

AUTOMATIC OBJECT RECOGNITION AND CHANGE DETECTION OF URBAN TREES

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Commission IV, Working Group IV/4

KEY WORDS: remote sensing, change detection, updating, segmentation, 3D, object oriented, urban, trees, database

ABSTRACT:

Monitoring of tree objects is relevant in many current policy issues and relate to the quality of the public space, municipal urban green management, management fees for green areas or Kyoto protocol reporting and all have one thing in common: the need for an up to date tree database. This study, part of the Tree and Image research project, developed a database-driven approach for object recognition and change detection using optical imagery including contextual data from urban tree databases and topographic data. Trees are 3D objects and vary in shape throughout the season. The tree is modelled in a 2D aerial image using the point location and species information. The tree model consists of a projected crown and shadow. These projections, polygons, are used to recognise the object with NDVI and texture parameters related to the ground surface derived from the topographic map and its neighbouring segments. This resulted in classifications of trees 'still present' or 'disappeared' with an overall accuracy of 85%. However, the errors of commission and omission were quite high due to the use of an early image with no full-grown crowns, resulting in difficult recognisable trees. Detected changes can be used for further human verification or directly serve as input for database management and decision making.

1. INTRODUCTION

1.1 Urban Trees

There is a clear question for objective and fast monitoring of individual trees, tree rows and groups of trees with regards to many current policy issues for municipalities, private organisations and the European Union. These policies relate to the quality of the public space, municipal urban green management, management fees for green areas or Kyoto protocol reporting and all have one thing in common: the need for an up to date administration of trees.

For municipal green management yearly an inventory is obliged on the status of trees. This is done by Visual Tree Assessments (VTA) for which solitary trees, tree groups, lane trees are monitored by visual inspection. During this control the status and condition is determined and stored in a database. Management software uses such databases to determine the appropriate maintenance as pruning, topping, felling, etc. A much heard complaint is that the VTA cycle takes too long and is too expensive and therefore the maintenance of trees is inefficient especially in areas outside the urban areas of municipalities. Geo-information of living objects, such as trees, easily becomes outdated. An efficiency increase in management of trees is therefore highly necessary.

1.2 Tree and Image

There is an increasing availability of digital Very High Resolution (VHR) satellite and aerial imagery including near-infrared band, The imagery is captured with various digital aerial cameras, e.g. Vexcel UltraCam-D. Satellite imagery is available from e.g. IKONOS, QuickBird and GeoEye. Also satellite imagery with 2-5 meter resolution, e.g. RapidEye can be used for object recognition and change detection. Many more satellites are going to be launched the coming 5 years.

VHR imagery is now a stable source for the (Dutch) spatial data infrastructure and will become an even more stable source.

The table below illustrates this for Enschede municipality, and is comparable to other municipalities in the Netherlands.

Year	Winter (resolution)	Summer (resolution)
2000		1.00
2001		
2002		
2003		
2004		
2005		0.40
2006		0.60
		0.40
2007	0.16	0.40
2008	0.10	0.25
2009	0.10	0.25
2010	0.10	0.25

Table 1. VHR imagery for Enschede Municipality

Aerial and satellite imagery can be used to keep the valuable tree data up to date. This includes characteristics among other things as presence, location and crown size. Classification of VHR imagery remains a very difficult task. This is mainly due to intra-crown spectral variation, heterogeneity of tree species and the complex spatial arrangement of individual trees with respect to other vegetated surfaces and elements of the urban space.

Pixel-based algorithms, are not suitable for the analysis of objects as trees, because important semantic information, necessary to interpret such an object, is not represented in single pixels, therefore, image analysis should be object based as well (Van der Sande et al., 2003). Van Delm and Gulink (In press) demonstrated a segmentation approach including vegetation indices and texture in the classification of urban green. Ouma and Tateishi (2008) combined spectral and

textural image characteristics in multi-scale wavelets for the extraction of urban trees.

The Dutch project Tree and Image ('Boom en Beeld') started in June 2007 to develop algorithms for object recognition and change detection on trees using optical imagery. The partners in this project are NEO, ITC and Alterra. The GEOBIA 2010 conference marks the end of the project and the results are presented. The project focussed on the use of optical imagery including contextual data from tree databases and topographic data. LiDAR data can also be used to update tree data, but the data is very expensive, especially if it is a yearly task. Therefore, this paper and the project Tree and Image focuses on the application of VHR imagery. In this research project the following results are achieved. Tree crowns are delineated using land cover information by region-growing segmentation (Ardila Lopez, 2010) and Super resolution mapping (Tolpekin et al., 2010). Tree data as location, size and shape is used in modelling tree objects on imagery for tree growth prediction (Kramer and Oldengarm, 2010). Bijker et al., (2010) shows how tree crown objects extracted from images of different dates and sensors can be compared on an object-by-object by describing it as a fuzzy object. This approach fits better with the perception of the users, who are managing objects rather than pixels, and combines well with their vector-based topographic data.

1.3 3D and Phenology

Similar to buildings trees are three dimensional objects stored in two dimensional databases. In 2D databases individual trees, tree rows and groups of trees are generally represented as points with an x and y coordinate. These points represent the location of the tree trunk. An extensive database is available for each tree with attributes as e.g. species, sub species, year of planting, condition, preferred crown perimeter and maintenance. Again as with buildings trees cause in non-vertical imagery relief displacements and shadows. If the heights and shapes of trees are known exactly, the 3D characteristics can be modelled in a 2D image. Object recognition and automation of change detection for tree objects is challenging because trees are dynamic objects. They vary through the season, show growth and are maintained. However, a lot of data is present to facilitate the object recognition process since every tree has its characteristics on status and condition stored in a geodatabase. As part of the project Tree and Image the objective of this study is to investigate in what way 3D and phenological object characteristics need to be integrated in the change detection process? The change detection process will result in two classifications for a tree: 'tree still present' or 'tree disappeared'.

2. METHODOLOGY

2.1 3D characteristics of trees

In Dutch tree databases a minimum of location and specie is known per tree. These characteristics are the starting point for the 3D characterisation of trees. Every tree specie has a unique shape. Ruyten (2006) divided these shapes in 13 classes as follows:



Figure 1. Tree shapes

In time a tree grows in height, crown and trunk. The next figure shows tree growth compared with age of the tree. Trunk diameter shows a proportional growth in time Height and crown diameter have a growth that can be expressed as a square root function.

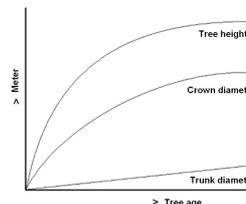


Figure 2. Tree growth

The time in season has effect on the shape of a tree. During the year tree growth varies depending on temperature, available water and sun light. Deciduous trees have several periods: growing of leaves, full crown, falling of leaves and a period without leaves.

2.2 3D modelling

Tree characteristics can be modelled by knowing the tree height, crown diameter, crown shape, trunk height and trunk diameter, see the following figure.

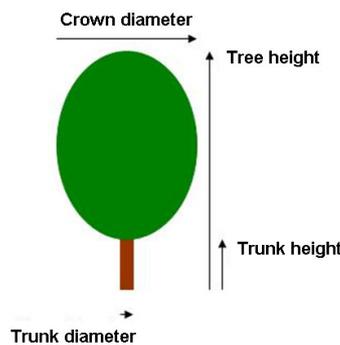


Figure 3. Tree characteristics

In a city neighbourhood the number of different tree species can easily exceed a 100. Therefore, we decided to model tree species in standard models. Tree age can be used to model the characteristics of trees. Tree databases have a field to indicate the planting date and information on the age of the tree when planted, however for the study area these data were incomplete. We decided to model trees using height and making the crown diameter and trunk height relative to it using the following equations:

$$Cd = Cf * H$$

$$Th = Tf * H$$
(1)

- where
- Cd = crown diameter (m)
 - Cf = crown factor (-)
 - H = tree height (m)
 - Th = Trunk height (m)
 - Tf = Trunk factor (-)

A standard ellipsoidal shape was used for the crown. Figure 4 displays the standard tree models.

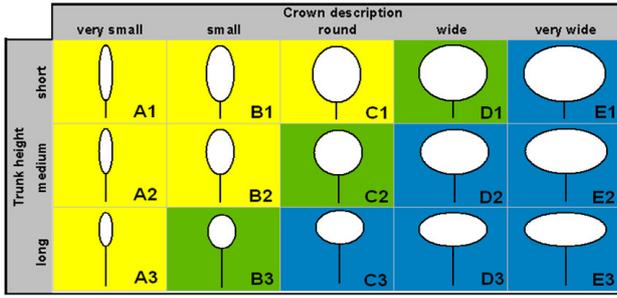


Figure 4. Standard tree model

For every tree model crown factor and trunk factor were determined based on field surveys, aerial winter images and database information, see table 2. These tree models were linked to tree species, see appendix 1.

Tree model	Trunk height Factor Tf	Crown diameter Factor Cf
A1	0.20	0.20
A2	0.40	0.20
A3	0.60	0.20
B1	0.20	0.38
B2	0.40	0.38
B3	0.60	0.38
C1	0.20	0.63
C2	0.40	0.63
C3	0.60	0.63
D1	0.20	0.88
D2	0.40	0.88
D3	0.60	0.88
E1	0.20	1.05
E2	0.40	1.05
E3	0.60	1.05

Table 2. Tree factors

The height data in the database was incomplete and therefore height information was gathered per tree by either from available LiDAR data or winter imagery by measuring the shadow length of a tree in an image. The height of the tree in winter imagery is calculated by using the azimuth and elevation angles of the sun, see equation 2.

$$\text{Shadow length} = \frac{\text{tree height}}{\tan(\text{sun elevation angle})} \quad (2)$$

The trunk diameter was in relation the optical imagery of minor importance to model, because it would be have a width of 1 or 2 pixels with image resolution of 0.40. Therefore a constant value was used of 0.40 meter.

2.3 Tree modelling in 2D imagery

2.3.1 Shadow modelling

Crow's (1977) shadow volume method has been to date the most practical method of rendering shadows. The basic idea is a source of light and a model to generate a projected shadow that has the silhouette edge of the model. The projection plane is always the ground level.

For modelling the shadow the tree characteristics are used. Since the elevation of the sun and the height of the trunk are known it's possible to calculate the length of the shadow for the points **A**, **B** and **P** with equation 2

The coordinates of the points **A** and **B**, that define the diameter of the trunk, can be found by solving equations 3 and 4 that use

the coordinate of the tree, **P**, the diameter of the trunk, T_w , and the slope, m_p , of the perpendicular line to the sun direction, s_2 . See figure 5 for further details.

$$\begin{cases} X_A = \frac{\frac{T_w}{2} + X_P \sqrt{m_p^2 + 1}}{\sqrt{m_p^2 + 1}} \\ Y_A = m_p (X_A - X_P) + Y_P \end{cases} \quad (3)$$

$$\begin{cases} X_B = \frac{\frac{T_w}{2} - X_P \sqrt{m_p^2 + 1}}{-\sqrt{m_p^2 + 1}} \\ Y_B = -m_p (X_P - X_B) + Y_P \end{cases} \quad (4)$$

The direction of the sun is known, so we can decompose the length of the shadow along the two main axis. If we sum these Δ_x and Δ_y values to the original ones we will obtain the x and y coordinates of the **C**, **D** and **M** locations.

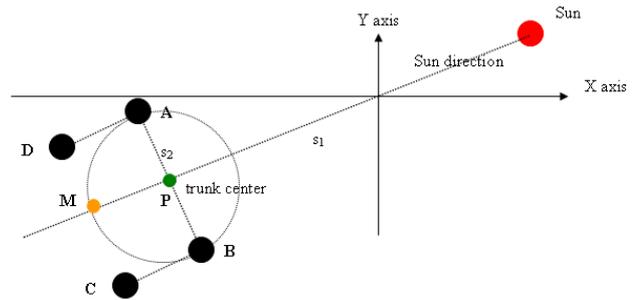


Figure 5 Trunk shadow modelling

For shadow modelling of the crown, see figure 6. Locations **I** and **L**, are the projections of the points indicating the height of the tree, **E**, and centre of the crown, **F** on ground level.

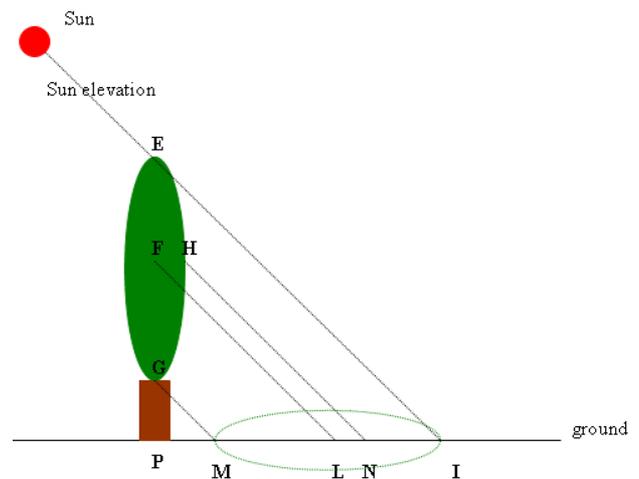


Figure 6. Crown modeling with a low sun elevation

Depending on the sun's elevation it is possible that the length of the PN segment is smaller or greater respect to the length of the PI segment. In the first case (figure 6), the LI segment is the length of the maior axis and the LN segment is the length of the

minor axis of the ellipse that represents the ground projection of the crown.

In case the length of the PN segment is greater than the length of the PI segment, see the figure 7, the LN length is the major and minor axis of the ellipse that represents the ground projection of the crown.

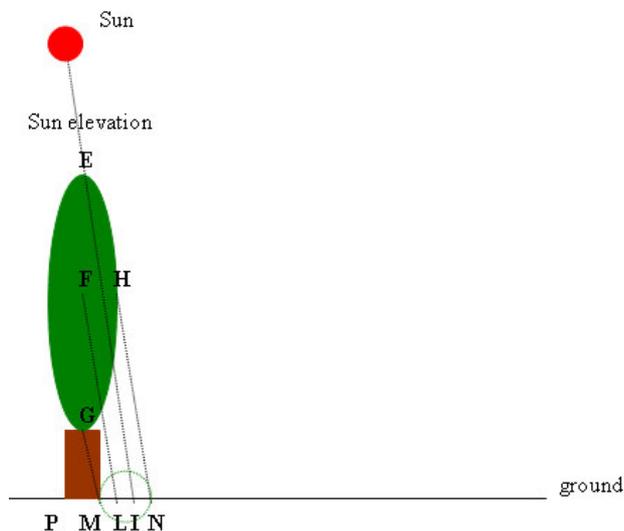


Figure 7. Crown modeling with a high sun elevation

2.3.2 Relief displacement modelling

The relief displacement modeling uses the same equations as the shadow modeling. For satellite images, the azimuth and elevation angles of the satellite can be used instead. For aerial images the azimuth and elevation are relative to the camera position. Since the airplane is close to the earth’s surface the projection beams are not parallel, see figure 8. We used however an simplification and assumed the lines as parallel.

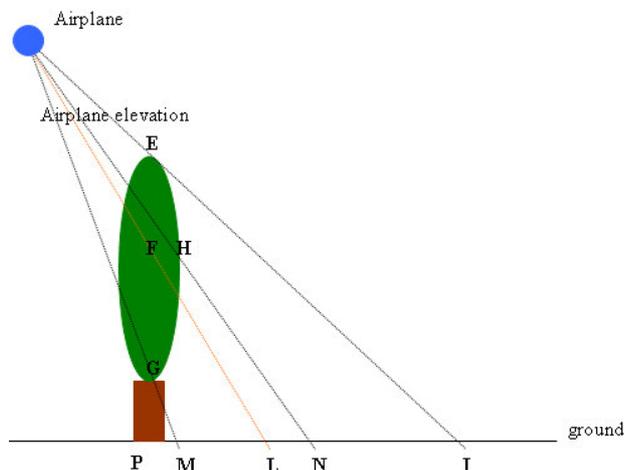


Figure 8. Crown modeling with a high sun elevation

2.4 Change detection process

Our approach to change detection is hypothesis-driven. Each object leads to a hypothesis (that a tree still exists at that place), and the imagery is supposed to provide the evidence for accepting the hypothesis – and in absence of sufficient evidence a change is detected.

An object-oriented approach for change detection is developed using Definiens Developer software. This software uses segmentation techniques to create homogeneous segments from pixels of VHR imagery.

This approach was successfully applied by Van der Sande et al. (2008) to buildings. In general the developed method compares the modelled object t0 with the image t1. Information is gathered on how each object represents in the image t1. The crown and shadow models at t0 are acquired from the database. As ground truth manually changes are detected to validate the automatic process.

The phenological state determines the presence and amount of leaves. Chlorophyll content in the leaves determine the reflection of leaves in the red and near-infrared image bands. The Normalised Difference Vegetation Index (NDVI) is the ratio of near-infrared and red and is an important classifier of vegetation. Moreover trees are not homogeneous in the reflection, due to internal shades between leaves and branches. A tree shows a structure or certain texture and this will be taken into account in the object recognition process.

3. STUDY AREA

For this study various type of data were present for a neighbourhood in the centre of Enschede municipality in the East of the Netherlands: 2D large scale base map, municipal tree database with 240 trees, height data and high resolution winter imagery (used for height determination of trees). For the object recognition and change detection an image with characteristics displayed in table 3 was used. Figure 9 displays the colour infrared image together with the large scale base map and point locations of trees.

Sensor characteristics	Vexcel UltraCam-D
Acquisition date and time	12-4-2007 at 13h21m
Image resolution (meter)	0.40
Spectral bands	Blue, green, red, near infrared
Image depth	12bit (8bit after cubic resampling)
Sun elevation (degrees)	45.402211
Sun azimuth (degrees)	196.539245
Centre Image X (meter)	259362
Centre Image Y (meter)	470997
Height (meter)	5589.06

Table 3. Image characteristics



Figure 9. Aerial image and large scale base map with municipal tree locations

4. RESULTS AND DISCUSSION

4.1 3D Tree representation in a 2D map

The trees were modelled in 2D representations of the displaced crown and the projected shadow on the ground. The next figure shows two modelled elms (*Ulmus 'Dodoens'*) and one can see that the model is not perfect, but the location of the crown and the location of the shadow can be used for the evaluation of the tree's presence.



Figure 10. Modelled elms

4.2 Tree change detection

The change detection approach started with hierarchical image segmentation into 4 levels using the image, large scale base map, shadow polygons, crown polygons and a union polygon map of shadow and crown per tree, see figure 11.

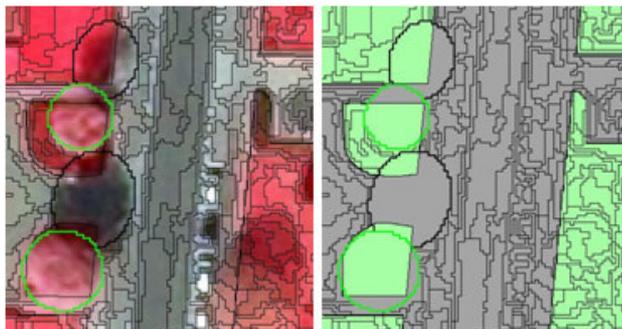


Fig 11. Image segments

In the classification hierarchy segments were classified using NDVI and the texture feature 'GLCM homogeneity NIR for all directions'. The class of the large scale base map was taken in the classification process. In case of buildings in shadow, shadow could not be evaluated. Neighbouring segments to the crown or shadow were evaluated for its values in NDVI and texture and compared with the segments in the crown and shadow. This resulted in a final classification in level 4 where the evidence of change from level 2 and 3 was combined and indicated that a tree is 'still present' or has 'disappeared'. Table

4 summarised the change detection approach that was executed in Definiens Developer.

Level	Layer used	Goal
1	Image	Making image characteristics: NDVI and texture
2	Shadow polygons, Crown polygons, Large Scale Base	Shadow evaluation using large scale base map and neighbouring segments
3	Duplicate of level 2	Crown evaluation using large scale base map and neighbouring segments
4	Union	Combining the evidence of change from level 2 and 3. Classification Export of results

Table 4. Summarised change detection approach

4.3 Results

Figure 12 shows an example of the classification result. For the red outlined areas no evidence was found



Figure 12. Classification example: 'tree still present' (green outline) 'tree disappeared' (red outline)

The next table shows the error matrix and the overall classification accuracy.

classification	ground truth		
	remained	disappeared	total
remained	192	24	216
disappeared	11	13	24
total	203	37	240

Overall accuracy: 85%

Table 5. Error matrix

4.4 Discussion

From points location of trees, tree models were created using height data and standard models. From these models the crown and shadow were projected well on the 2D image. The projected shadow and crown were a good classification unit. However, the errors of commission and omission were quite high due to the use of an early image with no full-grown crowns, resulting in difficult recognisable trees. This approach works best with imagery with clearly visible crowns. Errors also arise when trees are not solitaires or lane trees, but group of

trees or trees close to buildings. Finding evidence of change is then more difficult. Shadows that are dropped on trees by other trees are source of error. Also relief displacement of one (bigger) tree can block the viewing angle to another tree. This counts even more for buildings, because they can drop bigger shadows on trees. Or a building is causing relief displacement making the tree not visible. The projection of 3D buildings' shadow and relief displacement should be taken into account in the change detection process too (Van der Sande et al., 2008).

5. CONCLUSIONS

3D models and vegetation characteristics in a database-driven approach for tree object recognition and change detection give reasonable to good classification results of trees. Detected changes can be used for further human verification or directly serve as input for database management and decision making.

A recommendation is to use the same approach with an image with full-grown tree crowns.

Further improvements can be realised by introducing 3D models of buildings and improve the modelling of the objects in relation to each other.

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7. ACKNOWLEDGEMENTS

This study has been made possible by funding of the Netherlands Space Office (NSO) through their program Pre-qualification ESA Programs (PEP) for the project Tree and Image (Boom en Beeld).

Enschede municipality is kindly acknowledged for their contribution and supplying tree location data, topographic maps, cadastral data and aerial imagery. The Faculty of Geo-Information Science and Earth Observation (ITC) of the University of Twente is acknowledged for making the height data available.

APPENDIX 1. TREE SPECIES AND THERE MODELS

Specie	number	Shape
Acer Platanoides	1	C1
Acer Ps.`Negenia`	11	C2
Acer Ru "Scanlon"	15	B2
Acer Rubrum	5	C2
Acer Saccharinum	3	C1
Alnus Cordata	5	C1
Alnus Spaethii	6	C1
Betula Jacquemontii	1	C1
Betula Nigra	4	C2
Betula Pendula	5	B1
Carpinus Be "Fastig"	13	C1
Carpinus Betulus	2	C1
Castanea Sativa	18	C1
Catalpa Bignonioides	1	C2
Fagus Sy.`Dawyck`	1	A1
Fraxinus Or.`R`Dam`	3	B2
Gledit. Tr`Rubylace`	11	C2
Gleditsia Triacanth.	7	C1
Koelreuteria Panicu	6	D1
Liriodendron Tulip.	12	B2
Malus Floribunda	8	D2
Metasequoia Glypt.	8	B1
Platanus Acerifolia	14	C1
Prunus Avium`Plena`	7	C2
Prunus Ce.`Nigra`	3	C3
Prunus Sa "Rancho"	14	C2
Prunus Se "Kanzan"	12	C2
Prunus Serrulata	1	D1
Prunus Su.`Autumn.`	2	E1
Prunus Ye "Erecta"	1	C1
Pyrus Calleriana	2	C1
Quercus Palustris	4	C1
Robinia Pseudiacacia	5	C2
Sorbus Au.`Edulis`	3	C1
Tilia Vu "Pallida"	13	C2
Tilia Vulgaris	3	C1
Ulmus "Dodoens"	4	C1
Ulmus Ho.`Groenev.`	3	B2
Ulmus Ho.`Vegeta`	3	C1