car-navigation systems. The street vectors are transformed to a consistent map projection. Afterwards, the street vectors are SAR simulated, based on a DEM of good quality, if available.

Streets in SAR images appear dark, because the street surface is very smooth and reflects the SAR beam away from the sensor. Therefore, less energy is reflected back to the sensor. Strong reflecting objects atop the street, like cars and signs, are not taken into consideration in this approach. It is assumed, that streets can be found by their network structure.

The flight direction and the rough position of the SAR image, which should be delivered as meta-information together with the SAR image, have to be known for further processing. The initial coordinates of the DOSAR flight over Karlsruhe mentioned above, have an offset of about 150m. Obviously the data cannot be used directly for change detection purposes with such an offset. This spatial reference should be improved, using the GDF-street data, which have an accuracy of around ±3m (Walter, 1997).

The fundamental idea of the approach described in this paper, is to extract subsets from the street dataset. These subsets are SAR simulated and the results of the SAR simulation is compared to the real SAR image. This comparison should lead to correspondences between the SAR image and the street data.

For a stable geo-referencing, these search areas should be evenly spread across the real SAR image. To find and assign correspondences correctly and stable, the chosen subsets should include many streets and junctions. Unfortunately, the streets and junctions are normally not evenly spread across SAR images, making it a trade-off between the required spreading of the correspondences and the required amount of street junctions per subset.

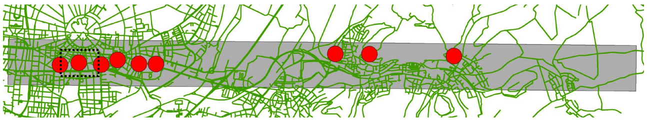

Figure 4. Footprint of the SAR image and the search areas

In Figure 4, the resulting unfavourable distribution can be seen. The main problem in the distribution of the search areas is the fact, that they are mainly located on one line. This is due to the small width of the SAR image strip and yields to a high sensibility for errors in range direction. Unfortunately, the overall error in range direction is influenced by the near range displacement of the assumed street position in SAR images, especially in inner city areas, as depicted in Figure 5.

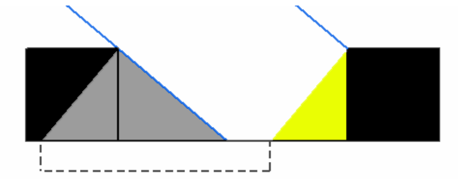

Figure 5. Assumed street position shifted in near range

Streets are assumed to be dark areas in SAR images, thus can not be distinguished from shadows and vice versa. Buildings next to streets influence the appearance of the street, due to shadow and layover. The dark area in the SAR image, assumed to be the street, can be a shadow, whereas the bright area of the building layover may be situated atop the street. This leads to a misinterpretation of the street position. The street seems to be closer to near range.

The algorithm searching for correspondences is comparable to a correlation. It assumes, that streets are dark areas in the image, while the surrounding areas are relatively bright. The algorithm analyses every pixel in the search area, by summing the pixel values of the real image in regions where, according to the street data, streets reside. These values are divided by the sum of the pixel values where no streets reside. The pixel with the lowest calculated value in the search area is the point with the highest concurrence.

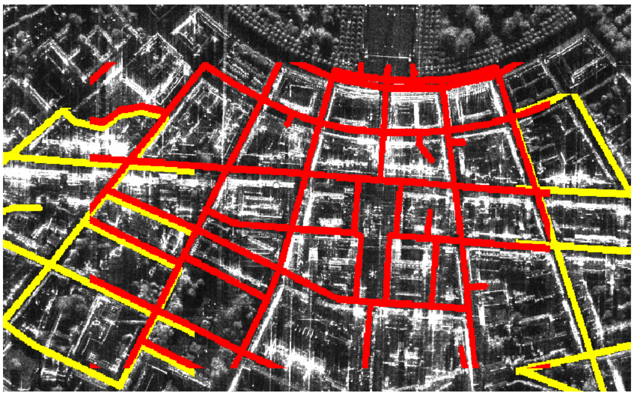

Figure 6. Three search area mapping results overlaying a DOSAR image

In Figure 6, the resulting differences caused by the near range shift can be seen. Three search area mapping results, from the region marked in Figure 4, are overlaid to a DOSAR image. The results mainly differ in range direction, while their positioning in azimuth matches quite well. The length of the shift depends on the height of the neighbouring buildings and the incident angle. The differences in range appear to be mainly caused by the shift, shown in Figure 5. The overall positioning although is rather good.

Outside of inner city areas, the automated geo-referencing method described in this paper has some problems, since only very few streets occur in this patch. Additionally, the small contrast between streets and the surrounding area, is another problem.

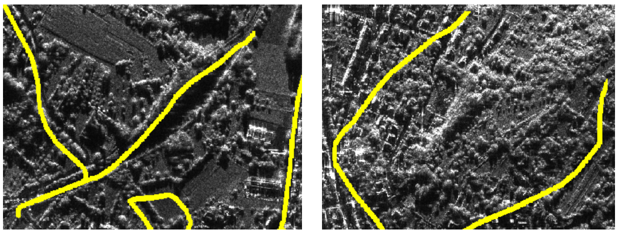

Figure 7. Erroneous mapping results overlaying a DOSAR image

Obviously there is some shift in the data on the left side of Figure 7, but the position is approximately correct. The shift seems to be caused by the large shadow of the forest area in the middle of the image. The position, in the example on the right side, is apparently totally wrong. The lower contrast and the lack of junctions in this example, causes this failure.

Because of the possible erroneous matching result and the near range shift of the correspondences, more correspondences than needed for the transformation must be found. By overestimating the transformation, some of the erroneous correspondences can be removed and the influence of the near range shift on the final result can be reduced.

An accuracy of the overall spatial reference of around 6m is achieved by the method described above. This error is caused mainly by the inaccurate street data and by the near range shifting of the streets. Still a good improvement of the overall accuracy is achieved.

6. CHANGE-DETECTION

Prerequisite for the change-detection is the co-registration of the different data sets, as it was demonstrated in the previous section. Changes of building heights, or roof shapes, are important indications for damages and are very important in disaster management applications.

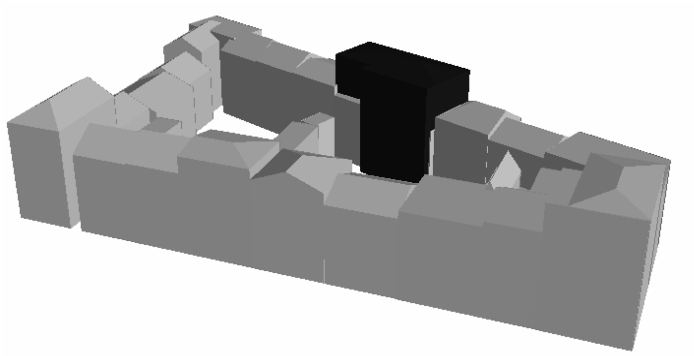

Figure 8. Changed 3D-model

After the improved geo-referencing using 2D street data, the co-registration of the different data sets have to be further improved. This is done using the 3D-information of the city model. Event-driven change detection in urban environments using SAR, should be based on 3D-data, because buildings are three dimensional objects. Available building models are being simulated and the results of these simulations are compared to the real SAR image, to locally improve the co-registration of the data.
After the successful co-registration, differences between the simulated model and the real SAR image can be identified automatically. In Figure 8, the 3D-model used for the change detection can be seen. The black building has been added to the model for the change-detection.

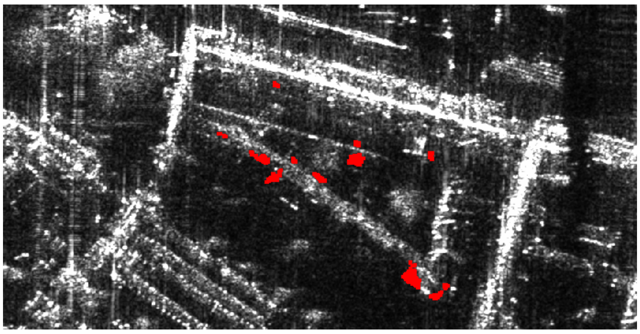

Figure 9. Detected changes of the building block overlaying a DOSAR image

The detected changes are visible in Figure 9. Not only the changes from the artificially inserted house are visible, but additionally some changes in the centre of the building block are visible and even larger differences are detected in the south-east corner of the block. These changes are related to the incomplete and erroneous city-model.

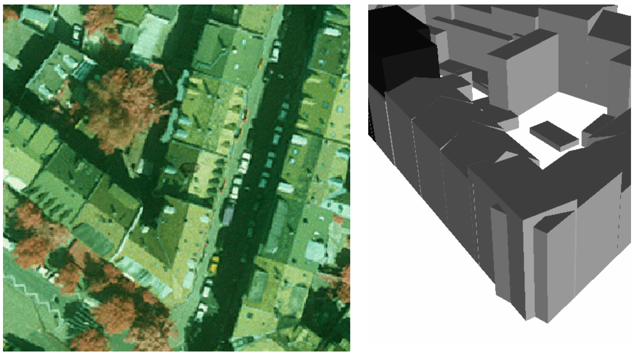

Figure 10. Orthoimage (left) and erroneous shaped 3D-model (right)

Incomplete, or even erroneous, models have to be always taken into account. This most certainly disturbs the automatic change-detection and leads to poor results or a lot of manual rework. Under these circumstances, tools for operator assisted building reconstruction based on SAR simulation, are more suitable for a fast reconstruction (Balz & Haala, 2003).

7. CONCLUSION

Within this article co-registration of SAR images to existing GIS-data for geo-referencing purposes has been demonstrated. Using street vectors, transforming, SAR simulating and comparing the results to the SAR image, correspondences can be found. Beside the different difficulties, i.e. due to the near range shift of the street, the initial offset of around 150m could be improved to approximately 6m.
For change detection in urban areas the availability of any 3D-data is indispensable. 3D-data instead of 2D-data should be used for a reliable change detection using SAR images. The side-looking property of a SAR system makes it most important to regard the 3D-shape of the analysed object. The SAR simulated image of the 3D-models, can be compared to the real SAR image. As a result of this comparison changes may be detected automatically. The final result of the change detection depends on the quality and completeness of the used 3D-model.
Incomplete, erroneous or the total lack of a 3D-city model may force the usage of manual reconstruction. Again a SAR simulator is a fundamental tool here. Simple building models can be reconstructed and their SAR simulated appearance can be compared to the real SAR image for manual change-detection purposes.

8. ACKNOWLEDGEMENTS

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