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ANALYSIS OF SETTLEMENT STRUCTURE BY MEANS OF HIGH RESOLUTION SATELLITE IMAGERY

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ABSTRACT

State of the art for the investigation of the settlements' extension and their temporal change is either conventional mapping (field work, cadastral maps, topographic and thematic maps) or aerial photo interpretation. As these are very time and cost intensive methods and, additionally, the information need for regional and local information systems increases continuously, quicker and cheaper methods are required. The paper demonstrates, to what extend high resolution satellite data like KWR-1000, KFA-1000, KFA-3000, and (historic) CORONA data are suitable for detecting the settlement structures and their changes by means of different evaluation methods. Visual interpretation and computer aided classification are performed independently and their results compared afterwards. As not all features are detectable by means of the computer aided evaluation, hybrid methods are developed which combine the advantages of both the visual interpretation (more precise, contextual interpretation) and the computer aided classification (quick, cheap and interpreter independent). Finally an assessment of the results is given with respect to their suitability for the needs of regional planning and the integration into the Styrian geographical information system. This assessment comprises the first results of a study currently undertaken for the Styrian government.

1 INTRODUCTION

The structure and use of settled areas is subject to a steady and quick change. In order to enable the assessment of their future development, the previous development has to be taken into account, too. State of the art for the investigation of settlements' extension and their temporal change is either aerial photo interpretation or the conventional mapping (field work, cadastral maps, topographic and thematic maps). As these are very time and cost intensive methods and, additionally, the information need for regional information systems increases continuously, quicker and cheaper methods are required.

Satellite remote sensing in general serves well for quick, cheap and standardised land use classification and change detection in many fields of application. However, satellite data up to now were not suitable for detailed analyses in settled areas due to their restricted spatial resolution. Objects like roads, buildings, or parking lots, have a low spatial extension and thus mainly are represented by mixed pixels in low resolution (10 m to 30 m) satellite data and therefore are not clearly discernible. With the new generation of high resolution satellite data as well as with the high resolution analogue Russian satellite images also large scale structured areas like settlements can be recorded. Small objects or plots now become recognisable and at the borderline of neighbouring classes the higher resolution allows a more precise classification. Besides data from the new – and partly already lost – satellite sensor systems IRS-1C, ADEOS and MOMS mainly the high resolution KWR-1000, KFA-1000, KFA-3000, and (historic) CORONA data have to be mentioned in this context.

2 STATE OF THE ART

Settlement analysis has not yet gained by those research subjects, in which digital satellite image processing provides a useful information source. The reason for this was that the low ground resolution of the spaceborne images did not allow to delineate the small plots occurring in settlements, especially of rural areas.

With present conventional satellite image systems (e.g. LANDSAT-TM, SPOT-XS and P) mixed pixels predominate, allowing differentiation only between a small number of settlement classes. Till the end of the Eighties, for example, only industrial areas, high densely built-up and low densely built-up settlements were classified with partly considerable mistakes (Achen, 1993). The land-use categories of settlements often are represented by heterogeneous spectral characteristics. With a pure computer aided classification of built-up areas by mere definition of training areas and combination of channels (TC; NDVI) sufficient results could hardly be achieved. The densely built-up areas are too small, and the intermixture of gardens, greens and pastures especially near the edges of the built-up areas leads to barely interpretable mixed pixel information. Dispersed settlements could only partly be detected by computer aided classification (Jürgens, 1997; Sulzer and Zsilincsar, 1997).

With the availability of high resolution images in the Nineties, which are providing more and more similarity to conventional airborne photographs, the area of interest focus on the analysis of settlement structures (Sulzer and Zsilincsar, 1996). In spite of the mainly panchromatic spectral information the analyses trend to computer-aided classification. Steinnocher (1997a, 1997b) proposes texture analysis for settlement detection by means of high resolution panchromatic satellite images (e.g. IRS-1C). In his papers the author describes the methodology of information extraction from panchromatic data by means of grey-level co-occurrence matrices that can be combined with multispectral images. The fusion of two or more different images forms a new image that provides new information about settlement structures. However, due to the high costs especially of the Russian images their application is reduced to small investigation areas.

Heinz and Spitzer (1997) calculated the building density in an objective way to separate different types of built-up areas by means of digital image processing of SPOT - Data and different thematic layers. The obtained information can also be used for analysing medium scale structures as well as for change detection and updating

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maps. The study shows that combined analyse of satellite images and vector layers provides better and quicker information about the settlement structure, density and change detection than by means of conventional single used aerial photo interpretation.

3 TEST SITE

As test site the region of Feldbach (Styria/Austria) was chosen not only due to the remote sensing data sets already available, but also because of its settlement structure being typical for large parts of Styria. A closed urban area is surrounded by rural and scattered settlements of eastern Styria. Due to the dynamic development around Feldbach the structure of the region has changed. This becomes visible, among others, by its changing settlement structure. Mainly areas near the urban border as well as rural areas close to the region's principal town are affected by this development. Here, a trend in reorganisation of natural and cultural landscape appears, which goes off in similar manner in large parts of Styria.

4 THE HIGH RESOLUTION SATELLITE IMAGERY

With the decision of the Russian government to deliver former military satellite images in 1992, the western remote sensing users have high resolution images at their disposal. The image products of KWR-1000, KFA-1000 and KFA-3000 with a ground resolution between 2-10 m were available. The costs for this imagery are very high (e.g. about 40 km^2 of KFA-3000 images cost 4000 US$). On 1995, President Clinton authorised the declassification of all Intelligence Satellite Photographs that had been acquired from American spy satellites over many parts of the Earth's surface during Cold War period. Very cheap (about 15 US$) high resolution (2-10 m) black and white photographs are now available from the Sixties to the beginning of the Seventies (Kaufmann and Sulzer, 1997). The satellite data used for this study are given in Table 1.

Table 1: Satellite data available for the test site.

Sensor	product	ground resolution in m	acquisition date
LANDSAT-TM	digital	30 (120)	24.8.1985
LANDSAT-TM	digital	30 (120)	16.5.1992
KWR-1000	analogue/digital	approx.. 3-5	24.10.1990
KFA-3000	analogue/digital	approx. 2,5	August 1993
CORONA	analogue/digital	approx. 2	1969-1973

5 DATA PRE-PROCESSING

The analysis of multitemporal/multisensoral remote sensing data sets can only be efficiently done if the data present itself in a common geometry. Geocoding of the images therefore has to meet extremely strict requirements if the data obtained at different acquisition dates with different systems are processed multitemporally in one "data stack".
Geocoding of the individual images of such a data set to the geometry of a topographic map is the most common procedure to accomplish comparability. In general, parametric approaches based on sensor specific mapping models have been used for geocoding. Achieved accuracies lie in the order of one pixel size. However, the experience from monitoring applications has shown the necessity of achieving mean geometric accuracies below the size of half a pixel, if pixelwise comparison is performed. This accuracy can be obtained by automated image matching and co-registration of the geocoded image data sets with acceptable efficiency under certain conditions. Investigations on co-registration methods are currently carried out at the Institute of Digital Image Processing of Joanneum Research in order to improve the performance of monitoring systems.

6 VISUAL INTERPRETATION AND COMPUTER CLASSIFICATION

The analysis of settlement structures first is performed using two separate approaches, a visual interpretation and a computer classification. After comparison of the results the methods are optimised and integrated into one combined approach.

6.1 Visual Interpretation

A visual interpretation of remote sensing data means not to overlay transparencies on images, in the way, how conventional airborne photographs were interpreted in former days. In present days the digital images are mapped by screen digitising. In spite of the digital image the interpretation technique is similar to the conventional airborne analogue photograph interpretation. The advantage of computer aided visual interpretation with geocoded airborne photographs (digital aerial maps**)** is the availability of rectified thematic maps. These can be integrated into a GIS based system and can be combined with computer-aided classification of settlement structures. The quality of visual interpretation of satellite images is connected with the skills of the interpreter. The more the interpreter knows about the landscape that is investigated the more information will be generated. The general advantage of a conventional visual interpretation is the high accuracy of the results. Figure 1 demonstrates the limits of visual settlement structure interpretation with conventional aerial map, KWR-1000, KFA-3000 images and CORONA photographs.

6.2 Computer-aided Classification

The methods generally used for classification of satellite image data mostly are based on signature features, that is on grey values of single picture elements. The maximum likelihood classifier and the box classifier have to be mentioned exemplarily in this context. The use of "intelligent" algorithms that consider texture (structure) and shape features, which describe the spatial context between the picture elements, only plays a secondary role in image evaluation. This is due to poor structure of the up to now mainly investigated satellite data which have a pixel resolution between 5.8 m (IRS-1C pan) and 30 m (Landsat-TM). In these images linear objects like streets or small objects like buildings are mainly represented by mixed pixels. The typical texture and shape of such objects is suppressed by the relatively low spatial resolution of the image data.
The demands made on classification of high resolution satellite images are principally different due to their higher ground resolution between 2 m (KFA-3000) and 7-8 m (KFA-1000, CORONA). The textures and shapes visible in these images allow the identification of contents that keep hidden to the observer for example in Landsat-TM data. If this information, which easily can be distinguished by the

human interpreter, shall be classified automatically, that is computer-aided, the above mentioned methods, which are only based on signature features, are no longer sufficient. Texture and shape features have to be integrated into the classification process.
Additionally, the potential of high resolution panchromatic satellite image classification for settlement analysis can be improved by fusion of these panchromatic images with lower resolution multispectral data. For example Steinnocher (1997b) described an approach sharpening object boarders but preserving the spectral characteristics within the objects, thus enabling image classification based on spectral signatures.

6.3 Hybrid Methods

As not all features relevant for the analysis of settlement structures are detectable by means of the computer aided evaluation (Figure 2), hybrid methods are developed. They combine the advantages of both the visual interpretation (more precise, contextual interpretation) and the computer aided classification (quick, cheap and interpreter independent). For example, in the first step a computer-aided classification is performed, which at least allows delineation of built-up areas of different density. Only in densely built-up areas, in which the function of the area respectively buildings cannot be assessed by this classification result, it is necessary to perform a visual interpretation afterwards. The hybrid method becomes even more important for change detection tasks (see below). Here the areas, which have changed, can easily be detected by computer classification. However, the interpretation of the type of change only partly can be done by classification, whereas some types of change (e.g. from a gravel quarrying to a shopping centre) have to be interpreted visually.

7 CHANGE DETECTION

Settlement areas in the vicinity of regional towns change their landuse structure very quickly. Mapping the basic information on the historical change of the settlement structure is a useful tool for planning purposes to estimate future developments. For monitoring the changes of the structures SPOT and LANDSAT cannot be used because of their lack of availability during the significant Sixties and Seventies. During these periods large areas (mostly arable land) were built up with houses and industrial zones. In the area of interest, conventional aerial photographs have a repetition rate of about 6 to 8 years. With the high resolution images of Corona Data the dynamic development of a large region can be mapped and documented. The lack of remote sensing information during 1964 until the beginning of the Seventies can be filled with CORONA data, although their ground resolution can not reach the one of the airborne images. Figure 3 shows a comparison of Corona data and KFA-3000 images of a very sensitive area in the surrounding of Feldbach. Here the landuse system has been changed in a significant way within more than 20 years.

8 INTEGRATION INTO A REGIONAL INFORMATION SYSTEM

For integration into a regional information system the approach has to be as simple as possible, which means, that no advanced programs or algorithms have to be used. It has to be tested, whether the results of the automatic classification and the hybrid method respectively meet the requirements of local and regional planning and, therefore, can be used as cheep instrument for investigation and monitoring of local settlement as well as regional structures. Some results of the analysis of remote sensing data are integrated into the ecological GIS-based cadaster of Feldbach region (Sulzer, 1997).

9 CONCLUSIONS

The presently available panchromatic high resolution satellite data for the first time allow analysis of settlement structures and their change by means of satellite remote sensing. With the currently announced multispectral high resolution satellite data (e.g. quick bird with 0.82 m pan and 3.28 m multispectral ground resolution) this potential even will be improved. Computer classification based on spectral signatures combined with texture and shape features can discriminate most categories as well as changes relevant for settlement analysis. However, some information, especially on the extension and location of very small buildings (e.g. in dispersed settlements**)**, still has to be investigated by visual interpretation. A cadastral quality cannot be achieved with remote sensing tools – it is still the advantage of field work (Klostius, Kostka and Sulzer, 1994). For example, the function or use of buildings has to be investigated by fieldwork and partly by visual interpretation. If the visual interpretation is based on a very detailed computer classification, this task can be performed much quicker and thus cheaper. As the approach has to be implemented into a regional information system, it has to be as simple as possible, not using advanced programs or algorithms. It has to be mentioned that this paper only comprises the first results of a study currently undertaken for the Styrian government.

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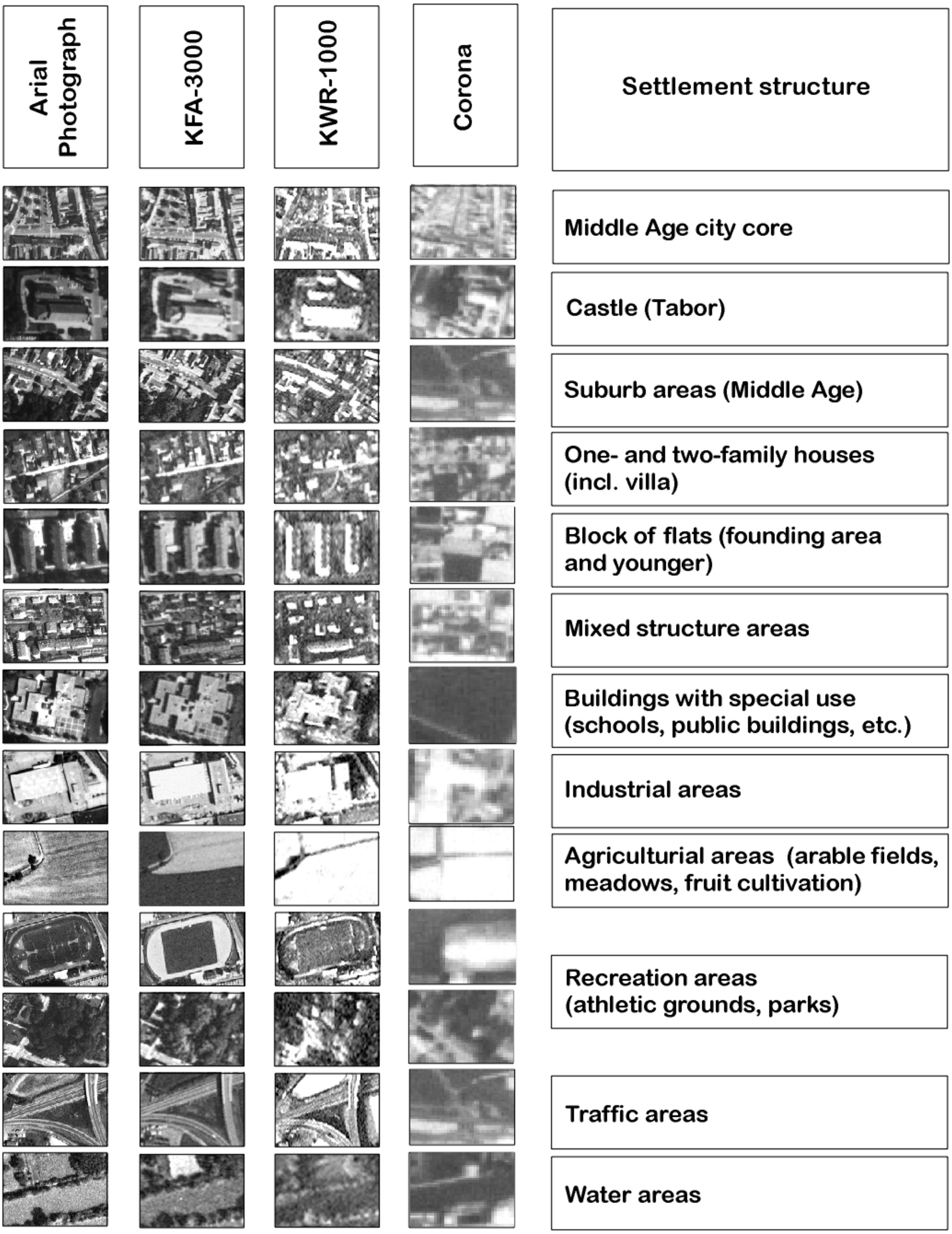

Figure 1: Settlement structures in aerial maps, KWR-1000, KFA-3000 and CORONA images.

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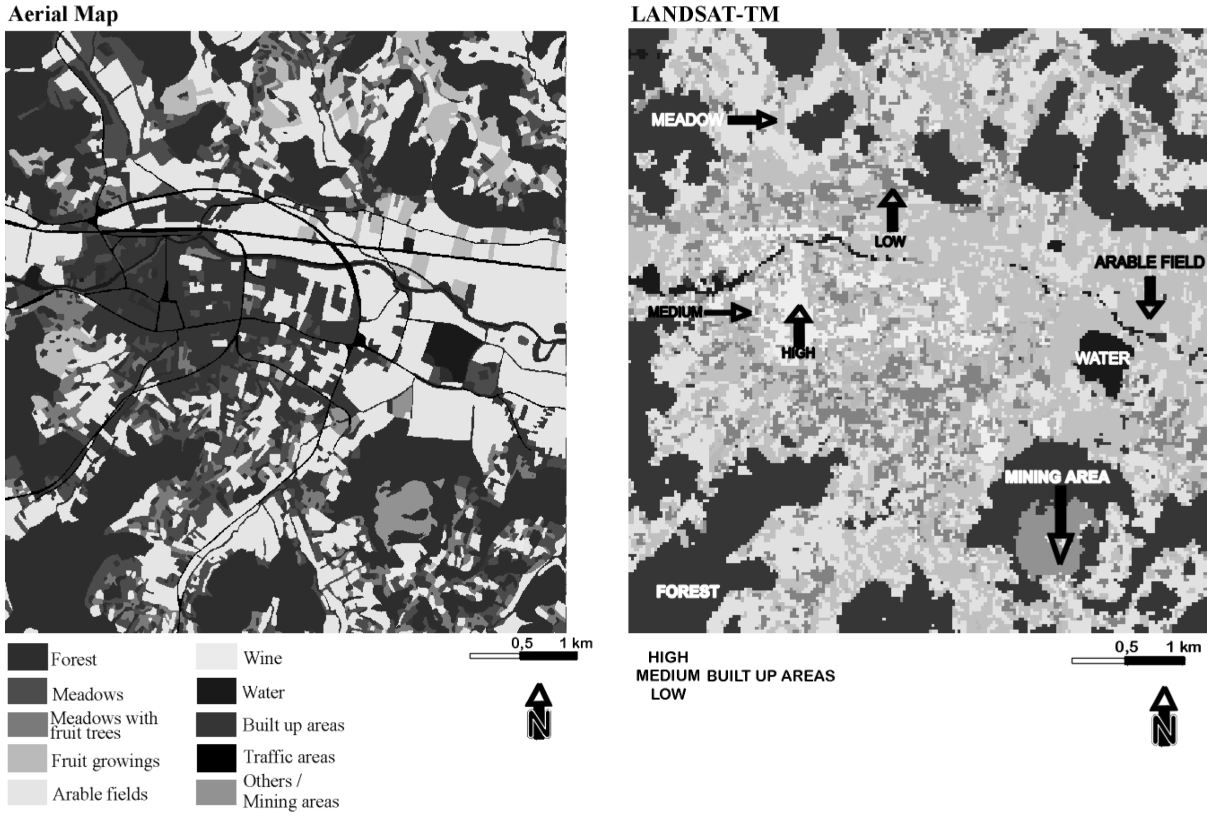

Figure 2: Comparison of an analogue and digital landuse classification.

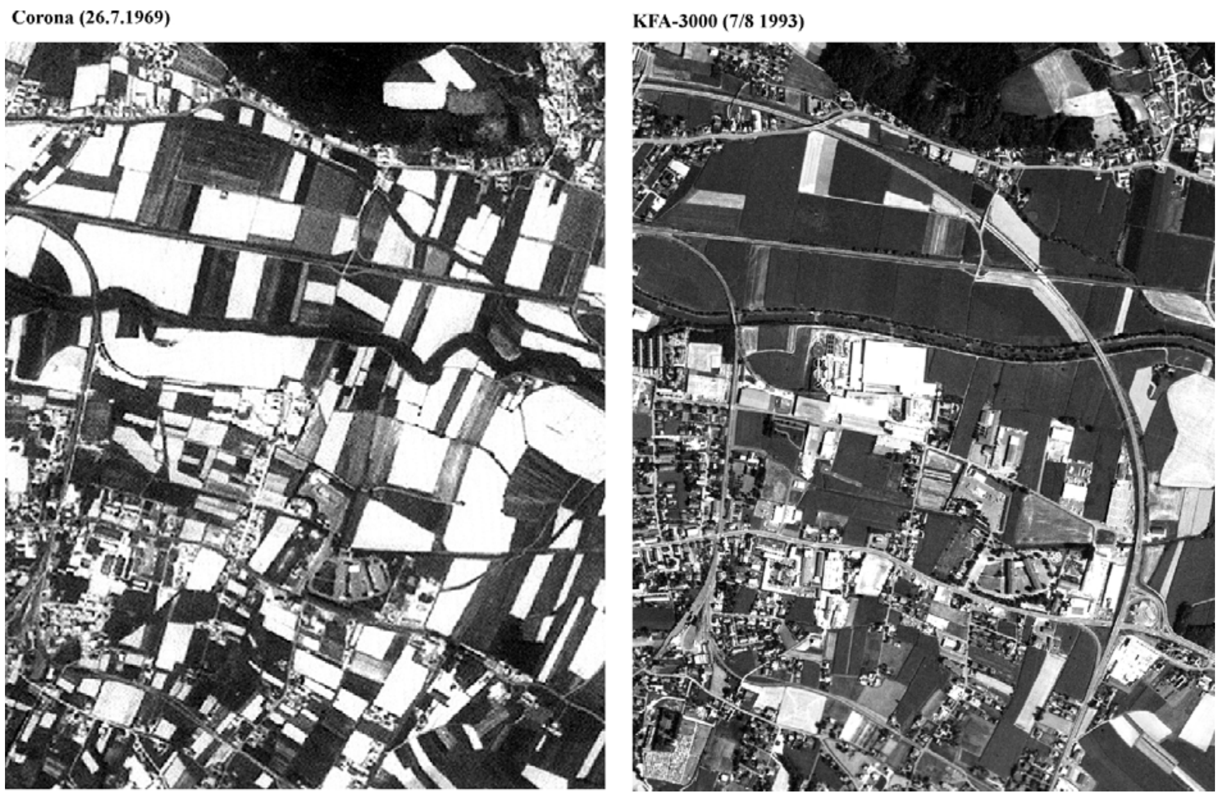

Figure 3: Change detection with CORONA (1969) and KFA-3000 images (1993).

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