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# Updating road databases using change detection techniques

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BELEIDSCOMMISSIE REMOTE SENSING

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# Abstract

The Traffic and Transport Advisory Service (AVV) at RWS supplies information on traffic and infrastructure on land and water. The information which is stored in the National Road Database (NWB) has therefore to be updated regularly. For this purpose remote sensing images are very useful due to their synoptic overview, high update frequency and relative low costs.

With help of change detection techniques remote sensing images of different years are processed into change detection images showing the changes that appeared in the meantime. Different change detection techniques are available and are evaluated in this project. After processing the images into change detection products the NWB can be updated by comparing the change detection images and topographic maps with the existing NWB. For this purpose a GIS-based system is developed.

This report describes the results of a validation study on the usefulness of change detection products from PHARUS, ERS and SPOT imagery for road extraction and the implementation of the results in a GIS-based system.

# Executive summary


The Traffic and Transport Advisory Service (AVV) at RWS supplies information on traffic and infrastructure on land and water. The information which is stored in the National Road Database (NWB) has therefore to be updated regularly. Up to now road maps are based on fieldwork and on data from aerial photography. In order to have a higher update frequency remote sensing images are very useful. They also enclose larger areas and are cheaper than the traditional methods.

The PHARUS high resolution mode is most relevant for urban/road detection applications and is the main advantage of PHARUS over ERS and SPOT. The main advantages of both satellite systems over airborne systems are the larger size of the acquired images and the much lower costs.
The disadvantage of SPOT images compared to radar images is the influence of the position of the sun. The survey is preferred to be planned in the winter period when there is less vegetation, but also a lower position of the sun. Because of this there are more shadowing effects. Also ice and snow can be wrongly detected as a change.
The disadvantage of radar images is the amount of noise present in the images. More processing is needed to remove this noise.

With help of change detection techniques remote sensing images of different years are processed into change detection images showing the changes that appeared in the meantime.
Edge detection: edges are detected by a Sobel-filter as places where large pixel differences occur. By comparing two edge detection images of different years it can be calculated where there is a decrease or increase of edges, as is expected with new roads.
Image subtraction: after a histogram equalisation of both images the pixel values of corresponding areas are subtracted. The resulting image shows the difference in reflection of both images. Significant changes are determined as values above 1,5 x the standard deviation of the difference image.

Roads can be detected with the change detection results from the PHARUS and SPOT images. The ERS images have a bad resolution for detecting changes. The reliability of the detected changes with SPOT and PHARUS, the accuracy of georeferencing, and the resolution are sufficient.
However, it is necessary to perform additional steps after the change detection procedure in order to assess a road extraction procedure. Often only parts of a road are detected. It is therefore necessary to extrapolate (or interpolate) these parts to obtain a complete road.
Furthermore, also non-relevant changes are detected. For example in SPOT images changes in use of agricultural areas are detected which may be wrongly interpreted as changes in roads. The detectability of roads is also dependent on changes in the context like the cultivation of ground surface or new buildings. An expert system designed for the extraction of roads should account for these dependencies.

The future high resolution satellites will give more possibilities to detect the changes of roads automatically. Nowadays, an operator is still needed to classify the different changes that are detected with help of maps and contacting municipalities.

After processing the images into change detection products the NWB can be updated by comparing the change detection images and topographic maps with the existing NWB. For this purpose a GIS-based system CHAD is developed.
Within this application the different sources of information can be displayed and compared geographically. The SPOT change detection images are used in this application for their results in relation to their price. The operator has also the possibility to administrate the researched areas.

# Table of contents

# Chapter 1 Introduction

The Traffic and Transport Advisory Service (AVV) at RWS supplies information on traffic and infrastructure on land and water. To facilitate the supply the information is stored in the National Road Database (NWB). The database consists of a collection of road centre-lines with an administrative layer. The NWB is a complete database. The scale of the database is 1:10.000 and the accuracy of the road lines is 5 meter.
Up to now AVV uses information from the TOP10vector database of the Topographical Survey. With this information the NWB can be updated once in 3 to 4 years. However, a more actual database becomes important because the database will be linked to the Integrated Incidents System (Geïntegreerd Meldkamersysteem).

The most direct way for updating the information in the NWB implies an active role for the local authorities to supply regularly the information on changes in infrastructure or recently constructed roads which is needed to maintain the NWB. However, this information is not passed through to AVV systematically and consequently. This severely hampers the revision of road databases. An update frequency of approximately 1 per year is preferred by AVV for updating the road databases.

In this respect remote sensing techniques are expected to be very useful due to their synoptic overview and high update frequency. By using remote sensing images large areas can be studied for possible changes in infrastructure. Also it is possible to obtain images of an area about each month. Using radar techniques they even can be acquired under cloudy conditions.

The method for updating the NWB with remote sensing techniques can be as follows: two images of the same area but with a time difference of approximately 1 year are processed into a change detection image. AVV imports this image into an ArcView application in order to visualise the changes in relation to reference data like a topographic map, the old and new remote sensing image, the existing road database, etc. From visual comparison the concerning local authorities can be addressed for the actual changes in infrastructure. This approach appeared to be very successful in a former project where AVV used change detection images from SPOT for addressing the local authorities.
Instead of looking in the terrain for changes in infrastructure, this method of visualising changes with remote sensing images implies a more efficient way for AVV to carry out the co-ordinate measurements.

**Objective**

The general objective of this project is to improve the operational aspects of change detection techniques for the revision of existing road databases. An evaluation has been carried out of the change detection results of optical and radar imagery. A system is developed which supports the interpretation of change detection results by integrating the results with road database information, topographic maps and remote sensing imagery.

The full scope of the project consists of:

1) The evaluation of change detection techniques available at TNO–FEL and RWS-MD using multiple sensors;
2) The definition of a GIS-based system in close interaction with the end user AVV which integrates results of change detection and other information.

**Contents**

In this report the results are described of a validation study on the usefulness of change detection products from PHARUS, ERS and SPOT imagery for road extraction. In chapter 2 the approach of the validation is described followed by a description of the change detection methods in chapter 3 and the results of validation in chapter 4. In chapter 5 insight is given in the commercial aspects of the use of PHARUS, ERS SAR and SPOT images for road detection. Chapter 6 contains user requirements for the system which is needed for interpretation of the change detection results and the technical design of the system. Finally the conclusions and recommendations are given in chapter 7.

# Chapter 2 Approach

In this project the areas of interest are selected on the availability of PHARUS images, SPOT images and experiences from former change detection projects.

The following PHARUS images are available:
- a flight path across The Hague and Ypenburg
- a flight path across Amersfoort
- a flight path across Apeldoorn
- a flight path across Tilburg
- a flight path across Utrecht

These images were taken in January 1998 and April 1996.
The available SPOT images are two complete sets of images, taken during the winter 1989-1990 and winter 1996-1997.

Based on former change detection projects it was decided to select the areas of interest at the edges of urban areas. This was decided for the following reasons:
- most of the changes in the road databases take place in these areas
- the problems which take place at edges of plots in agricultural areas are well noticeable in these areas

Except areas from the available PHARUS flight paths a supplementary area was chosen in the east, because there the problems at the edges of plots are even better noticeable by the relative small scale agriculture. In this area the change detection is carried out with only SPOT images.

This results in 7 areas of interest:
1) Amersfoort
2) Apeldoorn
3) The Hague
4) Ypenburg
5) Lochem
6) Tilburg
7) Utrecht

From the available PHARUS images areas are selected with a surface of 1 $km^2$ on the border between the urban and agricultural area. After this the matching SPOT images are selected. From the SPOT images, which have a larger coverage, the concerning areas are selected. These areas are geometrically corrected using the digital topographical map 1:25.000. Finally, from these images the exact areas of 1 $km^2$ are selected.

Two urban areas have been selected for the validation study: 1) The surroundings of Ypenburg with the former military airport and 2) the city of Tilburg. This choice is motivated by the fact that Ypenburg is currently an important building location and that new roads are expected to be found in the surroundings of Tilburg. The results of validation are described in chapter 4.

Besides images from PHARUS and SPOT, also three images from the ERS satellite were used for generating change detection images. These three systems are described in the following paragraphs.

## 2.1 PHARUS

The PHARUS polarimetric SAR is an airborne Synthetic Aperture Radar (SAR) system, developed by TNO Physics and Electronics Laboratory (TNO-FEL), in co-operation with the National Aerospace Laboratory (NLR) and the Delft University of Technology (DUT). PHARUS stands for PHased ARray Universal SAR. PHARUS is an imaging radar for civil and military remote sensing applications. Its practical use for application in road extraction from SAR images has been demonstrated in the PHARUS Familiarisation program (Rijckenberg et al., 1998).

Table 2-1 lists the configuration of the PHARUS system during the acquisition of the data and table 2-2 gives the specifications for the different flight paths.

| SAR mode | resolution (m) | polarisation mode | swath width (km) | θ (deg) | altitude (km) |
|---|---|---|---|---|---|
| Reference | 3.5 | polarimetric | 4.8 | 41° - 68° | 3.0 |

**Table 2-1 The configuration of PHARUS during the data acquisition**

| | Den Haag Ypenburg | Amersfoort | Apeldoorn | Goirle |
|---|---|---|---|---|
| *starting time* | | | | |
| 26 April 1996 | 11:37:53 | 09:56:55 | 10:59:30 | 11:17:58 |
| 27 January 1998 | 14:16:28 | 15:09:54 | 15:19:16 | 14:03:21 |
| | | | | |
| *starting altitude* | | | | |
| 26 April 1996 | 3103.44 m | 3077.26 m | 3122.37 m | 3041.90 m |
| 27 January 1998 | 2977.76 m | 3077.88 m | 3132.98 m | 3006.62 m |
| | | | | |
| *track angle diff.* | 0.064° | 0.005° | 2.277° | 1.613° |
| *look angle diff.* | 2.287° | 1.315° | 1.736° | 3.668° |
| | | | | |
| *record length* | 3400 | 3500 | 3200 | 3500 |
| *nr. of records* | 4000 | 4700 | 4700 | 4700 |
| *pixel spacing* | 1.40574 m | 1.39362 m | 1.51764 m | 1.46400 m |

**Table 2-2 Change detection image specifications**

Figure 2-1 on the following page lists the required steps in the change detection procedure for the PHARUS images. A description of the processing steps is given in chapter 3.

## 2.2 ERS

The ERS SAR is a satellite Synthetic Aperture Radar system. From the ERS the Precision (PRI) images are used, which are processed by ESA. The resolution measures 30 m (PHARUS 4 m) and the equivalent number of looks is 3 (PHARUS 14). The incidence angle of the ERS SAR is 18-22 deg. (PHARUS 41-68 deg.). Two images of 1992 and 1995 were already available, a third image of 1997 was ordered. Table 2-3 describes the dataset.

| *Acquisition date* | *platform* | *orbit* | *frame* |
|---|---|---|---|
| 12 August 1992 | ERS-1 | 7310 | 2547 |
| 21 December 1995 | ERS-1 | 23185 | 2547 |
| 26 December 1997 | ERS-2 | 14033 | 2547 |

**Table 2-3 Available ERS data**

From this dataset, two change detection images can be made, using the 1997 image. To minimise seasonal differences of crop state and leaf-densities of trees, the preference was given to the combination of 1995 and 1997. Both images were acquired during December. Unfortunately it was freezing in December 1995, so even more unwanted differences occurred. Therefore the combination of 1992 and 1997 was chosen.

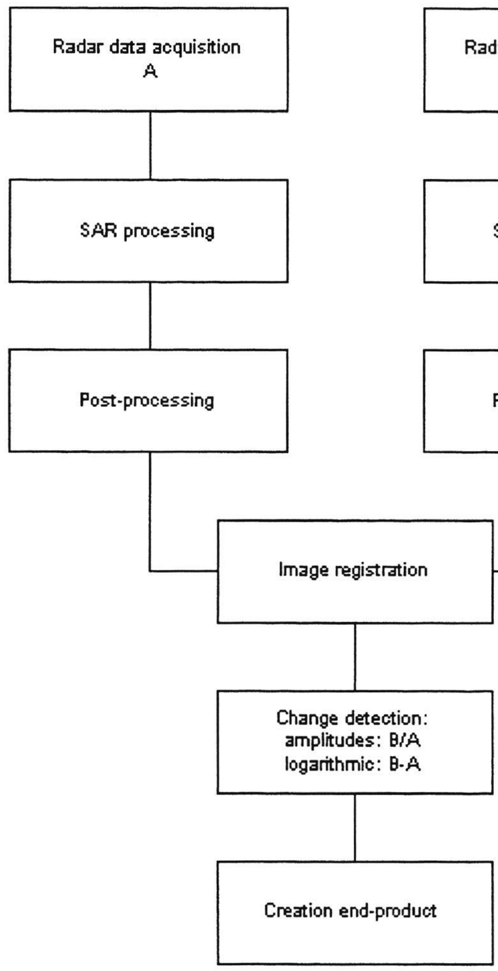



**Figure 2-1 The steps in the change detection procedure for PHARUS and ERS**

The steps required in the change detection procedure for ERS images can be described according to figure 2-1. However, there are some differences in the processing of PHARUS and ERS SAR, see chapter 3.

## 2.3 SPOT

The SPOT satellite contains a multispectral and a panchromatic scanner. In this project the SPOT-PAN images are used. The usefulness of SPOT-PAN imagery for change detection has been shown in former projects for AVV (Wicherson and De Wit,1996, De Wit, 1997).

The panchromatic mode of SPOT delivers images with a ground resolution of 10 x 10 $m^2$. The images cover a ground area of approximately 60 x 60 $km^2$. The look direction is programmable, depending on the user requirements.
Figure 2-2 lists the required steps in the change detection procedure for the SPOT images.

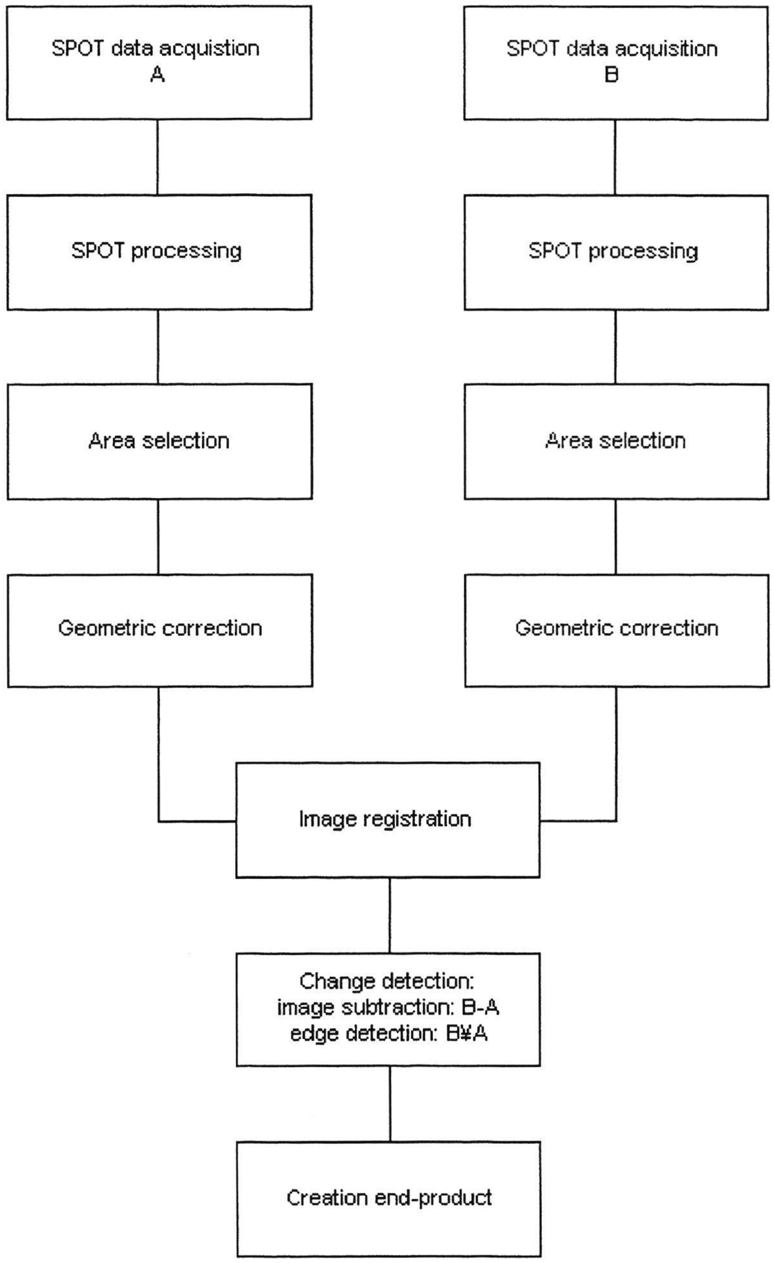



**Figure 2-2 The steps in the change detection procedure for SPOT**

For the change detection two different methods can be used: edge detection and image subtraction, see chapter 3 for a description. The global steps of both methods are given below.

- **Edge detection**:

- running the edge detection filter over the images;
- transforming the edge detected images with a threshold-value into images with significant edges;
- comparing images with significant edges mathematically with each other;
- removing the noise of the images with a neighbourhood majority filter;

- **Image subtraction**:

- matching of the histograms
- subtracting the images;

- choosing a threshold for a significant change and recalculating the images into significant change detection images;

After edge detection or image subtraction the change detection maps are produced and interpreted.

# Chapter 3 Processing

This chapter gives a description of the processing method of images of PHARUS, ERS and SPOT and an introduction to interpretation. It ends with an outlook towards automatic detection of roads in change detection images.

## *3.1 Processing of the PHARUS images for change detection*

### 3.1.1 Processing

The essence of SAR processing is a compression in both range and azimuth direction, focusing the image. During this process platform motion, which can give rise to errors in the focus, geometric distortions and radiometric distortions are corrected for. Radiometric correction also includes the antenna elevation pattern in range direction. Because only the theoretical pattern was available, the correction for the antenna pattern was applied in two stages. In the second stage the residual pattern was estimated from the data and subtracted.

**Registration**

In order to compare the PHARUS images they have to be registered accurately. Although in SAR processing platform motion is corrected for, a second order transformation had to be used. The results show that in a few areas, registration errors occur. These areas are mostly situated at the edges of an image. For the resampling (i.e. interpolation) of the images the Nearest Neighbour method (NN) was used. All other methods affect the resolution and the statistical distribution (Quegan 1990), which will be used in change detection filtering. NN interpolation is allowed because the images are oversampled.

**Speckle filtering: three stages**

Speckle in SAR images cause false alarms in change detection. Filtering the change detection images, reduces the speckle and the number of false alarms. The filtering applied consists of three stages. A measure for the amount of speckle is the so called Equivalent Number of Looks.

1) **Multi-looking**

   Multi-looking is a technique that uses the full azimuth bandwidth for speckle reduction (Li et. al. 1983). When processing an image in a resolution lower than the highest resolution possible, more images can be generated. Averaging these images will result in speckle reduction. The number of uncorrelated images averaged is the number of looks. If the images are correlated their number given by the Equivalent Number of Looks (ENL). The highest azimuth resolution of PHARUS is 1.0 m, but the desired resolution is about 3.5 m (equal to the range resolution acquiring a square resolution cell). Azimuth bandwidth is left over which can be applied for speckle reduction. This way an ENL of 5 is achieved for each polarimetric channel.

2) **Polarimetric filtering**

   Combining the polarimetric channels (HH, HV, VH and VV) is called polarimetric filtering. Several techniques can be used (Dekker and Groot 1998) but the maximum obtainable ENL of polarimetric filtering is 3, because HV and VH are fully correlated. The technique used is a Weighted Sum (WS) of the polarimetric channels. Here the channels are divided by their mean power and subsequently averaged. It is an easy method which gives a speckle reduction of 2.8 ENL. After this stage the total ENL will thus be 14. Polarimetric filtering does not affect the resolution.

3) **Change detection filtering**

   After registration and ratioing the SAR images, a more complex filter scheme is applied. This scheme, that is developed at TNO-FEL (Dekker 1998), consist of three steps:
   - structure detection
   - filtering within the structure boundaries (thresholding)

- exclusion of changes smaller than one resolution cell

Using this scheme (a) speckle is reduced while preserving the boundaries and (b) unreal small changes (e.g. detected due to registration errors) are excluded. Thresholding is applied after correction of the ratio image for a difference in the mean intensity. Although it is difficult to estimate the effect in ENL, experimental results have shown that this method gives a much more reliable overview of what has changed in SAR change detection imagery.

**Logarithmic scaling**

Until this moment the images are still in intensity (i.e. power) format. A property of this format is the dynamic range of the values which are difficult to display on a computer screen. Therefore the dynamic range is compressed by applying logarithmic scaling and the intensities and the threshold are measured in decibels (dB). The thresholds applied are ±6.215 dB which corresponds to a probability of false alarm of 0.01%.

### 3.1.2 Results

- The reliability of the detected changes is determined by the threshold, which was set on 6.2 dB, corresponding to a probability of false alarm (due to speckle noise) of 0.01%.
- The resolution of the detected changes equals the resolution of the radar. This resolution is 3.5 m.
- The accuracy of georeferencing is addressed by the RMS error of registration, which measured 2.0 m.
- The validity of changes is assessed visually, with the aid of available information like topographic maps and knowledge on backscatter properties of objects. This step is important in order to know whether it is a relevant change which has been detected.

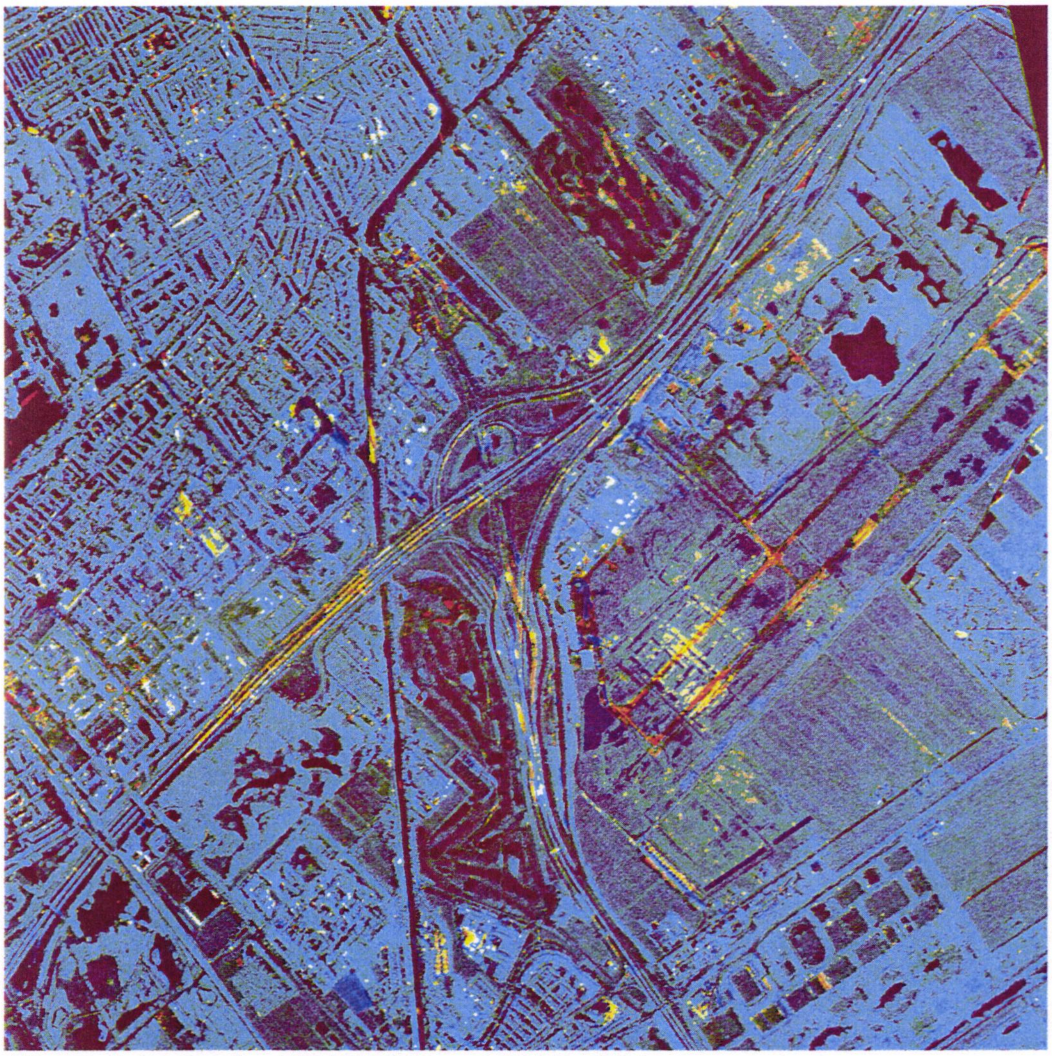
The feasibility of road extraction from the change detection products is assessed with a visual interpretation of the results obtained with the PHARUS images of the surroundings of Ypenburg. The results of validation are described in chapter 4.

The following layers are available after the change detection procedure, see also figure 2-1:

| | |
|---|---|
| layer 1: PHARUS image of 26 April 1996 | (A) |
| layer 2: PHARUS image of 27 January 1998 | (B) |
| layer 3: detected changes with decreased power | (B-A) negative |
| layer 4: detected changes with increased power | (B-A) positive |

With these layers two images can be created for interpretation:

- The first is an RGB image in complementary colours (e.g. red and cyan, which is green and blue) of the original 14 look images (layer 1 and 2), so changed areas or objects have a distinct colour (yellow and purple), while unchanged areas or objects are grey. See for example the RGB image of Ypenburg in figure 3-1. The yellow areas represent the areas with increased reflection and the purple areas represent the areas with decreased reflection.
- The second is a projection of the detected changes (layer 3 and 4) in equal complementary colours (red and blue) on one of the original greyscale images. This can be seen in figure 4-1.



**Figuur 3-1 Overlay PHARUS images 1998 - 1996**

### 3.1.3 Interpretation

After processing and presentation of the images, the question rises how to interpret the results. The detected changes in SAR imagery are in fact changes in the intensity, which can be caused by different kinds of mechanisms for different kinds of objects.

**Buildings and mobile objects**

Man-made objects like buildings, bridges or carriers (ships, trucks, etc.), can give rise to strong reflections, visible as one or a number of strong point-targets in a SAR image. Because of this, these objects can easily be detected if changed (read built, pulled down or moved). Sometimes the intensities of such objects are highly dependent on the angle of illumination of the SAR. This way a slight change in the track-angle of the platform (sometimes only a few degrees) can cause a significant change of intensity, although nothing has actually changed. New buildings are detected in all images.

**Natural targets**

Sometimes natural targets like agricultural fields, meadow and woods also show a significant change of intensity. These can be caused by seasonal changes (e.g. crop height or the density of leaves), harvest, mowing or cutting down trees. Some change detection images actually show chopped wood or rows of trees along roads. Another class of natural targets is water. Because wind causes ripples on the water-surface it becomes more rough and changes in the speed of wind can also be detected.

**Roads**
Roads form a specific class of man-made objects. Because roads have a smooth surface they mostly appear as dark patterns in a SAR image. Therefore, when a new road is built in natural terrain, this mostly results in a decrease of intensity. If a new road is detected, is also dependent on the intensity of the terrain that makes place for it. When roads are built within new estates, they will appear as a part of the dark structures between the new houses or buildings. Because shadows from houses or buildings are also dark, the exact location of roads are sometimes difficult to determine.

## *3.2 Processing of the ERS-1 images for change detection*

### 3.2.1 Processing

The processing of ERS images looks familiar to the PHARUS processing (see paragraph 3.1) but there are a few differences which are described below.

**Registration**
In order to compare the ERS images they were registered accurately. Registering ERS images is easier than registering PHARUS images. The motions of a satellite are much more linear so less ground-control-points had to be determined. For the resampling (i.e. interpolation) of the images the Nearest Neighbour method was used (Dekker 1998).

**Change detection filtering**
As opposed to PHARUS imagery, speckle reduction in ERS imagery only encloses change detection filtering. The data was already multi-looked during PRI processing, and polarimetric filtering can not be applied because ERS SAR is a single-polarisation system (VV). The change detection filter scheme consists of three steps (Dekker 1998):
- structure detection
- filtering within the structure boundaries (thresholding)
- exclusion of changes smaller than one resolution cell

Using this scheme (a) speckle is reduced while preserving the boundaries and (b) unreal small changes (e.g. detected due to registration errors) are excluded. A threshold of ±6.35 dB (corresponding to a probability of false alarm of 5% for a non-filtered 3 look image) was applied, after correction of the ratio image for the difference in mean intensity. The dynamic range of the ERS imagery was also compressed by applying logarithmic scaling, measuring the intensity in decibels (dB).

### 3.2.2 Results

The result of this change detection procedure is packed in ERDAS Imagine format (.img), together with the registered ERS images.

The following layers are available after the change detection procedure:
layer 1: ERS image of 12 August 1992
layer 2: ERS image of 26 December 1997
layer 3: detected changes with decreased power (B-A) negative
layer 4: detected changes with increased power (B-A) positive

With these layers two images can be created for interpretation:

- The first is an RGB image in complementary colours (e.g. red and cyan, which is green and blue) of the original 3 look images (layer 1 and 2), so changed areas or objects have a distinct colour, while unchanged areas or objects are grey.
- The second is a projection of the detected changes (layer 3 and 4) in equal complementary colours on one of the original greyscale images. See for example the image of Ypenburg in figure 3-2. The yellow and blue areas represent the areas with detected changes.

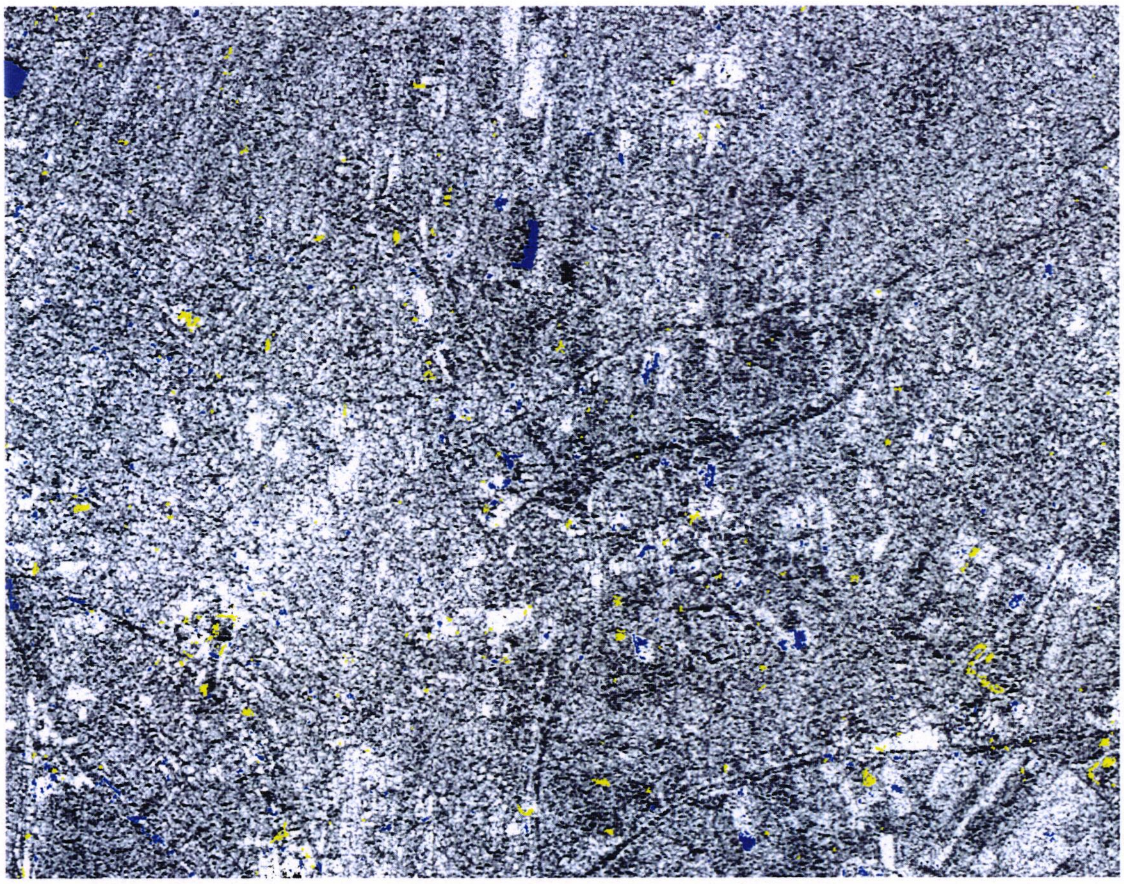


**Figure 3-2 ERS SAR image 1997 overlayed with detected changes**

### 3.2.3 Interpretation

The results show that only a few relevant changes were detected, over a period of 5 years. The PHARUS change detection images showed more changes, over a period of 2 years. The main cause is the resolution. The cities of interest (Amersfoort and Apeldoorn) show changes, mainly in the industrial areas, but roads can not be determined. Other built-up regions showing more changes, are Almere, Soest, Vleuten (near Utrecht) and Nieuwland (between Spakenburg and Amersfoort), but again, the extraction of roads is not possible.

## *3.3 Processing of SPOT images for change detection*

The change detection with SPOT images is carried out with edge detection and image subtraction. Both methods are described below. The registration of the SPOT images is carried out with the topographical map 1:25.000 and results in a RMS error of registration of 0.89 pixel.

### 3.3.1 Processing with edge detection

With this method all the edges which appear in the image are detected. This is done by the directionless Sobel-filter which detects the edges from their large differences in pixel values. A critical value must be chosen which the difference pixels should have to be classified as an edge. This results in an image with zero value for 'no edge' and value 1 for 'edge'. Edge detection is appropriate for detecting line shaped elements in remote sensing images. In figures 3-3 and 3-4 the original SPOT images of Ypenburg are shown. In figures 3-5 and 3-6 the detected edges of these images are shown.

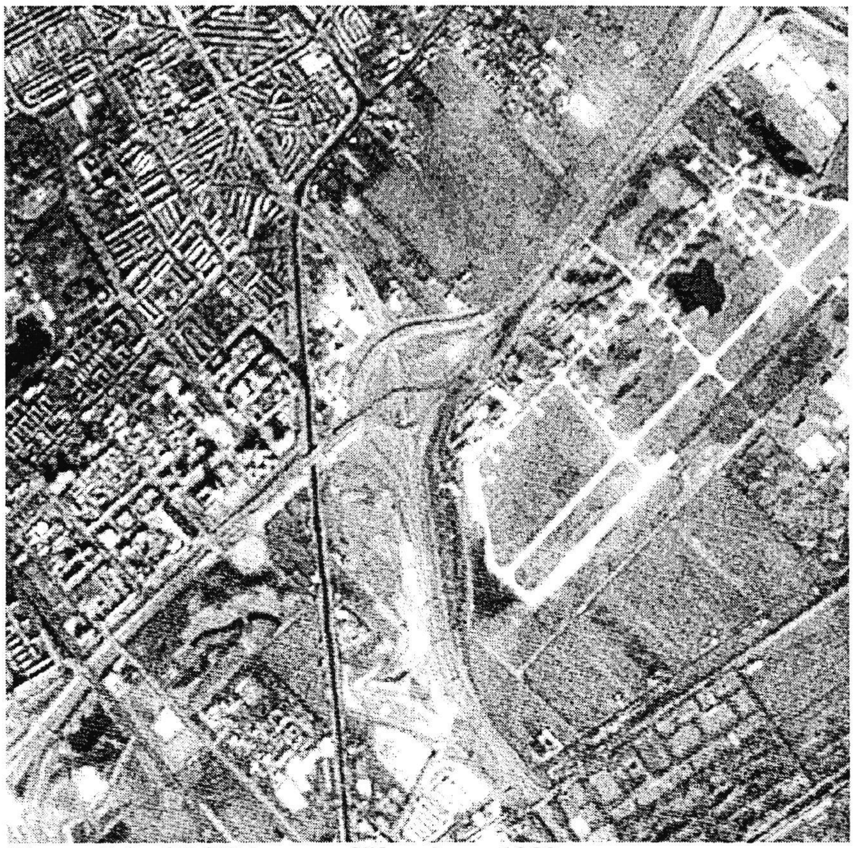


Figure 3-3 SPOT image of Ypenburg 1989

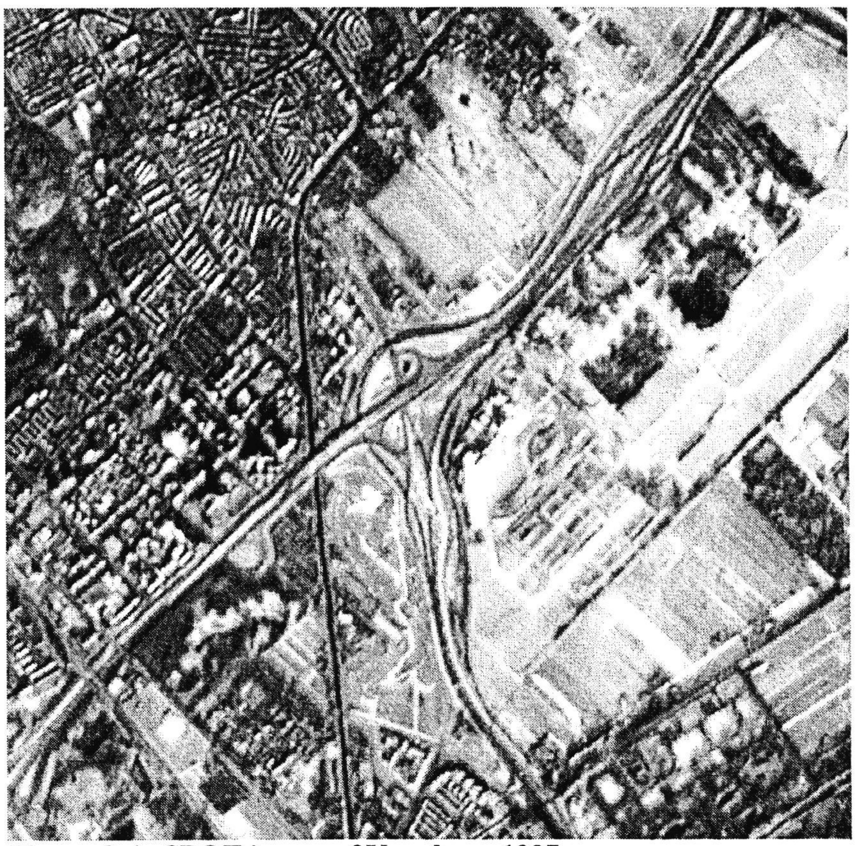


Figure 3-4 SPOT image of Ypenburg 1997

Figure 3-5 Results of edge detection from the image 1989

Figure 3-6 Results of edge detection from the image 1997

After the edge detection is carried out on similar images of different years the images are compared mathematically. This method is shown in table 3-1. For example when a pixel has value 0 in the first image and value 1 in the second image it means that an edge which was not present in the first image does appear in the second image and therefore gets value 1, an edge has appeared.

| image 1 | image 2 | resulting image | meaning |
|---|---|---|---|
| 0 | 0 | 0 | in both images no edge |
| 0 | 1 | 1 | an edge has appeared |
| 1 | 0 | 2 | an edge has disappeared |
| 1 | 1 | 3 | in both images an edge |

**Table 3-1 Method of comparing both edge detected images**

In this project we are mainly interested in pixels with the resulting value 1 which means that an edge has appeared. When these pixels are lineshaped it is possible that it concerns a new road. When these pixels are found in irregular groups it is possible that it concerns a new part of town (under construction).

A problem which appears with this method is that also very small displacements (with a size of 1 pixel) are detected in the images as significant change. The resulting image will therefore contain much separate pixels which are not of importance for this project. In order to prevent this the resulting images are transformed into images with only zeros and ones, where the zeros represent no changes and the ones represent changes, an edge has appeared. Next, a majority filtering is carried out based on 4-connectivity per pixel. For each pixel with value 1 it is determined which value belongs to the majority of the neighbouring pixels, see figure 3-7. This value is assigned to the central pixel. This implies that very small groups of pixels with value one will be removed.

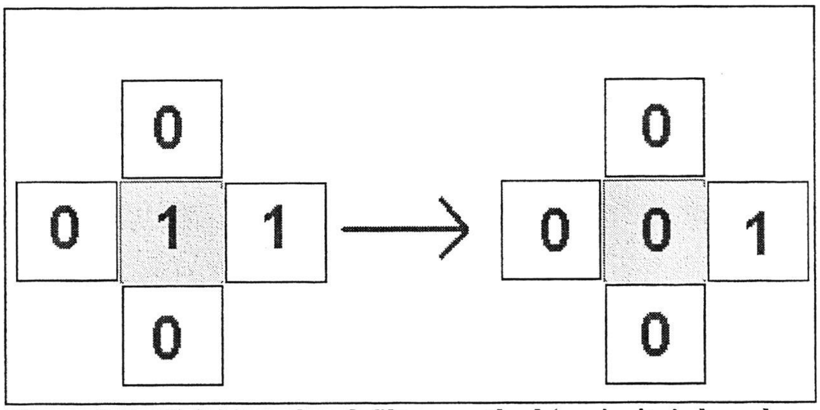



**Figure 3-7 Neighbourhood-filter, method 'majority': based on the most appearing value of the neighbouring pixels the value of the central pixel is determined.**

### 3.3.2 Processing with image subtraction

This technique is based on the assumption that images of the same area with the same spectral properties can be subtracted from each other based on their pixel values. The resulting images will show large (positive and negative) values where changes appeared and low values (positive and negative) where no changes appeared. To be able to use the images of different years for image subtraction, the distribution of the pixel values in the images has first to be made equal to correct for the differences in sun intensity and atmospheric circumstances. For this purpose histogram equalisation is used. The means and standard deviations of the first set of images (1989) are made equal to the histograms of the second set of images (1997) with the following formula:

$$x_{1989,histeq} = \left[\left(X_{1997} + \left(x_{1989} - X_{1989}\right) \times \left(sd_{1997} - sd_{1989}\right)\right)\right]$$

with:

$x_{1989,histeq}$ = the value of pixel x in 1989 after histogram equalisation
$X_{1997}$ = the mean pixel value in the image of 1997
$X_{1989}$ = the mean pixel value in the image of 1989
$x_{1989}$ = the value of pixel x in 1989
$sd_{1997}$ = the standard deviation of the pixel distribution in 1997
$sd_{1989}$ = the standard deviation of the pixel distribution in 1989

After histogram equalisation the images can be subtracted from each other. The resulting image contains pixel values which represent the difference in reflection between both images. In order to make a change detection image a value must be chosen above which the difference value represents a significant change. In this project is chosen for 1,5 x the standard deviation of the difference image. The values which lay in the interval *mean pixel value +/- (1.5standard deviation)* are set to zero. The other pixels are marked as significant change.

In a comparable project (de Wit, 1997) edges are called significant as pixel values deviate more than + or - 20 from the mean pixel value. After studying the resulting images this value was not usable for this project. Too many differences are filtered out in this way.

### 3.3.3 Results

In figure 3-8 the resulting edges are shown after comparing mathematically the edge detected SPOT images of 1997 and 1989 with each other. See for the procedure paragraph 3.3.1.

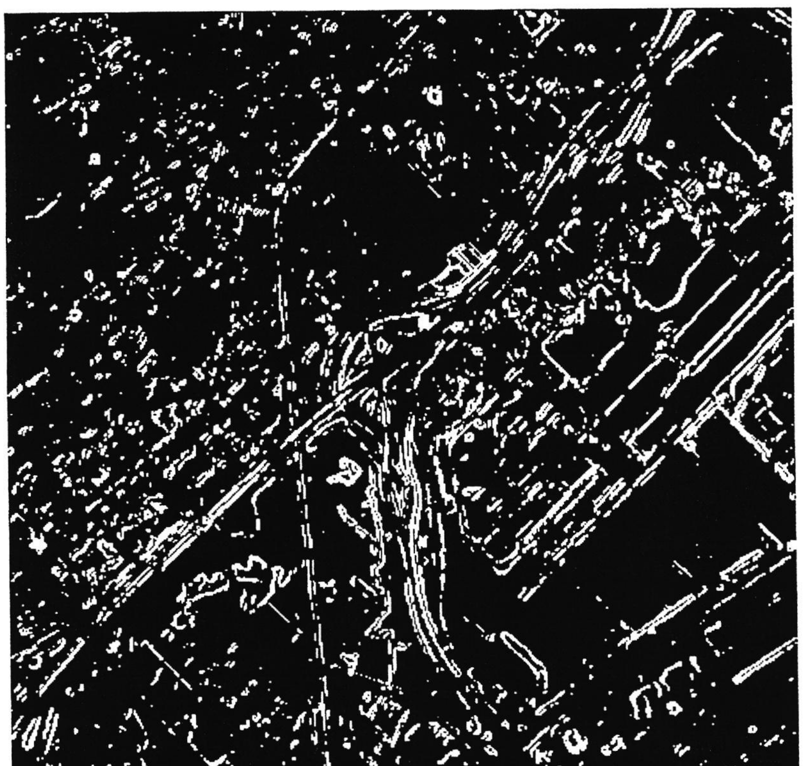


**Figure 3-8 Change detection image with edge detection 1997-1989**

In figure 3-9 the change detection results are shown after subtracting both SPOT images. See for the procedure paragraph 3.3.2.

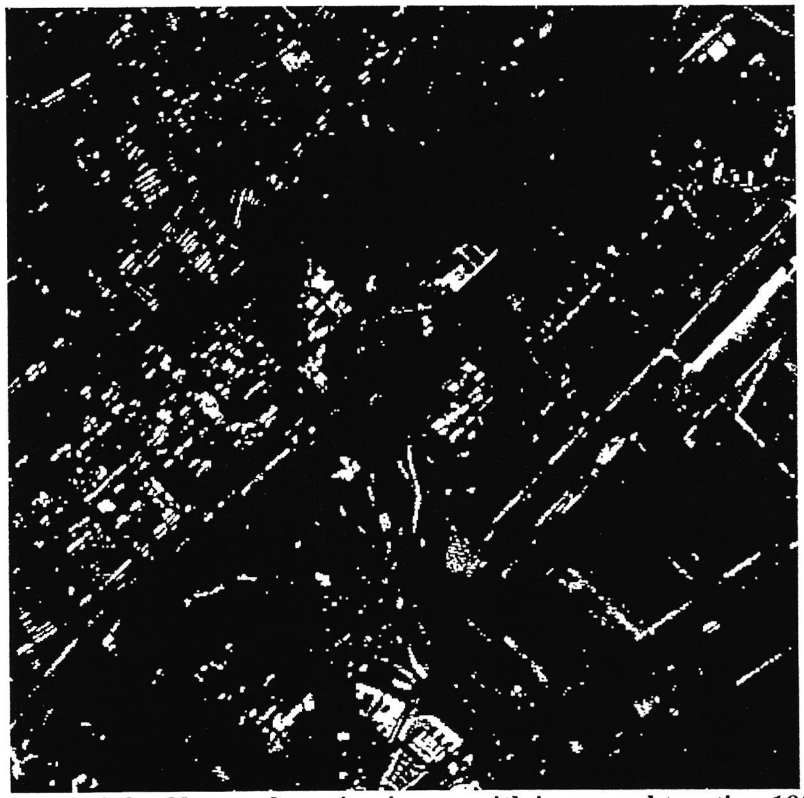


**Figure 3-9 Change detection image with image subtraction 1997 - 1989**

### 3.3.4 Interpretation

Using image subtraction the plane shaped surfaces become better visible in relation to the edge detection where the line shaped surfaces are very clear.

A problem with the edge detected images is that the edges of agricultural plots are also found by the edge detection method. These edges can differ per year and per vegetation type and are therefore detected during the mathematical comparison as a new edge. Because the edges of plots are line shaped it is difficult to distinguish between the edges of plots and new roads.

Another problem when using the edge detection technique is to prevent shadows along buildings in the SPOT images. The images are geometrically corrected based on clear recognisable points which are coupled to the co-ordinates on the topographic map. Because the images are taken by an optical system that measures the reflection of the visible sunlight and the images were taken during the winter (causing long shadows) it is possible that there are differences in the amount of shadows and the direction of the shadows in the images of different years. Differences between shadow and sun along houses are detected by the edge detection filter as an edge. When a shadow does not appear in the image of 1989 and it does in the image of 1997, it will be classified as a significant change. Because they are long-drawn these differences are difficult to distinguish from new roads.

The resulting images of image subtraction clearly show where changes appeared. Changes in agricultural plots are clearly recognisable from the closeness of the surfaces. Places where line shaped changes appeared are shown well.

**Time investment**

Most of the time is needed for selecting, cutting and geometrically correcting of the images (98 h). Especially the georeferencing with the topographical maps requires a lot of work (50 h). The change detection itself requires less time. Comparing both change detection methods, the image subtraction method requires a little bit more time than the edge detection method.

### 3.4 Automatic detection of roads

The automatic detection of roads in change detection imagery can be difficult. Detected roads are mostly interrupted and vary from straight lines to different kinds of curves. Extracting the connecting road with the eye is possible, but is dependent on the interpreter.
Connecting these structures by computer algorithms is a complete area of science in which sometimes progress is made (Tupin et. al. 1998). An algorithm which accurately extracts the roads from change detection images without the aid of an interpreter however, needs further investigation. The power of road detection at this moment, is thus strongly dependent on what the interpreter sees in the imagery.
This last point is especially important using the optical images. An operator must have a final look at the detected edges to classify them into changes of roads and other changes which a computer is not (yet) able to.
Using the high resolution future satellites the change detection procedure can be made more automatic because of the higher resolution of the data and therefore it is easier to discriminate between different kinds of edges.

# Chapter 4 Results of validation

As appeared in chapter 3 extracting road patterns from ERS is not possible. Therefore only the change detection images from PHARUS and SPOT are validated in this chapter. The results obtained from the Ypenburg area are described here, since these results represent sufficiently the feasibility of change detection for road extraction. The validation is done visually with the road databases of AVV.

## 4.1 Results of PHARUS

The results were obtained after SAR processing of the acquired images, speckle filtering and the application of a change detection algorithm, see chapter 3.

In the analysis three images of Ypenburg have been studied:
1. The first image is the colour composite of the original two SAR images. This image is used for the evaluation of the applied segmentation and edge detection algorithm.
2. The second image is the product of the change detection algorithm: the change detection map. This image is used for the assessment of the feasibility of road extraction.
3. The third image is the NWB road graph file of AVV projected on the original SAR image. This road graph contains the updates done by AVV.

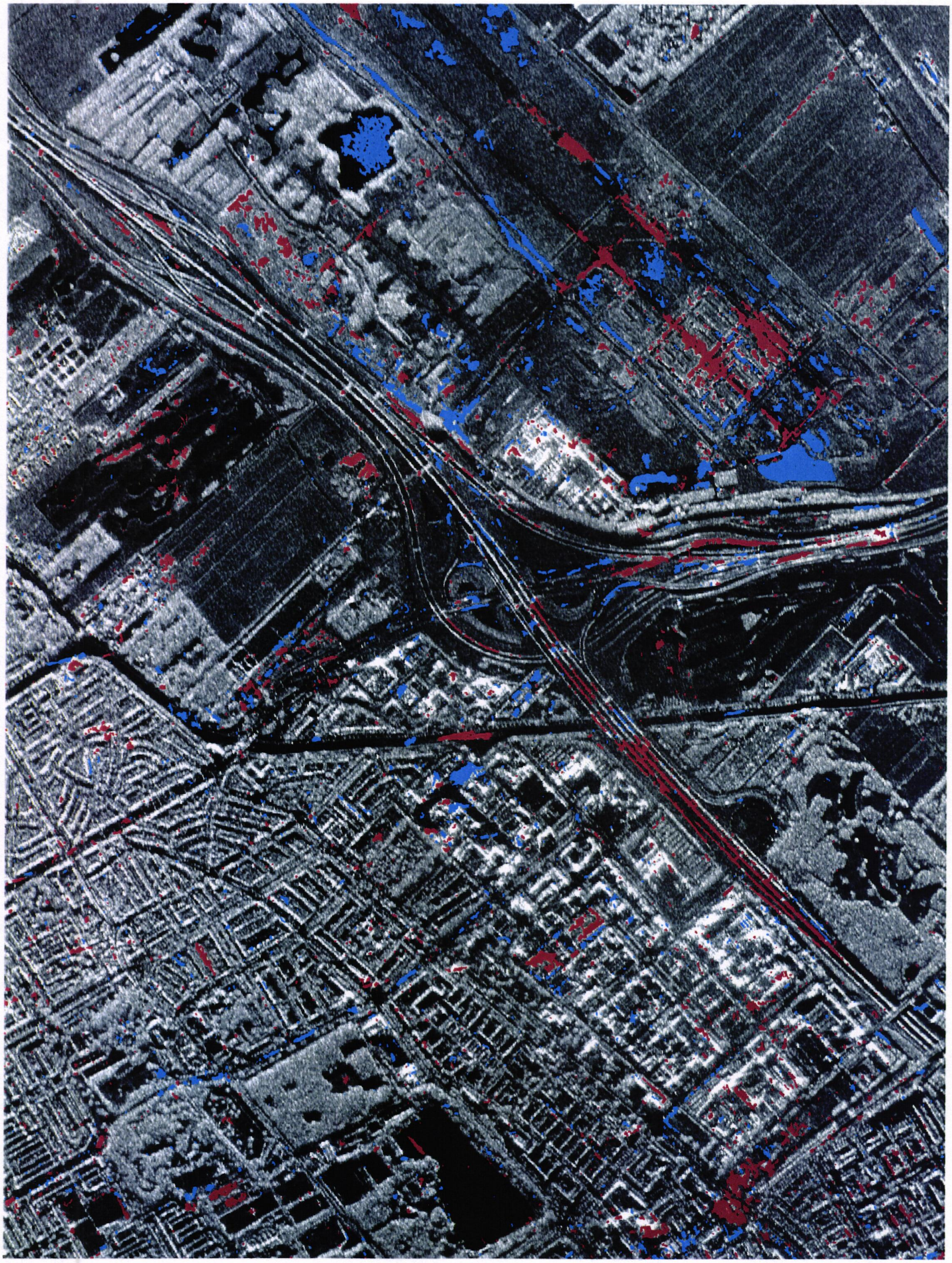
The first image has been used by TNO-FEL for the evaluation of the change detection procedure. Results obtained with the second and third images are presented in this section.
Figure 4-1 depicts a change detection image of the Ypenburg junction with the new building location at the former military airport. Figure 4-2 depicts the same SAR image with the road centre-lines of 1998 (pink) and 1996 (green) superimposed. These images have been visually interpreted.

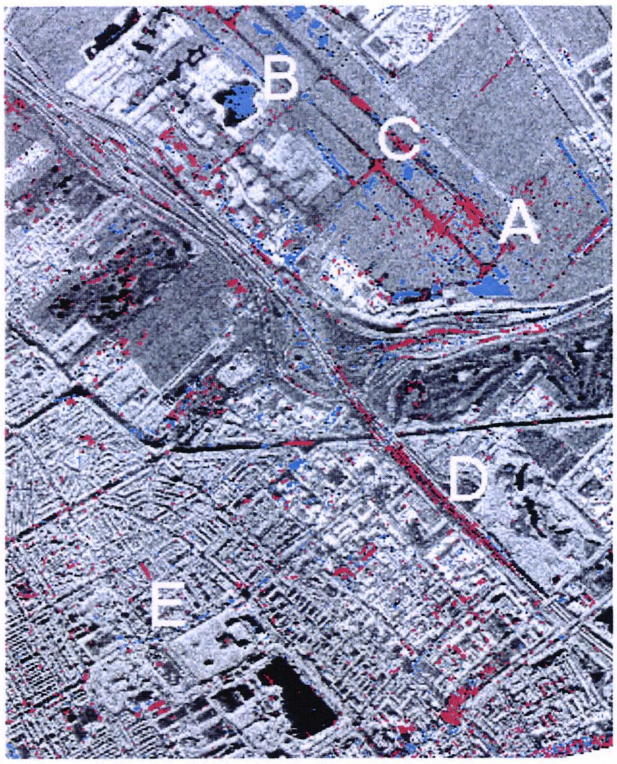
During the interpretation several limitations occurred:
- Because time has passed between the moment a new road was finished and the moment that the road was added to the NWB, the NWB updates do not fully correspond with the changes detected in the PHARUS images.
- Small differences in the direction of illumination can occur, causing intensity changes which are not relevant.
- Strongly reflecting targets appear in one image and obscure a part of this image. These dark areas can be detected as changes.

On the following pages the next figures are shown:

**Figure 4-1**
**PHARUS change detection image of the Ypenburg junction with the new building location at the former military airport. The red coloured pixels correspond to an increase in backscattered power, the blue coloured pixels correspond to a decrease in backscattered power between 1996 and 1998.**

**Figure 4-2**
**SAR image of the Ypenburg junction with the new building location at the former military airport, with road centre-lines superimposed. Green centre-lines correspond to April 1996 updates and pink centre-lines correspond to January 1998 updates.**





Copy of figure 4-1 with points of attention

There is a clear difference between the change detection results depicted in figure 4-1 and the road centre-lines depicted in figure 4-2. In the upper-right of figure 4-1 changes (red and blue) appear due to building activities and new roads (A), which are not seen in figure 4-2. On the other hand the surface of water (lakes, ditches) (B) also appear as changes (blue), which are not seen in figure 4-2. The backscattered power of water surfaces strongly depends on environmental conditions such as wind, making these changes insignificant. It is possible to eliminate these changes with a classification algorithm, which excludes water surfaces from the (automated) analysis.

Changes related to roads can sometimes be detected directly by a decrease in the radar reflectivity (blue) or by an increase (red), because the roughness of a surface has changed. In the upper-right of figure 4-1 it can be seen that the old runways (C) are being roughened (red). Most new roads, however, are detected by changes in the context. For instance the extension of the A4 highway (red) is clearly visible in the bottom part (D) of figure 4-1 and figure 4-2. The explanation for this visibility is to be sought in the presence of electric cables between lightpoles on the carriageway, these cables have probably resulted in a significant increase in cross-polarised power.

The presence of electric cables is an example of road detection by context information. Other examples are:

- Cutting down of trees (blue) for constructing a new tramway: this can be observed in the lower-left part of figure 4-1 (E).
- The cultivation of ground surfaces (blue) (e.g. grassland) by grading machines: e.g. the building location at Ypenburg in the upper-right part (A).
- Shadow and lay-over effects of buildings.

It is important to realise that new roads are not completely detected, mostly only segments are found. From these segments a road centre-line must be constructed.

## *4.2 Results of SPOT*

After the selection of areas of interest and the geometric correction, two change detection methods are applied:

1) Edge detection: edges are detected by a Sobel-filter as places where large pixel differences occur. By comparing two edge detection images of different years it can be calculated where there is a decrease or increase of edges, as is expected with new roads. This is shown in figure 4-3.
2) Image subtraction: after a histogram equalisation of both images the pixel values of corresponding areas are subtracted. The resulting image shows the difference in reflection of both images. Significant changes are determined as values above 1,5 x the standard deviation of the difference image. These are shown in figure 4-4.

During the visual comparison of the results of the edge detection and image subtraction methods the following differences occurred:

- Using image subtraction the plane shaped changes are better visible, while using edge detection the line shaped changes are better visible.
- The edge detection method is more sensitive for differences in quality in both images than image subtraction.
- When comparing the final results, both methods appear to give the best results alternatively. So it is not possible to prefer either edge detection or image subtraction.
- The edge detection method gives too many edges. A classification of the edges is necessary to determine the changes in roads.

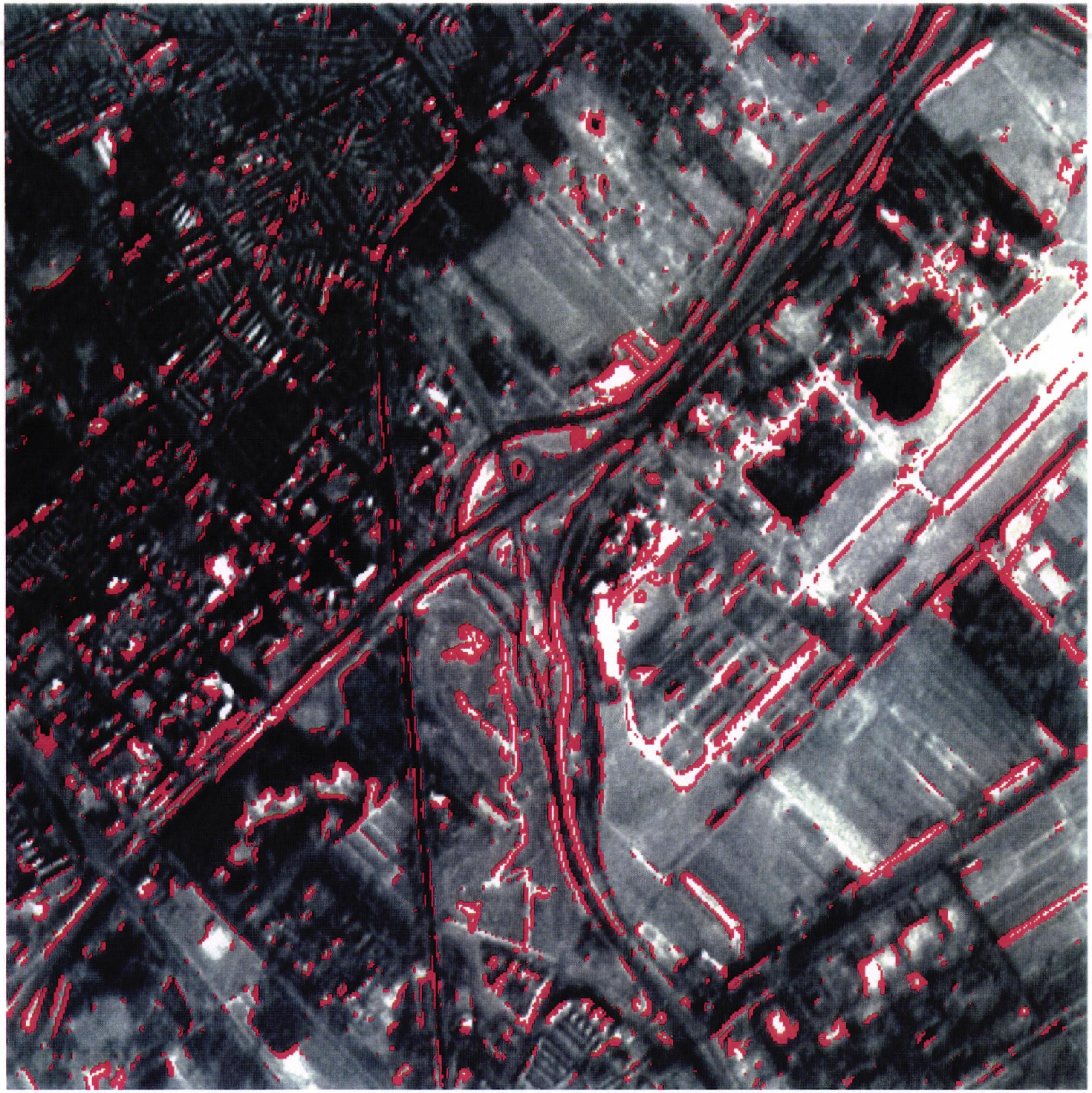
Validation of both methods has been done visually with the road databases of AVV. Figure 4-5 shows the road databases of 1990 and 1997 plot over the SPOT image from 1997. As is already remarked in paragraph 4.1, the road databases may not be completely up to date, so this has to be taken into account when comparing the detected changes with changes in the road databases.

On the following pages the next figures are shown:

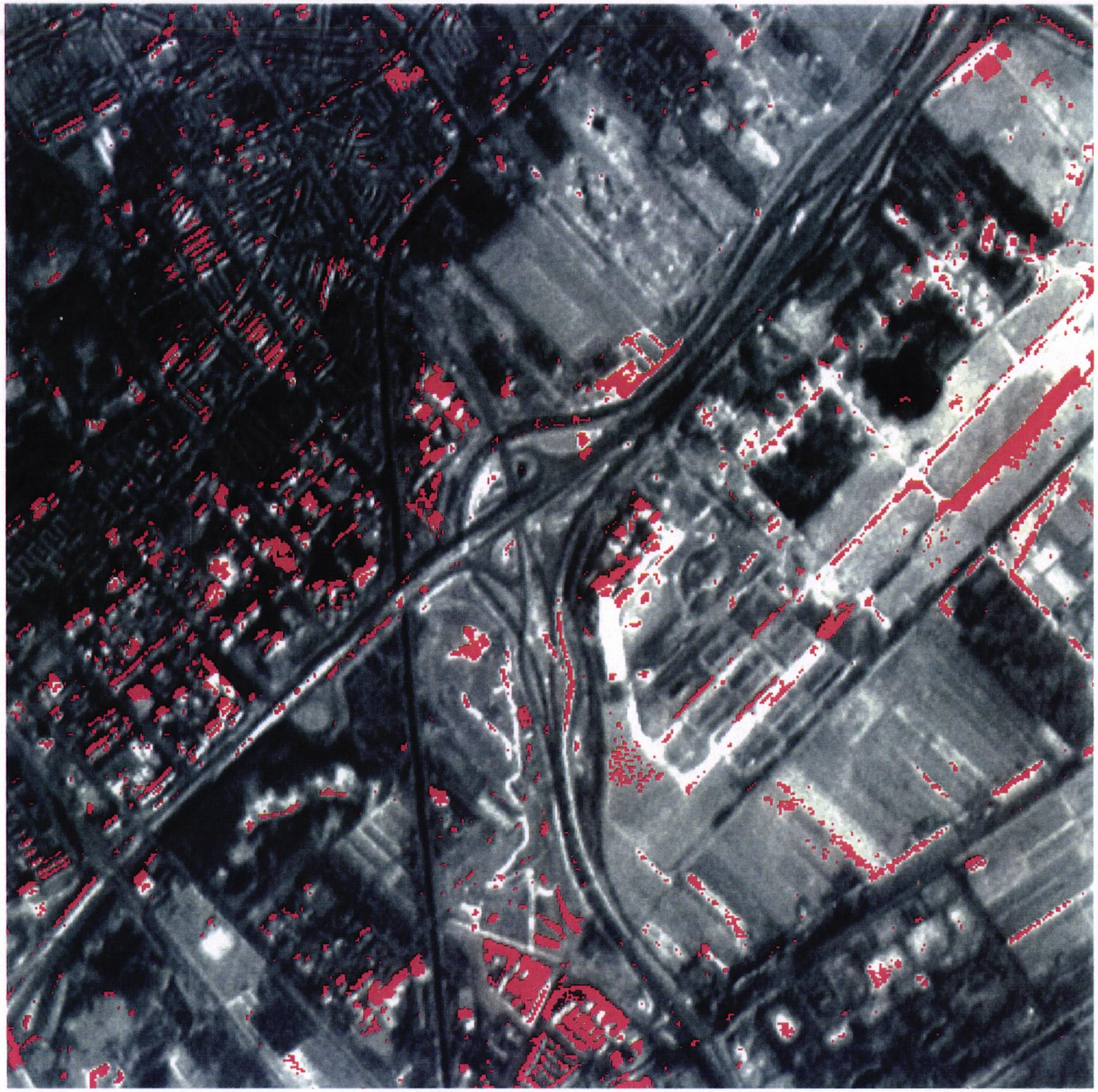
**Figure 4-3**
**SPOT change detection image of the Ypenburg junction with the new building location at the former military airport. The method applied was edge detection. The red coloured pixels correspond to increased edges between 1989 and 1997.**

**Figure 4-4**
**SPOT change detection image of the Ypenburg junction with the new building location at the former military airport. The method applied was image subtraction. The red coloured pixels correspond to significant changes between 1989 and 1997.**

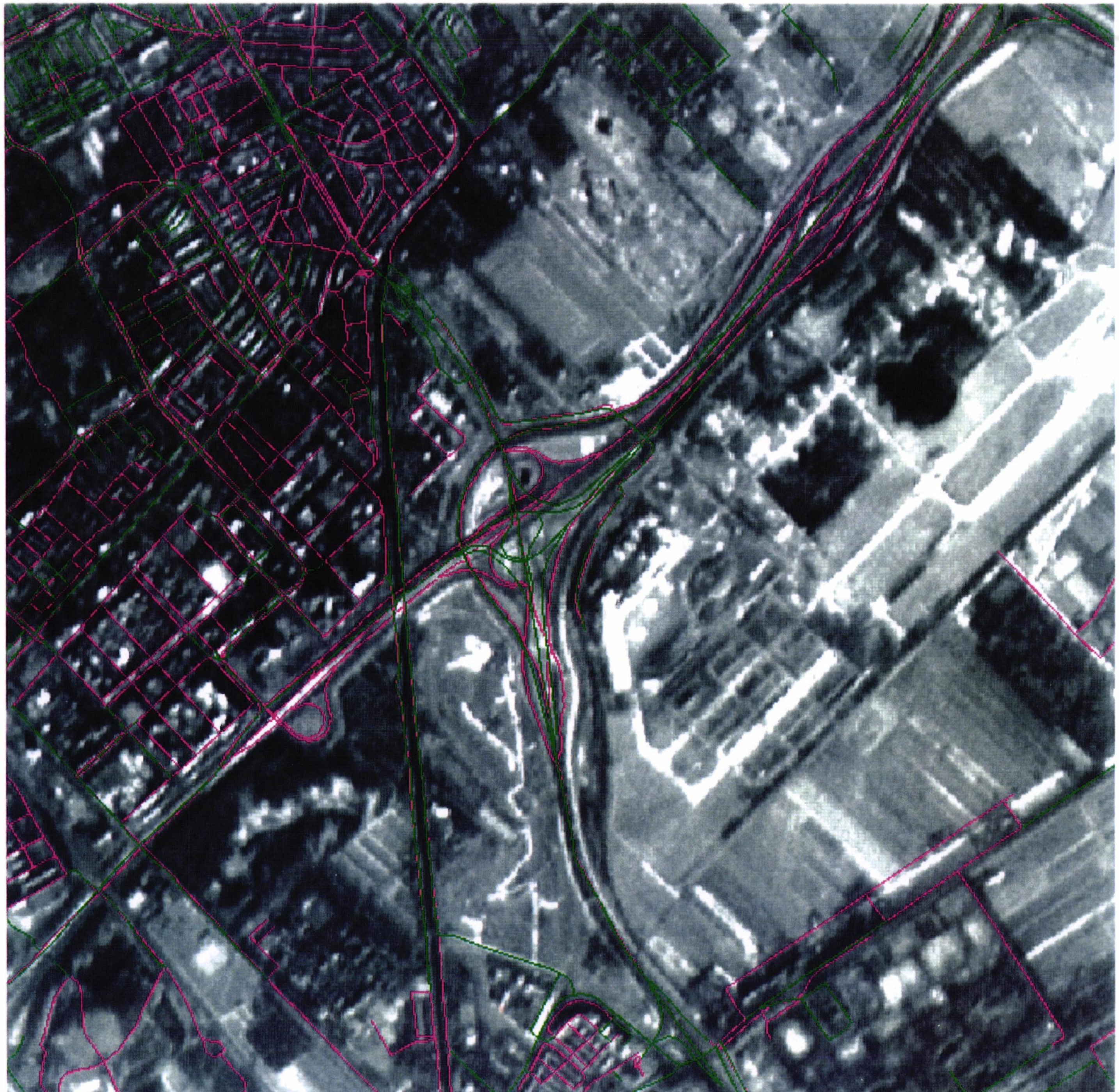
**Figure 4-5**
**SPOT image of the Ypenburg junction with the new building location at the former military airport, with road centre-lines superimposed. Green centre-lines correspond to May 1990 updates and pink centre-lines correspond to January 1997 updates.**



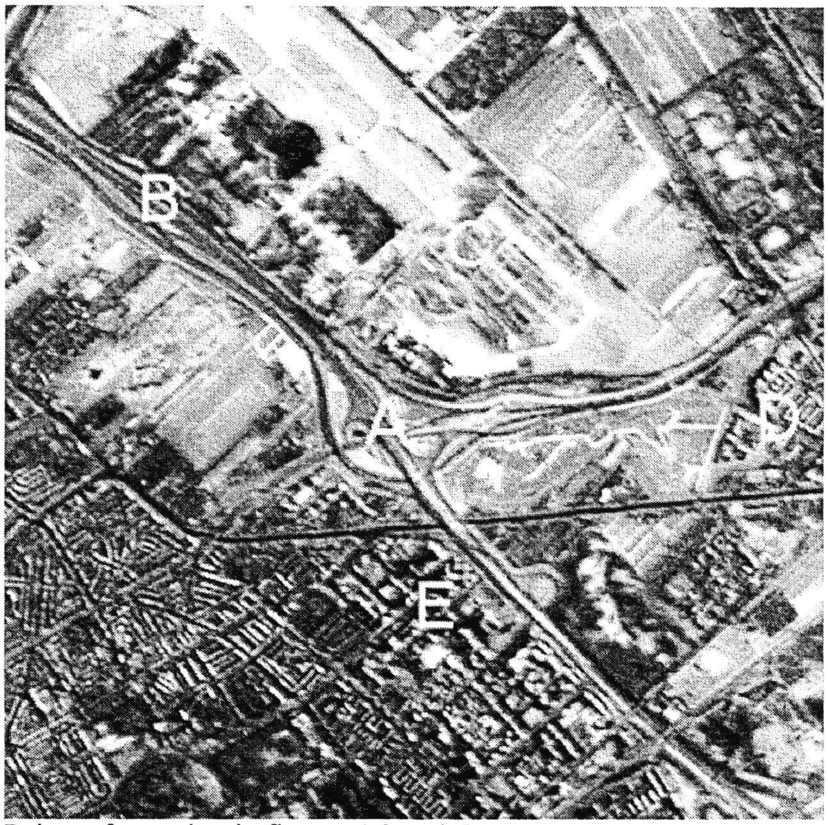
Results edge detection



Results image subtraction



Road databases
1990 (green), 1997 (pink)



Points of attention in figures 4-3 to 4-5

From figures 4-3 to 4-5 the following can be seen:

- The crossing of the highway in the centre (A) is changed. These changes are clearly visible in the edge detection results. Also changes in the highway in the upper-left (B) are clearly visible in the edge detection images.
- The cultivation of the Ypenburg area is not jet visible in the road databases. However, both change detection images show significant changes in this area (C), which can be the result of removing the airport Ypenburg.
- In middle-right part of the images new roads can be detected from changes in buildings (D) (changes in context), which are clearly visible in the image subtraction results.
- In the bottom part there appear many new roads in the road database, but in both change detection images there are only spots of changes visible (E).

Also with SPOT images, like PHARUS images, it is difficult to detect whole new roads, mostly only segments are found.

# Chapter 5 Commercial use of change detection products for road detection

Up to now road maps are based on fieldwork and on data from aerial photography. There is much competition in this field, and prices for maps are subsequently not very high. SPOT images have already been used in some change detection projects for the AVV and appeared to be useful for indicating areas where new roads have been constructed. In addition SAR maps are unknown to the users. Partly, because SAR is a relatively new concept, but also because users do not know how to interpret the data. This section provides insight in the commercial use of airborne (PHARUS) and spaceborne (ERS) SAR data against SPOT data for the determination of road maps.

## *5.1 Image costs*

ERS images are available as commercial products with standard prices, for road detection full images should be used (100 x 100 km). The price of such an image is *kfl.* 2.4,-. The creation of the change detection products from ERS images will involve some additional costs in the order of *kfl.* 1.5,-. This results in a price of *fl* 0.39 per $km^2$.

Roughly the same costs apply to the creation of change detection products from PHARUS images. However, there is a significant difference between the prices and quality of ERS and PHARUS images.

The collection of PHARUS images can be subdivided into two types:

case 1: 'research measurement':
1 flight of 3 hrs., 5 scenes (measure something 'here and there'); with a total processed (effective) area of 320 $km^2$. The costs per image (with postprocessing included) are ~ *kfl.* 11,- (with a minimum of 5 images). This results in a price of *fl* 169 per $km^2$.

case 2: 'mapping campaign':
1 flight of 4 hrs., 4 tracks, 80 scenes mosaiced images (production flight); with a total processed (effective) area of 3000 $km^2$. The costs per image (with postprocessing included) are ~ *kfl.* 3.5,- (with a minimum of 80 images). This results in a price of *fl* 91 per $km^2$.

The difference between these two cases is caused by the flight costs. In case 1 these costs are about 80% of the total and in case 2 the flight costs are 20% of the total. In case 2 the costs are mainly determined by the processing (40%) and by the change detection procedure (40%).

The presented figures here are based on experience obtained during the PHARUS familiarisation program and the PHARUS market survey project. It is anticipated that these figures can decrease because of two reasons:

1) Costs can be reduced when more flights are combined.
2) The processing chain is in an ongoing process of optimisation, e.g. improvement of algorithms, system upgrading, etc.. This optimisation reduces labour costs by a factor two or more.

SPOT images are also available as commercial products with standard prices. The images enclose 60 x 60 $km^2$. The price of such an image is *kfl.* 2,- when it concerns an image from the archive and *kfl.* 8,- when it concerns an image to be taken in order and therefore includes costs for programming. The creation of the change detection products from SPOT images will involve additional costs in the order of *kfl.* 18.4,-. This results in a price of *fl* 7.33 per $km^2$. This price is in between ERS and PHARUS costs.

## *5.2 Advantages and disadvantages on the use of PHARUS compared to ERS and SPOT*

The PHARUS high resolution mode is most relevant for urban/road detection applications and is the main advantage of PHARUS over ERS and SPOT. The main advantages of both satellite systems are the larger size of the acquired images and the much lower costs.

The counterpart of the high resolution of PHARUS imagery is the smaller width of the acquired image. Widening the area by adding several strips together generally introduces strong intensity gradients at the transition between two strips. This complicates further processing of the images.

The disadvantage of SPOT images compared to radar images is the influence of the position of the sun. The survey is preferred to be planned in the winter period when there is less vegetation, but also a lower position of the sun. Because of this there are more shadowing effects. Also ice and snow can be wrongly detected as a change.
The disadvantage of radar images is the amount of noise present in the images. More processing is needed to remove this noise.

A request of SPOT images is a standard procedure and because there are three working SPOT satellites with variable look directions many images can be delivered in a short time. ESA is also an experienced organisation which can take orders and program the ERS satellite. For the PHARUS system, this experience has yet to be built up.

PHARUS can successfully compete with ERS and SPOT when a high resolution and/or high accuracy maps are required for relatively small areas, and time pressure prohibits waiting for collecting sufficient satellite images.

In conclusion the user requirements and needs, and the market size are factors that will motivate the choice for either the air- or spaceborne images, or the conventional methods in the application to road mapping.

## *5.3 Evaluation of the added value (cheaper as well as better) of remote sensing images related to the traditional aerial photography.*

This is an analyses of the costs and benefits of different techniques, where SPOT, ERS and PHARUS (and possible future HRS-data) are compared with the traditional aerial photo's. As AVV does not use the aerial photography for updating the road database, it is not a traditional technique in that sense, but AVV orders the topographical maps from the Topographical Survey and these maps are based upon aerial photography. For the completeness of available techniques for change detection the aerial photography is therefore considered here.

When ordering photo's from airborne flights it is important to know at what scale the photo's should be acquired. To be able to measure changes of roads with a minimal width of 5 meters, the scale should be in the best case 1:10,000. The width of the photo is 23 cm, corresponding then with 2300 meters in the terrain. An overlay of 20 % is sufficient for this application, so the costs per flight km become approximately *fl* 250,-. The price for the approach is approximately *fl* 5000,-. The processing costs are negligible because it can be seen on the map which photonumber corresponds to a certain area. For this purpose no tiepoints are needed.

In order to give a idea of the costs: suppose in one day four flight paths of 100 km length can be flown containing an area of 4 x 2.3 (- 20% overlap) x 100 = 830 $km^2$. The costs are 5000 + 4 x 250 x 100 = *fl* 105000. This comes to a price of *fl* 126,- per $km^2$.

The advantages of aerial photography are that with a plane it is easy to measure specific areas, the aerial photographs have a better geometry than satellites and are therefore more accurate. They also are less influenced by the atmosphere. The disadvantage is that for a large area the costs are too high.

In paragraph 5.1 it is shown that change detection products from remote sensing images include the following costs:

- ERS: *fl* 0.39 per $km^2$
- PHARUS : *fl* 91 per $km^2$
- SPOT: *fl* 7.33 per $km^2$.

In paragraph 5.2 the (dis)advantages are given of these systems.

The future high resolution satellites can also be an option to use for change detection. For example IKONOS encloses scenes of 11 by 11 $km^2$ and has a resolution of 1 m (pan mode) or 4 m (multispectral mode). The price will be about *fl* 20 per $km^2$.

The advantage of these satellites is the high resolution which makes it easy to detect the changes in the terrain and to distinguish the changes of buildings, etc. from changes of roads. The disadvantage of these satellites is that they may have some "start" problems.

# Chapter 6 Design GIS-based system

In this chapter the specifications are given for a computer-application in which remote sensing (difference-) images are interpreted to detect changes in roads. These specifications are formulated by the end user AVV.

## 6.1 User requirements of the ArcView application

**Operating system**:
Windows NT

**Tools and overall structure**:
GIS-tool: ArcView
Programming language: Avenue
At AVV recently applications are built for presenting and updating digital geographical road information. AVV prefers the change detection application to have a structure and overall 'look and feel' that is comparable to these applications already built.

Remark: an alternative tool, Erdas MapSheets, is not able to read vector files. Reading vector files is a requisite, because NWB (Nationaal Wegenbestand; National Road File) is a vector file, which should be read into the application.

**Selecting difference images**:
The user should be able to select a 'working area'. For example by drawing a box on an overview map of the Netherlands.
Experience learns that it's easy working by selecting the 'working area' on community borders (548 communities), because information is often delivered to the users ordered by community. Dutch community borders are available at AVV.
Another possibility is selecting the 'working area' by mapsheets from the 1:25.000 Dutch Survey Map (topographic map 1:25.000). Digital files of this maps are available and can be used together with the difference images.

**Input**:
The user should be able to read and open a minimum of three images in the application:
- difference image
- old image
- new image

Images can be delivered to AVV on CD-ROM and put on a server disk, to be accessed by LAN.

**Reference files**:
The user needs geographical reference on the screen. Of course NWB (digital road network) is a requested reference file. Also digital topographic maps are wanted as reference files. For example the digital pixel map from Geodan (GeoStreets) and the 1:25.000 digital pixel Dutch Survey map 1:25.000 (Topografische Dienst). AVV already purchased GeoStreets and RWS-MD can deliver Dutch Survey maps.

**Output**:
When a user is ready processing an area, he should be able to mark the area, for example in an overlay image. The user can chose the overlay to be in view or not.
Also the status of the processing should be preserved:
- observed, no supplier-information requested

- in process, supplier-information requested
- in process, supplier-information received

User should be able to save combined images and views in files and send them to plotters via the LAN.

**Linking of views and images:**
The various images, reference files and overlays that are presented in the windows on the computer screen should be linked concerning:
- geographical location
- crosshair position
- 'working area'
- image scale and mapscale

When the user moves the image/reference map/overlay in one of the windows ('panning'), the images in all other windows should move simultaneously in the same direction
When the user moves the crosshair in one of the windows, the crosshairs in other windows must move simultaneously to the same location.
When the 'working area' is adapted by the user in one of the windows, it should simultaneously be adapted in the other windows.
When the user adapts the scale (zooming) in one of the windows, it should automatically be adapted in all other windows.

## 6.2 Technical design ArcView application

**Description CHAD 1.0 (Change Detector)**
The ArcView application for change detection CHAD is developed by Geodan Geodesie. In this paragraph a global description is given of this design.

The objective of the application is to interpret visually, and to detect the possible gaps in the National Road Database (NWB) of RWS-AVV. This is realised by overlaying the NWB on the change detection results from remote sensing images. The remote sensing images will be SPOT images because these images cover a large area and show reasonable results for a good price. These images are processed in Erdas Imagine at RWS-MD. The operator at AVV has the availability to administrate the researched areas geographically. On their findings AVV can take their actions to actualise the NWB. The application is not suitable for manipulating the files, except the administrative shape file.

CHAD is developed in ArcView 3.1. For reference files the following files are available:
- Top10vector
- ERDAS Imagine images
- Top25raster
- Community borders

The following workflow can be carried out with CHAD:
1. Starting the application and selecting the name of the operator from a list.
2. Selecting of a working area by means of selecting a name of a municipality, a number of a map or interactive with the mouse in an Overview. After this the application zooms into this area.
3. Selecting the NWB from the SDE database with simple standard symbols.
4. Selecting one or more images and displaying them in one or more Views.
5. Selecting (optional) a reference topography and displaying it in an existing or a new View.
6. Turning on (optional) "Synchronising Views". The scale and image borders of all opened Views, except "Overview", are coupled to each other. When one zooms into an area of interest in a View then all Views are zoomed into the same area. In this way different images and files of the same area can be compared simultaneously.

7. According to the working method of the user the NWB files are checked. When a user has checked a certain area he can mark this area by means of a polygon in an administrative shape file. It is possible to couple a (predefined) status value to this polygons. Examples of status values are: in investigation, in process, ordered maps, etc. When adding a polygon the name of the operator and date are filled in automatically.
8. When a status has changed the polygon can be selected and a new status value can be added. Also the date of change of status is registered.
9. On each moment and of each View a map can be printed. Therefore a layout developed for CHAD is used.
10. The user can store a session under his own given name.

In the development of the user interface attention is paid to user friendliness and flexibility. This is visible in a clear user interface, sufficient feedback to the operator and extra tools which replace for example repeated actions. The reference files are selected automatically on the positioning of the View.

# Chapter 7 Conclusions and recommendations

The main conclusion of this study is that roads can be detected with the change detection results from the PHARUS and SPOT images. The reliability of the detected changes, the accuracy of georeferencing, and the resolution are sufficient.
In this project it appears that from ERS data only general change information, like the locations of new estates, can be obtained. Extracting road patterns from ERS is not possible. The main reason for this is the resolution of ERS of 30 m. PHARUS, with 4 m resolution, shows much better results. Nevertheless, ERS data can be used as a cue for PHARUS.

It is necessary to perform additional steps after the change detection procedure in order to assess a road extraction procedure. Often only parts of a road are detected. It is therefore necessary to extrapolate (or interpolate) these parts to obtain a complete road.
Furthermore, there are changes detected which are not relevant. For instance water surfaces in PHARUS images can induce intensity changes between images. A classification procedure can eliminate such changes. Water can easily be identified in a polarimetric image, but also objects with a reflectivity which strongly depends on illumination angle, can be found. In SPOT images changes in use of agricultural areas are detected which are not relevant for this project. It is recommended to design an expert system for the extraction of roads which accounts for these dependencies.

The detectability of roads is also dependent on changes of the context like:

- cutting down trees;
- the cultivation of ground surface (e.g. grassland) by grading machines;
- electric power cables between lighting poles in PHARUS images;
- shadow and lay-over effects of buildings in PHARUS images;
- shadow effects in SPOT images;
- new blocks of houses in SPOT images.

The PHARUS high resolution mode is most relevant for road detection applications and is the main advantage of PHARUS over SPOT. However, SPOT is cheaper and covers a larger area. The results of change detection are more or less the same.
The user requirements and needs, and the market size are factors that will motivate the choice for either the air- or spaceborne images, or the conventional methods in the application to road mapping.

When comparing the results of the change detection methods, the edge detection and the image subtraction, both methods seem to give the best results alternatively. It is not possible to prefer one of both methods.

The GIS-based system CHAD which is developed for this project satisfies the following requirements:

- ArcView application;
- it is possible to select a 'working area';
- a minimum of three images can be read (difference image, the old and the new image);
- a geographical reference is present on the screen (NWB and topographical map);
- the images, reference files and overlays can be linked on the screen;
- it is possible to administrate the researched areas.

A complete automatic extraction of road changes is not yet possible. Still the operator has to determine which detected changes are belonging to roads or to the environment. The new generation of satellites therefore looks promising for the automatic change detection of roads. Due to their high resolutions it is recommended to look at the possibilities to distinguish different kinds of changes within these satellite change detection images.

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