OBJECT-BASED CHANGE DETECTION FOR A CULTURAL-HISTORICAL SURVEY OF THE LANDSCAPE – FROM COW TRAILS TO WALKING PATHS

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ABSTRACT:

Historical maps, aerial images and other historic documents are finding their way into the digital world. This offers new possibilities but also requires adapted technologies and interdisciplinary approaches. The ProMeRe project connects historic, architectural and planning methods with remote sensing and geoinformation technologies. It aims to analyse the development of tourism and its effects in an alpine environment over the last 150 years.

We present an object-based change detection approach with IMAGINE Objective for the monitoring of country roads and walking paths networks in the project area. Changes in these networks contribute essential information for historic research questions concerning the development of tourism and its impact on the landscape. IMAGINE Objective employs feature models which work on objects produced by image segmentation and various other pixel-based algorithms which, after being vectorised, can be processed by geometric and textural parameters. This process is used and optimised for the extraction of the walking path network from high resolution colour ortho imagery of 2000 and 2004.

The results show that the similarity of scree and rocks with walking paths is a major challenge. In comparison of different feature extraction models "centerline detection" yields the best results for walking path network detection. Preliminary change detection tests using a semi automated post-classification approach show reliable results. For this project, the applied methods prove to be useful to detect changes in the walking path network in the example imagery even without producing a complete extraction of all walking paths and country roads. The approach will be extended to the whole project area and additional mostly older black/white sets of ortho imagery.

1. INTRODUCTION

The work presented in this paper is part of an interdisciplinary project called "ProMeRe - Processes and methods for interdisciplinary and collaborative spatial analysis and development" (ProMeRe 2010) which focuses on the examination of the history of tourism and its impacts on communities, housing and architecture using the example area of Andermatt and its surroundings in the Swiss Alps. Methods and technologies of disciplines such as architectural science, land use planning, geoinformation engineering, history and cultural science are combined in this project. The collaboration between disciplines will open new ways and possibilities and yield new insights into traditional data sets, but also requests new approaches and solutions of data management and analyses. The project aims to gain mutual benefit from combined methods and technologies through profound understanding and complementation.

Central piece of the project is a spatial-temporal database for the storage, analysis and visualisation of all data and information collected by the researchers of the different contributory disciplines. Detecting changes in the walking path network is a request of the historians. The work presented in this paper shows approaches for change detection with OBIA (Object Based Image Analysis) targeting walking paths.

The findings of the OBIA approaches will be combined with inputs from field studies and other research methods in the spatial-temporal database which will provide a basis for further interdisciplinary analysis and visualisation.

1.1 Study area

Andermatt is situated in Central Switzerland at an important traffic junction of the Alps – the Gotthard (N-S) and the Furka-Oberalp (E-W) routes (Figure 1). The history and development of the valley and its people are based on this fact. Due to its advantageous connections within Europe, tourist infrastructure developed in an early phase ("Belle Epoque"), reaching its peak in the 1920ies.
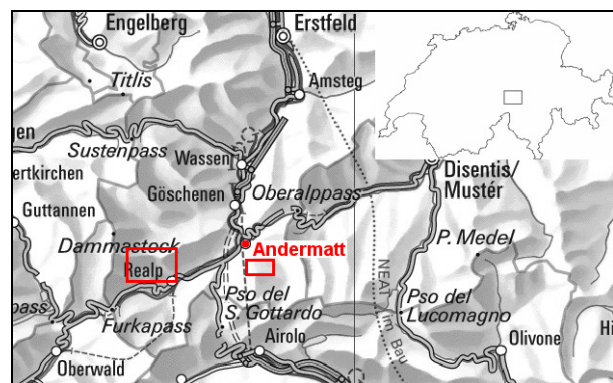

Figure 1. Location of Andermatt in the Swiss Alps and the two example areas (red frames) for the extraction of walking paths

Andermatt and its surroundings serve as test area in the ProMeRe project as the historic project partners have already

done research there and these results are an important part of the current project. However, the developed methods and processes shall be transferable to other regions of the Swiss Alps.

1.2 Target: walking path networks

The tourist history of Andermatt and its surroundings is closely connected with the development of the road network through the Swiss Alps. Additionally, path networks and path consistencies are important factors regarding tourist development on the one hand and a sign for tourist behaviour and its changes over the years on the other hand. A close connection also exists to the impacts that tourism has on the landscape and nature of a region, which are usually hard to detect especially if happened so in the past. Therefore, historic aerial images, which also show the development of paths which are not existent on current or historic maps, are very valuable.

In the area of Andermatt, most walking paths are found above the timber line. In lower areas walking paths become broader and turn into country roads (Figure 2). Such small roads are a target in this project for verification purposes and further refinement of the object extraction methods. The example areas chosen for the walking path and country roads detection and extraction are shown in Figure 1.

1.3 Reference to related works

There are some studies that deal with time series of geographic information based on historic maps and GIS (Bender et al., 2005; Braun et al., 2009) with similar goals as the ones defined for this project. In our case the information in the maps can only support but not completely cover the historians requirements. However, some of the GIS processes found in the mentioned works can be adapted for our study. An approach to data pre-processing for long time series of historic aerial images is found in Walde (2009). The results from her work will gain in importance for our project when the time period is extended to include more historic image material.

Regarding the present task OBIA is the most suitable approach (Hay (2006) or Blaschke (2010)). Many OBIA approaches with similar targets e.g. path and tracks on natural and semi-natural habitats (Varela et al., 2006) or habitats in alpine environments (Preiner et al., 2006) use multi-scale segmentation and fuzzy logic approaches. In this project we use the software IMAGINE Objective which allows slightly different approaches which will be presented in the subsequent sections of this paper.

1.4 Goals

As mentioned above, the focus of the study presented here is on the requirements given by historian researchers. They ask questions such as "When do cow trails become walking paths?" The answer to such a question will certainly need more information than what can be extracted from ortho imagery. However, we can support the answer of the question by aiming to automatically extract walking path networks from different sets of historic ortho imagery and detect obvious changes. Additionally, the historian researchers will employ their methods and, for example, will extract information from interviews, which are an important source of information which is often difficult to place. The combination of both methods will make it possible to place the historian's vague information such as about where a new path was built or an avalanche might have changed the course of a path.

The goals of the study reported in this paper were to investigate the possibilities and to develop an easy-to-handle method to automatically monitor path networks from ortho imagery over time. Given the requirements from historic research and the assumption that path networks generally evolve over time the focus was to look back from today's path network and to find out, for example, when each path was built or when it obviously changed its course. We hypothesised that in order to detect the changes in walking path and country road networks over time it is not necessary to detect and extract the complete path and country road network. It should suffice to detect major parts of it to decide if a walking path existed at a specific time.

The results of this study shall be transferable in space and time. Therefore, the developed feature extraction models will need to be sufficiently robust to be applied to other images in other areas. Additionally, in order for the study to be of wide use to other scientist as well as users from different backgrounds, easy handling of the results is an important postulate of this study. To this end an "all in one solution" OBIA-software is employed as the central module to compute feature extraction and change detection.

2. DATA AND METHODOLOGY

2.1 Base data

Available data of the example area since the 19th century are historic maps, terrestrial photographs, postcards, aerial imagery and 3D-geodata and -services which are provided by the Swiss National Mapping Agency swisstopo (swisstopo 2010).

For the work presented here, ortho imagery (Swissimage) from 2000, 2003 and 2004 were used for OBIA (Table 1). The path and road network is of different quality but visible in these data (Figure 2). The ongoing study intends to include historic aerial images of the area which date back as far as the 1950ies and the terrestrial images as far as 1915 for further analysis.

name	Swissimage
years	2000, 2003, 2004
format	GeoTIFF
type	3 bands RGB
resolution	50 cm /24 bit

Table 1. Technical characteristic of used ortho imagery

Figure 2. Four examples of walking paths (left) and country roads (right) as they are visible in the used ortho imagery

2.2 Methods

For this study IMAGINE Objective 9.3 was employed for extraction of walking path networks primarily. In parallel some evaluation runs were carried out with Definiens Developer (former eCognition) for comparison purposes. These results are not reported here. For pre-extraction processing like the preparation of the image data, ERDAS IMAGINE was used.

The three different approaches for change detection were accomplished with ERDAS IMAGINE 9.3, ArcGIS 9.3.1 and PaintShop Pro.

IMAGINE Objective was used to define features models employing different feature detection and extraction methods from recent ortho imagery (Table 1). To simulate feature detections in historic grey scale images one of the images was turned into an 8-bit grey scale image (BW) and the same feature extraction model was run.

target	example area	detection method	year of ortho images
walking path	Gemsstock	Centerline detection	2000, 2004, 2003, 2004 (BW)
	West Urserental	Centerline detection	2000
country roads	East Andermatt	Centerline detection	2000
		segmentation	2000

Table 2. Overview of the developed feature extractions for the different targets, areas and ortho imagery

2.2.1 Walking paths: The feature extraction for walking paths was created and optimised for a small area above Andermatt (Gemsstock). Later this model was transferred to a whole ortho image (West Urserental). Details about this approach and the results are presented in the following chapter. Additionally, the developed feature model for the extraction of walking paths was run on images from different years of which one had been transferred to a grey scale image (Table 2).

2.2.2 Country roads: As walking paths get broader down in the valley they mostly turn into country roads (=gravel roads, Figure 2, right). The line based feature model (centerline detection) developed for the walking path in an alpine area was transferred to country roads in the valley near Andermatt with only minor adaptations (new training areas) in a first step. Since country roads are broader than walking paths, a polygon based model was developed and compared to the line based approach. Polygon based feature models offer a wider range of tools especially for segmentation and extraction based on geometric cues.

2.2.3 Transferability: To transfer a model to different images the training areas have to be adjusted for an automatic extraction. This is necessary due to possible changes in walking paths on one hand and small differences in the georeferencing of the images which, especially for narrow training areas as walking paths, show a relevant effect on the other hand.

It is a common problem that aerial images show differences in the georeferencing over the years. This issue can be resolved using two different approaches mainly. Either the images are georeferenced accordingly as a series or all onto one reference image (Walde, 2009). Or the problem is tackled on a later stage with special change detection methods. In this study the second option was chosen because many different images and maps from different sources are to be integrated.

2.2.4 Change detection: Four different change detection approaches were tested. Firstly, the automated methods offered by IMAGINE Objective were looked at. For the reasons detailed above automated change detection on the basis of two outputs from the line-based extraction from different years are an impracticable approach because the extracted lines are neither complete (as not sought-after) nor identically placed.

In another approach a visual analysis in ERDAS IMAGINE (changed and non-changed areas) was conducted to check reliability and quality of the results.

Additionally, two different post-classification based change detection approaches (Zhou et al., 2008) were tested as a pure GIS-approach and as a mixed approach using segmentation results. Details about the processes and results are given in the following chapters.

3. WALKING PATH

A 'feature model' forms the basis for the extraction which consists of seven sequenced 'Process nodes'. There is a given set of algorithms within these nodes that can be freely arranged in terms of order and settings. Especially for the 'Operator nodes' the chosen order of algorithms is essential. A detailed description which outlines possibilities and constraints of the software with suggestions for improvements is given by Hölbing (2009).
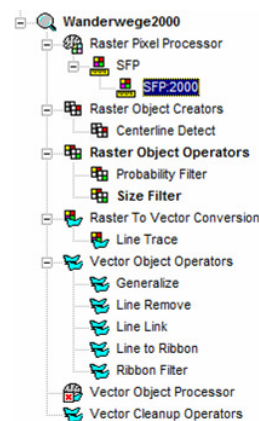

Figure 3. Feature model tree for walking path extraction

The following procedure describes the developed single class feature extraction for walking paths step-by-step (Figure 3):

1. Raster Pixel Processor: For this pixel based classification the SFP (single feature probability) was chosen, which uses a bayes-classifier (=statistic classification). The definition of training areas for walking paths as well as for background pixels is of central importance to the outcome. Training areas have to be chosen carefully to not include any background pixel.
2. Raster Object Creators: In this step the function 'Centerline Detect', which attempts to align pixels and assigns an average pixel probability (combined with result of step 1) for each pixel, was evaluated (Figure 4).
3. Raster Object Operators: Using 'Probability Filter' and 'Size Filter' allowed to keep pixel objects with high probability and a certain amount of pixels only.
4. Raster to Vector Conversion: With 'line trace' pixel objects are automatically vectorised. The following steps are working with vectorised objects.

5. Vector Object Operators: In this step the vector objects are generalised which accelerates later processing. To keep lines with a certain length and within short distance to neighbouring lines only the function 'Line Remove' was used (Figure 5). With the 'Line Link' filter lines can be connected if they fit certain criteria. With the attribute 'Ribbon Width' originating from the 'Centerline Detect' function the lines can be converted to ribbons ('Line to Ribbon') and then be filtered ('Ribbon Filter') according to their width (Figure 6).

6. 'Vector Object Processor' processes geometric and textural features of the Vector Objects and writes the probability value for each feature to each object in a attribute table. For line based extraction there are only few object cues available in IMAGINE Objective, compared to a wide range for area based extraction. For this approach Vector Object Processors only marginally improved the results.
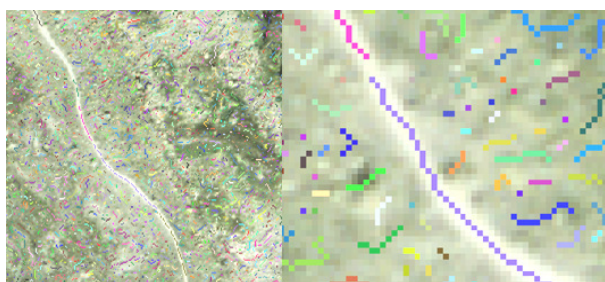

Figure 4. Detail view after the segmentation with "Centerline Detect" for walking path.

Figure 5. Detail view of walking path extraction result (after vectorisation, "Generalize" and "Line Remove").

Figure 6. Detail view of walking path extraction result (after "Ribbon Filter").

False positive detection appeared due to the similarity of walking path with scree and rock mostly. With the algorithms available in IMAGINE Objective (like "Ribbon Filter") scree and rock could be filtered out partially only. The quality of the results varies depending on the surroundings; in rocky and scree areas the results are less satisfying.

When the walking paths had irregular width 'Centerline Detect' did not work very well. For these walking paths an area segmentation based model would have solved this problem. However, walking paths are too narrow for an area based approach in general.

4. COUNTRY ROADS

The "Centerline detection" model showed to be more robust and reliable for country roads compared to the walking paths extraction. The algorithms developed for walking paths in high alpine area could be successfully reused for country roads. Only training areas and width cues had to be adjusted.
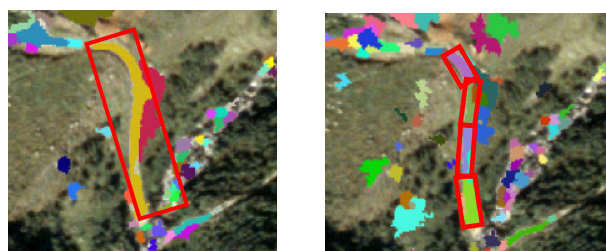

Figure 7. Large segments (left) and small segments (right) with Minimum Bounding Box

Additionally an area based feature model was developed for country roads. For this purpose the segmentation process can be optimised with mainly two parameters: Min Value Difference (minimum margin between two segments) and Variation Factor (variation of pixel values within a segment). The size of the resulting segments varies on the values which are chosen for these two parameters.

ERDAS IMAGINE offers the possibility to improve segmentation results with a kind of classification based approach. It consists mainly in "Segment Merge" and "Split" algorithms which aim to improve the pixel probability of an object by rearranging them.

Choosing a method with larger segments (Figure 7, left) has the disadvantages that narrow roads might not be segmented and that e.g. in curved roads the geometric features of the objects are lost. This defeats the object of this method, which was to profit of the wide range of possibilities in "Vector Object Processor". For this task the "Split" algorithm was tested but didn't solve the problem.

On the other hand selecting the segment size smaller (Figure 7, right) would have the advantage of keeping the geometric features of a resulting object. But it also had the side effect that country roads e.g. with a grass stripe in the middle were divided and could not be reconnected with "Segment Merge" satisfactorily. For these reasons overall the "Centerline Detection" approach showed better results.

The here developed approach for the extraction of country roads is limited to non urban area. There are limitations to this method that could not be overcome so far: grassy roads could not reliably be detected and in some cases rivers and railway tracks with a similar width as country roads were falsely classified as country roads.

5. CHANGE DETECTION

Given the requirements from historic research the focus was to look back from today's walking path network and detect major

changes in walking path network in the past. Generally an important condition for change detection is the transferability in time. Three different approaches for change detection were tested.

5.1 Visual Analysis

In the Viewer of ERDAS IMAGINE visual analysis was conducted between two classification results of walking paths. The results from the walking path extraction were overlaid.

Visual analysis and comparison serves to check the reliability and quality of the results. The visual overlay showed to be helpful to detect changes (Figure 8) as well. If there are not many changes to be expected and the size of the area is manageable this manual approach for a final analysis is helpful. For larger areas and many changes a more automated approach is recommended (Lu et al., 2004).
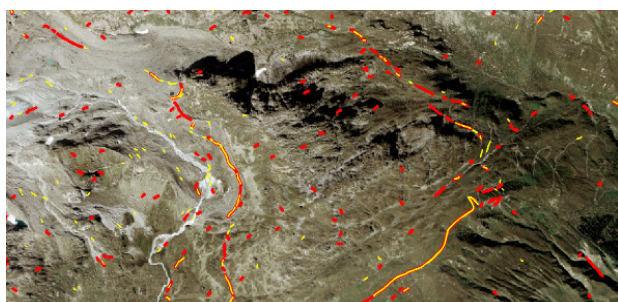

Figure 8. Walking path extraction results from 2000 (red) and 2004 (yellow)

5.2 Segmentation based Approach

The segmentation based change detection approach was tested on country roads. A change has been simulated with PaintShop Pro to run a check-up because there were no changes in the original images of the example areas.

The procedure was as follows:
- The feature model was run on the input image 2004 (Figure 9, left).
- The feature model was run on the input image 2003 for the pixel based classification processes only (Figure 9, middle).
- The extraction results 2004 were used as line vectors to clip the pixel based classification results from 2003. For this step GIS-analysis tool "overlay" in ERDAS IMAGINE was used. The overlay sets the lines back to pixel which each has a pixel probability
- Then a probability threshold for change was defined. All pixels with a low probability (0-0.3) indicate change (Figure 9, right).
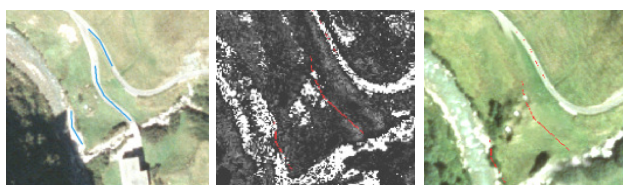

Figure 9. Result 2004, pixel based classification 2003 and change indicating probability pixel (red)

This approach was tested on a simulated change on country roads, which could be easily detected (Figure 9, right). For walking paths this approach needs to be adapted because they are too narrow. Thus inaccuracies in georeferencing add up too much.

If required this procedure can be automated as far as the last step. For the simulated change this showed very reliable results. However it has not been tested yet on larger scale and the use of different software packages make it less transferable.

5.3 Reference based GIS Approach

This GIS approach bases on a current reference (2009) to detect changes in walking path network exemplary from 2004. Due to lack of changes in this period this method also helped to verify extraction results. It was conducted on a 4 square kilometre area as follows:

1. As current reference walking path networks digitised from newest 1:25'000 map (2009) were used because they are easily available and contain walking paths. AV-data or information from historic archives might be a more accurate alternative especially for walking paths However, they are less consistently available.
2. A 10 m buffer around the reference and a 30 m buffer as described in Braun (2009).
3. To calibrate the results a random non path line is buffered the same way (Figure 10). Where this reference overlaps walking path buffers, they are erased – so a "non-path-reference" is build.
4. Clip these buffers with the extraction results (ribbon areas which carry probability and width attributes).
5. 10 m buffer gets highest probability. Statistically compare the non path reference to the walking path results and define probability threshold for change.
6. Visually analyse in GIS the false positive for change on the ortho imagery background.

Figure 10. "Non path calibration reference" (left) and buffered walking path network (right)

For this task the percentage of the length of extraction results to the length of the walking path was chosen as statistical cue. This method should give hints for the quality of the results but the potential for optimisation is huge and it offers a wide range of possibilities by including more statistic parameters.

Going back in time from a current reference is a reasonable choice: it is usually the most complete and consistent available data and walking path networks have generally grown over time – in that sense today's network reference is expected to be the most complete one.

Regarding the example area nearly 90 % of the totally 10 km walking path could be identified with this method. This means that more than 10 % of the walking path from map 2009 were not confirmed by the extraction results from 2004 and therefore indicate changes. A manual comparison with the ortho image showed that these were false positive changes – walking paths that can be hardly detected on the ortho image even visually. For this period no changes were found. There was a spatial

pattern concerning the quality of results which could be narrowed to spree and rock areas where the feature extraction had more difficulties detecting walking path.

Walking paths that have existed in the past and which do not exist on the reference map can not be detected with this method. For this case visual analysis would be suitable.

Advantages of this approach are the statistical basis, the concentration on GIS software only and the potential for automatisation.

5.4 Transferability in time and space

Tests showed that training areas allow transferability of feature model to another images (also BW) and/or other regions with no or only minor adjustments which makes this approach very useful for change detection where a lot of different images of different times will have to be processed.

Since there are no relative file paths available in IMAGINE Objective, one has to make sure to use the same file paths for a successful transfer of the model to another computer.

6. CONCLUSIONS AND OUTLOOK

The developed feature extraction models detect walking paths and country roads in recent colour ortho imagery. The results show that the similarity of scree and rocks with walking paths is a major challenge. For both, walking path and country road extraction, a line based approach shows the best results. Additionally, the models proof to be robust to be applied to ortho imagery in different example areas. In most cases only the training areas have to be adjusted. The current software limitations in transferring models because of saving absolute file path references together with the models are expected to be solved in one of the upcoming software updates.

The proposed hypothesis that, in order to detect changes in path and road networks backwards over time, it is not necessary to detect and extract the complete path and country road network showed to be true. Within the framework of this project it suffices to detect major parts of the network edges to decide if a path existed at a specific time.

Depending on the goal, one or more of the three evaluated change detection methods can be applied. The visual change detection is very quick and the interpreter's knowledge comes to full display. The reference based approach is more systematic and independent of the interpreter, but more work intensive. The segmentation based change detection seems to be difficult to adapt for walking paths and it too requires costly processing steps. On the other hand, the segmentation based approach is systematic and reliable.

All of the evaluated change detection methods are semi-automatic. The segmentation based and the reference based approaches have the potential to be fully automated if need be. But since the processes developed in this interdisciplinary project benefit from the specialist inputs of historians and architects full automatisation may only makes sense for selected processes.

To optimise the developed feature extraction models and the change detection methods it will be profitable to analyse a larger time span and more image material. This is planed for further sub-studies within the ProMeRe project. The methods and feature extraction models presented here will be developed further to be applied to true black and white imagery and a time span as far back as the 1950ies (aerial images) or even as far back as 1915 (images from high altitude terrestrial viewpoints).

Such further research will also include all of the area around Andermatt if imagery is available for these places.

7. REFERENCES

Bender, O., Boehmer, H.J., Jens, D., Schumacher, K.P., 2005. Using GIS to analyse long–term cultural landscape change in Southern Germany. In: *Landscape and Urban Planning 70*: pp. 111-125.

Blaschke, T., 2010. Object based image analysis for remaote sensing. In: *ISPRS Journal of Photogrammetry and Remote Sensing* 65. pp.2-16.

Braun, F., Pawlikowska, K., Muhar, A., 2009. Analyse der Entwicklung des hochalpinen Wegnetzes in drei österreichischen Gebirgsregionen auf der Basis historischer und aktueller Kartendarstellungen. Angewandte Geoinformatik 2009, Beiträge zum 21. AGIT-Symposium, Salzburg: pp.706-791.

Diaz Varela, R.A., Ramil Rego, P., Calvo Iglesias, M.S., 2006. Tracking environmental impacts and habitat fragmentation on costal protected areas through object oriented analysis. ISPRS Archives, Vol. XXXVI/4-C42.

Hay, G.J., Castilla, G., 2006. Object-based image analysis: strengths, weaknesses, opportunities and threats (SWOT). ISPRS Archives, Vol XXXVI/4-C42.

Hölbling, D., 2009. snapshot: Erdas Imagine Objective 9.3. In: *GIS.BUSINESS*, 2009(8), pp. 47-51.

Lu, D., P. Mausel, et al. (2004). Change detection techniques. In: *International Journal of Remote Sensing* 25:12: pp 2365-2407.

Preiner, M., Weinke, E., Lang, S. 2006. Two structure-related strategies for automatically delineating and classifying habitats in an alpine environment. ISPRS Archives, Vol. XXXVI/4-C42.

ProMeRe. (2010). "ProMeRe - Prozesse & Methoden für die interdisziplinäre, kollaborative Raumanalyse und -entwicklung am Beispiel Andermatt." from http://www.promere.ch.

swisstopo. (2010). "swisstopo, das Geoinformationszentrum des Bundes ", from http://www.swisstopo.admin.ch.

Walde, I., 2009. Zeitreihenanalyse historischer und aktueller Luftbilder. Angewandte Geoinformatik 2009, Beiträge zum 21. AGIT-Symposium, Salzburg: pp. 61-70.

Zhou, W., A. Troy, et al. (2008). Object-based land cover classification and change analysis in the Baltimore metropolitan area using multitemporal high resolution remote sensing data. In: *Sensors* 2008 8: 1613-1636.