MONITORING URBAN DEVELOPMENT USING ENVISAT ASAR

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ABSTRACT

To monitor and manage urban areas a lot of information is necessary for different tasks. One way to obtain such information is to apply change detection to satellite images. A system is developed to apply this technique on SAR images. The core of the system is an adaptive speckle-noise filter. To study urban monitoring it was applied to Envisat ASAR images of Leidsche Rijn, one of the largest housing and industrial developments in The Netherlands at this moment. Special about Envisat ASAR is that it enables to study alternating polarisations. In case of urban monitoring there is evidence that HH and HV are most favourable. Applying the change detection system to these images, both polarisations show different parts of the developments and complete each other. The filter is able to deal with the speckle noise in both polarisations and the increased thermal signal-to-noise level in HV. The major changes that were detected in the Envisat ASAR images correspond with the major housing and industrial developments at that moment. Smaller changes correspond to smaller developments and relocated objects such as ships. Generally can be said that some changes are better detected in HH and some in HV because of the different scatter mechanisms of the developments and their backgrounds, and consequently the ratio between their radar returns. In false alarm reduction one has to be careful not to reject too much true changes. Rejection of false alarms can be done using object-based and context-based features.

INTRODUCTION

By now the majority of the world population is living in urban areas and their number is growing. To monitor and manage urban areas a lot of information is necessary for different tasks such as health care, supplies, waste management and legal matters.

This paper presents the results of a change detection system that makes it able to monitor urban development based on geocoded SAR images. Several change detection techniques are possible (i). Chosen was to develop a system based on an adaptive speckle-noise filter.

With this system, changes in Envisat ASAR data of urban areas in The Netherlands were studied. Envisat ASAR was chosen because it enables monitoring with alternating polarisations and different incidence angles. In case of monitoring urban environments the following SAR parameters are preferred (ii, iii):

- L, C, or X band
- Incidence angle between 35º and 50º
- HH and HV polarisation (HV interesting to investigate urban land use) or quad pol

Due to the resolution of Envisat (30 m) small objects can not be fully analysed. However, the same system can be used in combination with higher resolution satellites such as Radarsat 2, TerraSAR X and airborne SAR systems.

The Netherlands was chosen because of a large number of development projects that take place at the moment, especially in the west. With that, it is one of the most densely populated countries in the world.

Next section discusses the change detection system, followed by a description of the test area Leidsche Rijn. The paper will end with results and conclusions.

CHANGE DETECTION SYSTEM

The change detection system consists of three elements:

- Co-registration – Although geocoded images are often well registered to an ellipsoid or the earth surface, small deviations of a few pixels can occur. Because the detection of changes is sensitive to such errors the images are accurately co-registered using correlation techniques. With the help of FFTs the co-registration speed is high.
- Change detection – When the images are co-registered, changes can be extracted by division or subtraction. Most important in SAR change detection is to deal with the speckle noise. This is done by applying a dedicated speckle filter (iv). The speckle filter is optimised to enhance the processing time for large images such as Envisat ASAR APG. The reduction of false alarms (i.e. false detections) is also an issue.
- Information management – The detected changes are offered to an information management system that is able to query changes, view changes over longer periods of time, combine changes with other geospatial information and to help the interpretation.

Table 1 and Figure 1 give a more detailed overview of the system modules and their functions. The actual change detection module (the orange box) is split into three functions. The parameter selection module is included as a central interface that converts the user requirements and sensor characteristics into suitable algorithm parameters.

The system is implemented in Erdas Imagine (http://gis.leica-geosystems.com/) using its C++ developers toolkit. The information management system and database will be implemented in ArcGIS (http://www.esri.com/) but this system is beyond the scope of this paper.

Table 1. Overview of change detection system modules.

module	**function**
co-registration	accurate and fast co-registration of SAR images based on FFTs
speckle filter	speckle-noise filter, output is filtered difference image
thresholding	threshold difference image
false-alarm reduction	reduce false alarms by feature-based selection
information management	query and classification of changes based on object features and additional maps, change database
parameter selection	translation of product settings and sensor characteristics in algorithm parameters (e.g. threshold, number of looks, date/time, map)

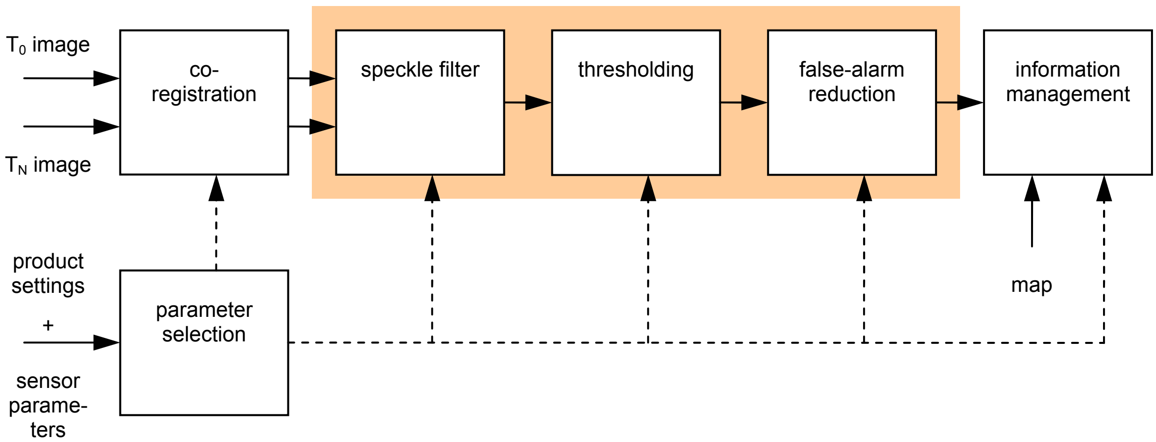

Figure 1: The SAR change detection system.

ENVISAT ASAR DATA

Envisat was launched by ESA in March 2002. The Advanced SAR (ASAR) on board of the satellite acquires SAR images of the earth's surface. ASAR is a C-band SAR.

The most important requirement of a SAR system so that it can be used for automatic change detection is that the images are acquired using similar tracks and imaging geometry (i.e. the point of view from which the images are taken). The imaging modes must be the similar too (projection, resolution, pixel spacing, number of looks, etc.). Envisat is a repeat-orbiting satellite and is therefore suitable for this task.

Table 2 gives an overview of the ordered Envisat ASAR images. All images are Alternating Polarisation Geocoded (APG) IS6 mode images. IS6 means an incidence angle between 39.1º and 42.8º. The area that was imaged is 100 x 70 km. Contrary to the resolution of 30 m, the pixel spacing is 12.5 m. The polarisation combination that was chosen is HH/HV. The Equivalent Number of Looks (ENL), a measure for the amount of speckle-noise, is 2. Besides speckle noise, both channels also contains thermal noise which is -22 (sigma zero noise level IS6, worst case) (v). Ulaby and Dobson (vi) give average values of -12 and -17 for respectively HH and HV of vegetation in C-band, which means that the signal-to-noise (S/N) ratio in HV is worse than that in HH. Urban areas often result in higher radar backscatter, smooth surfaces in lower backscatter.

Table 2: Overview of ordered Envisat ASAR images of The Netherlands.

orbit	frame	shift (nodes)	date	mode	pol
04993	1035	-5	12-02-2003	IS6	HH/HV
10504	1035	-5	03-03-2004	IS6	HH/HV
15514	1035	-5	16-02-2005	IS6	HH/HV
18520	1035	-5	14-09-2005	IS6	HH/HV

LEIDSCHE RIJN, THE NETHERLANDS

The Envisat ASAR images were scanned for changes using colour composites in which the before image is put in the red channel and the after image in the green and blue channels. This way an image is created in which the colours are complementary, meaning that changes occur in red or cyan and non-changes in a tone of grey. See also Figure 3 upper left and upper right image. So it was observed that there is a lot of activity at Leidsche Rijn, one of the largest housing and industrial development in the Netherlands (http://www.leidscherijn.nl/). It measures 30,000 houses (about 80,000 residents) and 700,000 m^2 of office accommodation (about 40,000 employees). Because there is a lot of additional data of this project, it was chosen as a test area for studying urban development using Envisat ASAR. Besides, the project started in 1998 and is planned to be finished in 2015, so the time span of development is long.

Figure 2 shows a PHARUS image and an overview of the project with the different residential and industrial estates (vii). PHARUS is the airborne polarimetric SAR of TNO Defence, Security and Safety that was operational from 1995 to 2001 (viii). From the PHARUS image can be seen that the project has started with the estates Veldhuizen, Langerak, Parkwijk and De Wetering. Vleuten, De Meern and Oudenrijn were already there before the project started. In the centre of the project a lot of greenhouses is seen that will be moved outside the project to make way for a central park. The PHARUS image also shows existing residential and industrial areas of Utrecht, northeast of Leidsche Rijn.

The PHARUS image can be compared to what is to be expected from Radarsat 2 and TerraSAR X. Because the image that is shown is part of a sequence of three images (15 July 1999, 27 January 2000 and 5 July 2001) this can also be used for change detection. However this is not evaluated yet and will be part of another study. The period of these images cover the beginning of the development project.

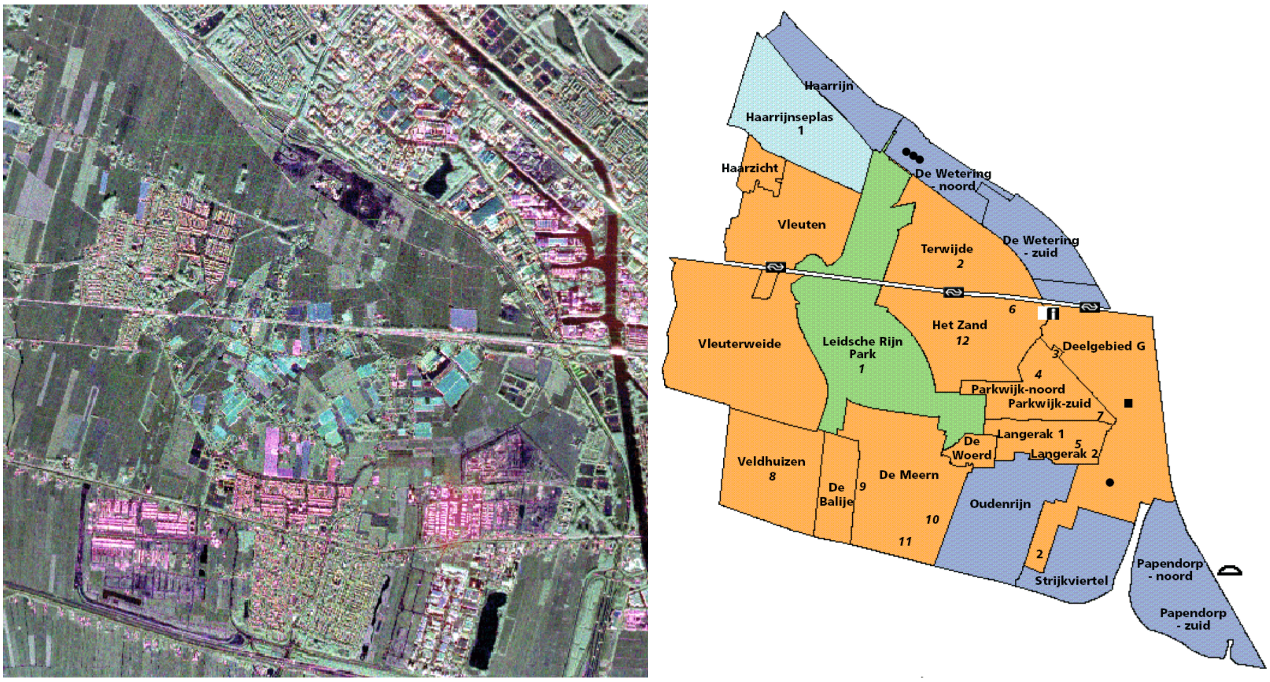

Figure 2: PHARUS image of Leidsche Rijn of 27 January 2000 (left) and an overview of the project (vii) (right). Orange = residential, deep blue = industrial, pale blue = lake, green = park.

RESULTS

Figure 3 shows the colour composites of the HH and HV channels of the Envisat ASAR images of 12 February 2003 and 14 September 2005. In this period many changes are observed. An increase in radar backscatter (often new dwellings) appears in red. A decrease of the radar backscatter (e.g. new lake, clearings) appears in cyan. The detected objects projected on top of the original HH and HV images show different parts of the development and complete each other. The colours correspond to those of the colour composites. The threshold was set to 6 dB.

From the composites and the original ASAR images can be seen that the S/N ratio due to thermal noise in HV is worse than that in HH, especially in the new lake Haarrijnseplas, the dark patch in the upper part of the area. Although thermal noise has another characteristic than speckle-noise, the speckle filter will reduce the thermal noise too. Therefore the number of false alarms due to thermal noise will be reduced too. Note that Figure 3 shows the result after speckle filtering and thresholding, false alarm reduction has not been applied here. However, most changes correspond to actual developments.

The major changes in the Envisat images correspond with the development of the estates Vleuterweide, Terwijde, De Balije and De Wetering, see also Figure 2 and 4. Most changes are new dwellings. Changes in De Wetering are new enterprises and a sound barrier for the motorway, see Figure 4 (d). Another major change that has been detected in HH is the second part of the new lake Haarrijnseplas, behind Terwijde, see also Figure 4 (b) and (d). Hardly detected but seen in the colour composite of HV is the demolition of the greenhouses in the areas Leidsche Rijn Park and Het Zand. The reason for that is that greenhouses are built up of large metal frames. Many bars are not oriented accordingly with the orthogonal radar H-V basis and result in a backscatter components in HV. Generally can be said that some changes are better detected in HH and some in HV because of the different scatter mechanisms of the developments and their backgrounds, and consequently the ratio between their radar returns.

Other changes that are detected are smaller changes such as smaller developments, and changes in the existing industrial area northeast of Leidsche Rijn such as relocated ships and other objects, see also Figure 5. Some of these smaller changes are false, for example the changes related to the large reflection shaped like a cross in the eastern part of the HH images. Most probably nothing has changed over there except for the intensity of the reflection. This can be due to small changes in the geometry and interpolation effects. False alarm reduction is a difficult task. One has to make a distinction between true and false alarms on some ground, and be careful not to reject too much true changes. Besides, changes can still be queried in the information management system.

A common method to reduce false alarms is to use object-based (e.g. size, shape) or context-based (e.g. land use, land cover) features. Because false alarms are often small, the size of a change is a good measure. Figure 5 shows the result after false alarm reduction, rejecting changes smaller than 5,000 m² (i.e. 32 pixels). In this figure changes in HH and HV are combined because they complete each other. In fact Figure 5 is an example of something that can come out of an information management system showing the contours of changed objects, making interpretation easier.

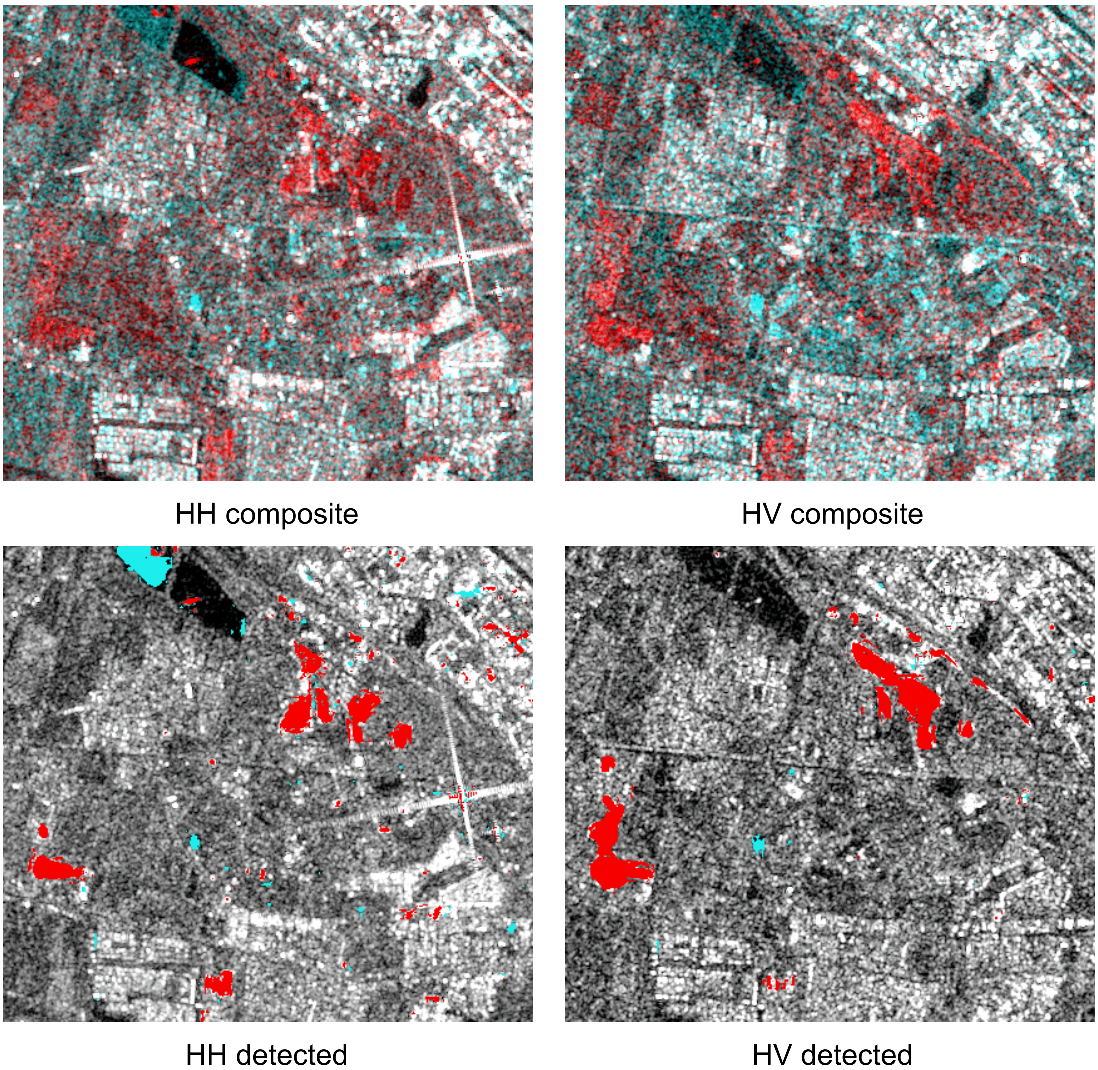

Figure 3: Envisat ASAR colour composites of HH (upper left) and HV (upper right) plus detected changes in HH (lower left) and HV (lower right) on top of the original ASAR HH and HV images of 14 September 2005.

(a)

(b)

(c)

(d)

Figure 4: Aerial photographs of summer 2005 of detected developments in Vleuterweide (a), Terwijde (b), De Balije (c) and De Wetering (d). Source: http://www.leidscherijn.nl/

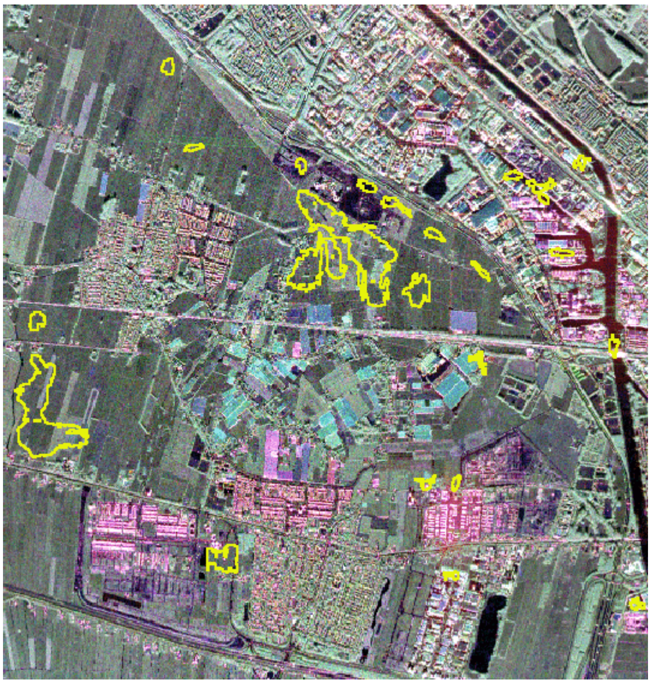

Figure 5: Combined HH/HV change overlay in yellow on PHARUS image of Leidsche Rijn.

CONCLUSIONS

In this paper a SAR change detection system was applied to Envisat ASAR images of Leidsche Rijn to study urban monitoring. Leidsche Rijn is one of the largest housing and industrial developments in The Netherlands at this moment. Special about Envisat ASAR is that it enables to study alternating polarisations. In case of urban monitoring there is evidence that HH and HV are most favourable. Applying the change detection system to these images, both polarisations show different parts of the developments and complete each other. The filter is able to deal with the speckle noise in both polarisations and the increased thermal signal-to-noise level in HV. The major changes that were detected in the Envisat ASAR images correspond with the major housing and industrial developments at that moment. Seen mainly in the HV images but not detected was the demolishing of greenhouses to make way for a central park. Generally can be said that some changes are better detected in HH and some in HV because of the different scatter mechanisms of the developments and their backgrounds, and consequently the ratio between their radar returns. Smaller changes correspond to smaller developments and relocated objects such as ships. Some of these smaller changes are false but in rejecting them one has to be careful not to reject too much true changes. Besides, changes can still be queried in the information management system that follows the change detection system. Rejection of false alarms can be done using object-based and context-based features.

ACKNOWLEDGEMENT

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