Automated Recognition of Forest Patterns using Aerial Photographs

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Abstract

In Switzerland, aerial photos are indispensable tools for research into ecosystems and their management. Every six years since 1950, the whole of Switzerland has been systematically surveyed by aerial photos. In the forestry field, these documents not only provide invaluable information but also give support to field activities such as the drawing up of tree population maps, intervention planning, precise positioning of the upper forest limit, evaluation of forest damage and rates of tree growth. Up to now, the analysis of aerial photos has been carried out by specialists who painstakingly examine every photograph, which makes it a very long, exacting and expensive job.

The IMT-DMT of the EPFL and Antenne romande of FNP, aware of the special interest involved and the necessity of automated classification of aerial photos, have pooled their resources to develop a software programme capable of differentiating between single trees, copses and dense forests.

The developed algorithms detect the crowns of the trees and the surface of the orthogonal projection. From the shadow of each tree they calculate its height. They also determine the position of the tree in the Swiss national co-ordinate thanks to the implementation of a numeric altitude model.

For the future, we have the prospect of many new and better uses of aerial photos being available to us, particularly where isolated stands are concerned and also when evolutions based on a diachronic series of photos have to be assessed: from timberline monitoring in the research on global change to the exploitation of wooded pastures on small surface areas.

KEYWORDS: automated aerial photographs analysis, automated assessment of forestry cover, perception of forest dynamic, computer assisted monitoring of timberline

1. INTRODUCTION

Many foresters make use of aerial photographs in the context of their planning, management and monitoring work. These photographs provide invaluable information and substantial support for field activities in such wide-ranging areas as producing maps of forest populations, intervention planning, determining forest limits, assessing forest damage, estimating the percentage of forest cover and so on.

In research on ecosystems, aerial photographs of various scales are essential documents providing a snapshot of reality and allowing an objective assessment to be made of a situation at a given time. The traditional black-and-white photographs produced by the Federal Office of Topography (OFT) have been available for several decades. The first complete set of photographs covering the whole country and suitable for stereoscopic interpretation dates back to the early 1950s, since which time photographs have been taken at the rate of one-sixteenth of the national land area per year. The great benefit offered by these photographs is that since they are retaken periodically they allow changes in the forests and the dynamics of the landscape to be analysed in time and space in any part of the national territory.

Aside from the information which these photographs provide, data is also available in the form of other types of aerial photographs taken in response to particular needs, the earliest ones dating back to 1924. Nearly 47,000 infrared aerial photographs on a scale of 1:9000 and 1:3000 were produced between 1984 and 1991 under the Sanasilva programme. This is equivalent to more than half of Switzerland's forest territory (Wandeler *et al.*, 1992).

Many cantonal forestry departments have complete or partial coverage of their forests with aerial photographs taken specially to meet their specific needs.

Since 1981, the Federal Land Registry Directorate (Direction fédérale des mensurations cadastrales) has published an annual catalogue of photogrammetry flights carried out in Switzerland. All aerial photographs are listed, and a glance through the catalogue shows clearly what a vast quantity of documents is available.

0-8194-2309-2/96/$6.00

These aerial photographs taken together represent an exceptional heritage and an extremely abundant source of information.

The interpretation of aerial photographs **has to date necessitated examination and assessment by operators** who manually transcribe the information onto a plan or map. Although with the growing popularity of computers it is becoming increasingly common to digitize this data and manage it under a geographical information system (GIS), the data is still the product of laborious work with the stereoscope, which is hard on the eyes, may be tedious and is always expensive.

The advent in the eighties of digitized images from Earth observation satellites has greatly boosted international research. The past two decades have seen such a vast upsurge in the development of computerized methods and applications for analyzing digitized images that it can safely be said that they have by now been thoroughly mastered. Research on the automated analysis of aerial photographs, particularly black-and-white ones, appears to have been partly shelved during this period in favour of multispectral image analysis (Bodmer, 1993). In the forest sector, the limits in interpreting "traditional" satellite images are quickly reached in the geographical conditions that prevail in Switzerland, a small country with a very rugged relief. Extrapolation is meaningless below the value of a pixel. These values vary between 20 and 30 m on the ground for the most widely used satellite images (SPOT, Landsat TM). Pixel values of this kind in themselves represent the limits of fine forest interpretation. Moreover, the first satellite images of this type date back to 1984 (Landsat 5) and 1986 (SPOT); the timescale they cover is too short for real dynamics to be discovered in the forests.

Consequently, even today only aerial photographs and *in situ* observation can provide the information necessary for forest management and planning and for research.

Interest in automated classification of aerial photographs

At a time such as the present when the second national forest survey (Inventaire forestier national - IFN) is under way, permanent observation posts have been set up in the forests, cantonal surveys and regional forest planning programmes are being carried out and issues such as the protection of peat bogs and alluvial zones are topical, then all applications requiring the use of aerial photographs and the development of automated aerial photograph analysis are of great interest - not only for the Swiss Government and the cantons, but also for research.
It is not possible here to give an exhaustive list of all the forest management and ecosystem research applications which would allow automated recognition of single trees of different sizes and species, groups of trees and "dense" forest (including structure and texture analysis) from existing aerial photographs. They are too numerous to count.
Aerial photographs are extremely useful - and indeed essential - for creating forest population and sylvicultural intervention maps, for updating general plans and for mapping wetlands or dry grassland, as well as in the context of environmental impact studies and more generally in the area of town and country planning. The fact an operator is needed unfortunately results in these documents being underused, particularly in respect of forests.

2. INITIAL RESEARCH

Since its inception in 1990, the French-speaking office of the Swiss Federal Institute for Forest, Snow and Landscape Research (AR-FNP) has forged many links with various national and international scientific institutions. The objective has been to initiate and coordinate forestry management research with the most direct results possible, particularly in the areas of sylviculture and forestry planning.
Aware of the wealth of information provided by aerial photographs and the need to encourage their widespread and regular use in the forest area, the AR-FNP has focused on methods for the automated processing of previously digitized aerial photographs.

2.1 CLAPA: the AR-FNP's pilot study

The privileged situation of the AR-FNP as a guest institution within the Swiss Federal Institute of Technology at Lausanne (EPFL) enabled it to establish collaboration with the image processing specialists at the Department of Rural Engineering (Département de génie rural - DGR) in 1993.
The pilot study defined at that time had the following goals:

- To test methods of digital image processing in the specific case of determining percentages of forest cover.
- To outline an automated mapping methodology for forested pastureland and other irregularly wooded forest areas.

- To evaluate the opportunities for supplying forestry practitioners with a powerful new tool to assist them in their planning work.

The pilot study entitled "CLAPA: Classification automatisée de photos aériennes numérisées" (Automated classification of aerial photographs) (Bodmer, 1993) was launched. The DGR provided its knowhow in image processing and its powerful information technology (IT) infrastructure, and the AR-FNP enlisted the services of one of the few forestry specialists in remote sensing to carry out this work.
Carried out over a period of four months, the pilot study mainly revealed (on the basis of detailed bibliographical research at an international level) that there were surprisingly few reference works relating directly to this topic. To our knowledge, there is to date no software which allows the automated analysis of forest populations from aerial photographs in the manner referred to above.
Tests were conducted in a zone of forested pastureland in the Franches-Montagnes (Breuleux region, canton of Jura) based on infrared aerial photographs on a scale of 1:9,000 and OFT black-and-white photographs at 1:33,000. The area chosen was representative of this landscape, which is found throughout the whole of the Jura mountain chain and had the advantage of boasting a relief which was not particularly distinct. The spatial distribution of single trees, trees in groups or populations of varying density could also be compared with that shown by the timber line.

The results and conclusions from this pilot study can be summarized as follows:

- The black-and-white photographs from the OFT are of satisfactory resolution and sufficient contrast to allow a differentiation between forest and non-forest on the basis of spectral classification. It is possible to recognize single trees digitally, using simple methods such as thresholding, but the shadow that is cast makes it substantially more difficult to determine the percentage of forest cover. Depending on the angle of incidence of the sun's rays, the rate of error could be in excess of 200%. It ought to be possible to adjust for any error by combining the date and time when the photograph was taken and the digital altitude model of the zone concerned.
- Due to a lack of time it was impossible to analyse the textural and structural characteristics of the image, but this nevertheless represents the potentially most interesting avenue for the future.
- To facilitate research on image segmentation, it is necessary to use a system which allows the insertion of filters and the application of user-defined routines. Object recognition is another essential feature. These requirements greatly reduce the range of appropriate software available, making the development of *ad hoc* software unavoidable.
- A link-up with a geographical information system (GIS) is important in all cases.
- At this stage of development, the complexity of the problems is far too great to be handled with the resources and facilities committed and the analytical methods used.

The CLAPA pilot project has made it possible to take stock of the research situation at an international level. Many routes suggested by modern digital image processing and analysis methods had been pursued in line with the goals set, but none of these pointed to the development of a tool for the forestry practitioner - at any rate not without the kind of financial resources and equipment that were well beyond the means of the AR-FNP.

2.2 Same objectives, different approach

At a seminar on object recognition organized by the Department of Microtechnology of the Swiss Federal Institute of Technology at Lausanne (EPFL), the AR-FNP established contacts with the Institute of Microtechnology, demonstrating shared interests in solving the problems identified by the CLAPA pilot study.
Although it might seem odd at first glance, it was in the field of microtechnology that the AR-FNP located specialists capable of extracting image elements on the basis of schematic modelling. The appeal of this approach is that it takes foresters' needs into account while scaling models down to the essential.

The team under Prof. Jacot suggested using techniques developed in the field of microvision for a trial in the context of a study project (Kreiss, 1995). Since the results were very promising, the research assignment was continued as a diploma thesis (Kreiss, 1996) over a period of four months, followed by two months' work to improve and fine-tune the software. Thus the foundation was laid for a tool to be used for the **quantified observation** of a state or an evolution from aerial photographs. The software which was developed was named CLAPA, after the pilot study referred to above.

3. THE CLAPA SOFTWARE

The CLAPA software, which was designed for processing black-and-white aerial photographs from the OFT (which are most numerous and offer the widest coverage in terms of time and area), is capable of recognizing, locating and measuring the surface area of zones of dense forest, groups of trees and single trees. It can also process infrared and colour aerial photographs provided these are transformed into grey tones and have sufficient contrast. The software was developed to recognize spruce trees, but can now process any other type of conifer with similar propensities.

3.1 Characteristics

The features of the CLAPA software can be summarized as follows:

- Processing of black-and-white and infrared images, and in some cases colour images.
- Evaluation of the percentage of forest cover by reference to the image portion under consideration, distinguishing single trees, groups of trees and dense forest with a precision of higher than 3% with the aid of a digital altitude model (MNA).
- Possibility of considering only part of the digitized image by defining it beforehand by a polygon of any shape; this makes it possible, for example, to process zones with relatively homogeneous percentages of forest cover or to analyze them in relation to the land register.
- Simplicity thanks to a user-friendly user interface (Fig. 1) and fast and cost-effective operation: the software runs on Macintosh and processes an area of 10 hectares in less than 30 seconds.
- Measurement of the height of single trees and determination of their position under the Swiss national coordinates system.
- Compilation of a summary table of extracted data allowing input into a GIS (Fig. 1).

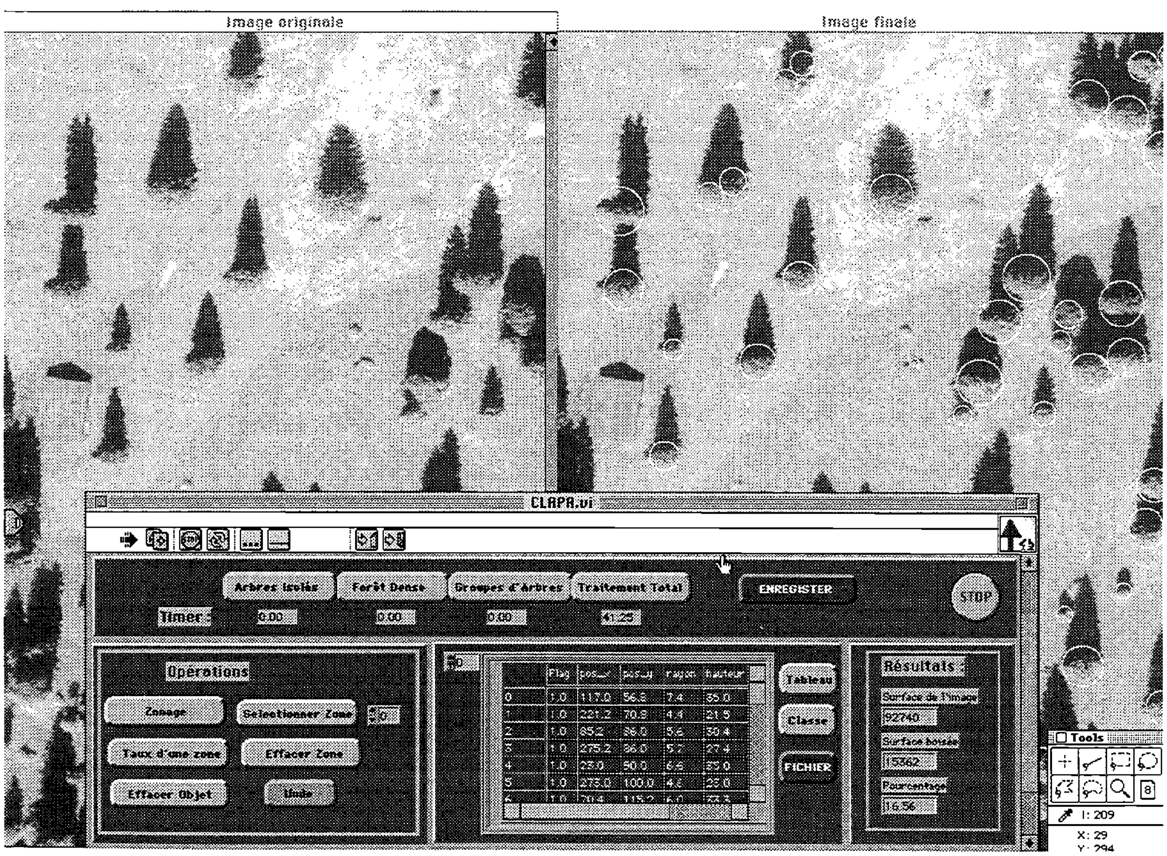

Fig. 1: User interface and summary table of CLAPA software

3.2 *Principle of operation of CLAPA*

Before the software is used, a number of preliminary tasks have to be carried out. These necessitate a scanner and the use of image processing software such as Adobe Photoshop ™.

3.2.1 *Digitization of the photograph*

Whatever the scale, the photographic image must be digitized with a resolution such that one pixel corresponds to a square on the ground with sides of 40 to 80 cm, e.g. with a resolution of 40 to 80 µm for a photograph on a scale of 1:10000. This resolution can be achieved with commercially available scanners. Higher resolution, which is possible with more powerful and more expensive scanners, does not bring about any significant improvement in the precision of the results, apart perhaps from regions with high natural regeneration through single plants less than one meter in height. The lowest tree height that the software can normally handle is 1 meter (parameterizable limit).

3.2.2 *Work on the image and entry of basic data*

The image is rotated so that the axis of the shadows is oriented vertically; this procedure saves on software working time. The program also requires the following information from the operator:

- the coordinates of the corners of the image as used under the Swiss national geographical coordinates system,
- the date and time of the photograph,
- the altitude from which the photograph was taken,
- the focal length of the lens used and the scale of the photograph.

The digital altitude model of the area under consideration is extracted from the appropriate OFT file (MNA 25).

3.2.3 *Processing of the digitized image*

Referring to the grey scale of the grassland, single trees are identified by the presence of their shadows. Various types of processing allow the diameter of the crowns to be defined so that the orthogonal projection can be deduced. Although the software is capable of determining the height of the tree from the length of its shadow (depending on the date and time of the photograph and the MNA), the heights were calculated in tests carried out on the basis of a linear approximation stemming from a forestry database (Lässig *et al.*, 1992) relating to the region where the photograph was taken.

The shape and area of the shadow allow objects to be distinguished on the image such that only single conifers are retained (Fig. 2 and 3).

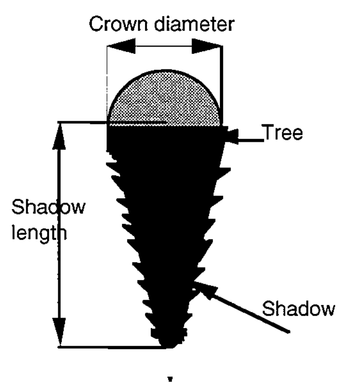

Fig. 2: Schematic representation of a single spruce with its shadow

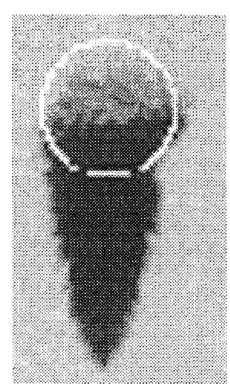

Fig. 3: Result of the program

The shadow is not used in the same way for groups of trees and dense forest; the image is processed in a fairly conventional way by a gradient filter followed by thresholding, a low-pass filter, expansion, filling-in of holes and finally erosion (Fig. 4, 5, 6, 7, 8, 9, 10).

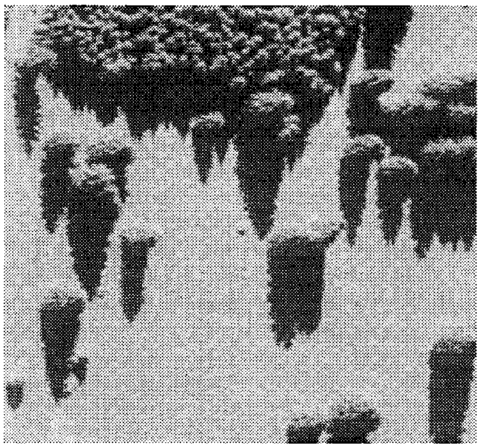

Fig. 4: Original image

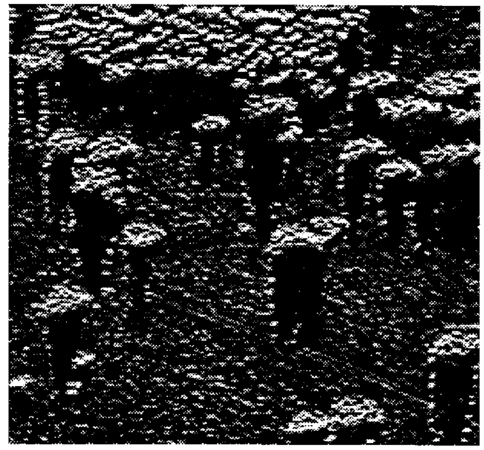

Fig. 5: Gradient filter

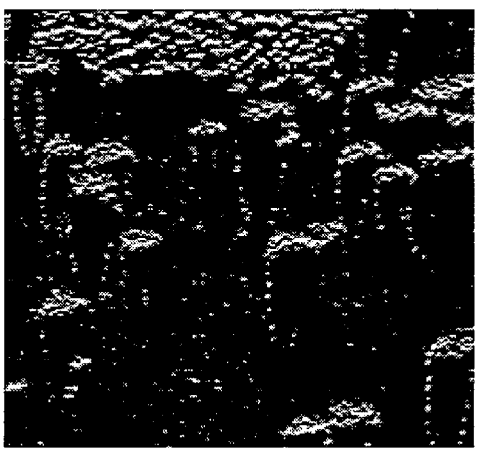

Fig. 6: Thresholding

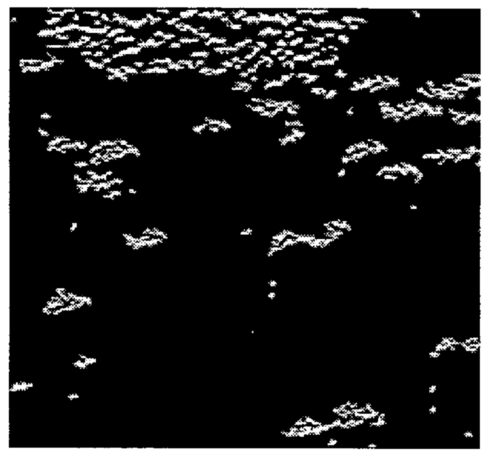

Fig. 7: Low-pass filter

Fig. 8: Expansion

Fig. 9: Filling-in of holes

Fig. 10: Erosion

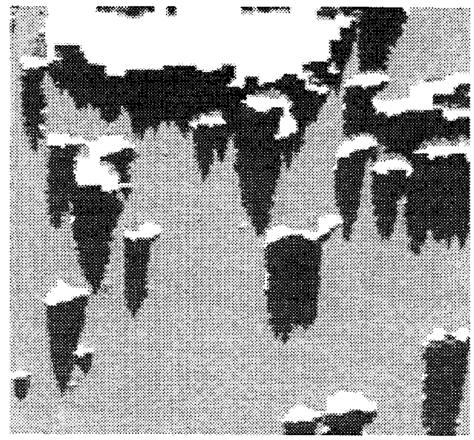

Fig. 11: Resultant image

Figure 11 corresponds to the image resulting from processing, superimposed on the original photograph. The interpretation which the system then performs is based on the modelling of conifers, in this case spruce (*Picea abies*), which is built into the processing software. The data required for this modelling comes from ground observations relating to the crown diameter and height of a number of trees representative of the region under consideration. The maximum dimensions and the range within which the ratio between height and crown diameter varies are therefore known. This allows trees to be identified and deductions to be made on the likely number of individuals in a group. Figures 12 and 13 show how groups of trees have been represented for a larger image portion. Image processing in this binary form is extremely fast due to the very small size of the file.

Fig. 12: Binary image

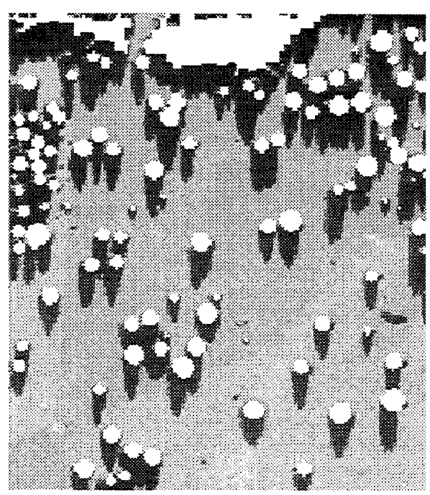

Fig. 13: Binary image superimposed on the original

The system sometimes locates two trees instead of three, but it is found that the approximation of the size of the forested area is perfectly good.

The calculation of the orthogonal projection of the crown of a tree always remains an approximation, even from precise ground measurements. Substantial differences may occur, if only in the method of calculation. During his tests, Kreiss (1996) clearly illustrated this on a sample of sixteen trees measured on the ground. Two commonly used methods for calculating orthogonal projection (Figs 14 and 15) were compared with each other (Fig. 16), and then with the results from processing with the CLAPA software (Fig. 17).

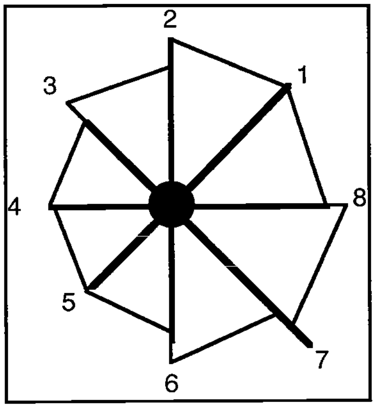

Fig. 14: Method based on the mean of segments connected by straight lines

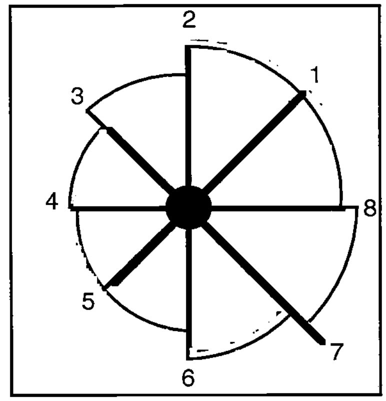

Fig. 15: Method based on the mean of segments connected by arcs of circle

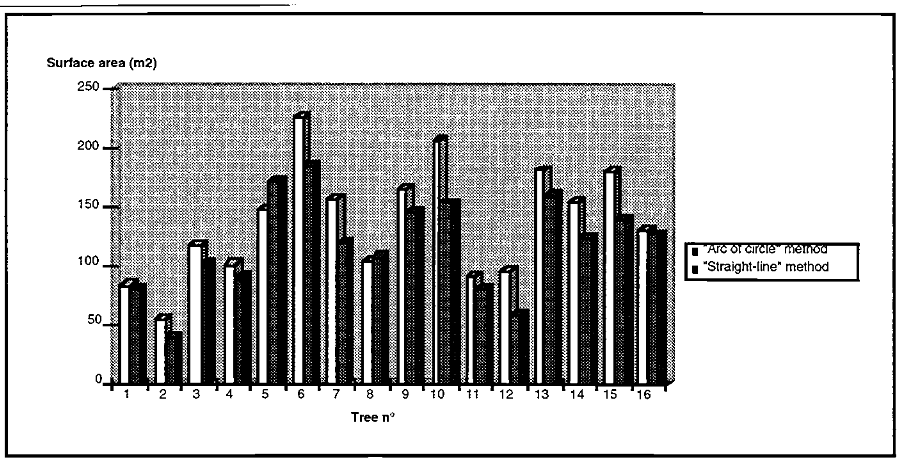

Fig. 16: Comparison of two methods for calculating orthogonal projection from ground measurements

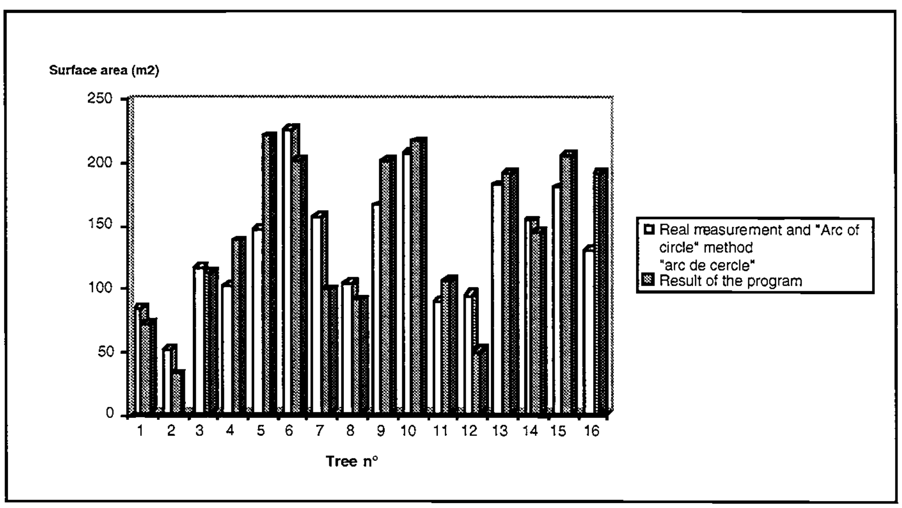

Fig. 17: Comparison of the "arc of circle" method with CLAPA software calculation

The area covered by the projections of the 16 trees and calculated by the "straight-line" method is 1882 m^2; it is 2193 m^2 with the "arc of circle" method and the software assesses the area as 2274 m^2.

Once processing is complete, the operator may delete or add as many trees as he wants. All he has to do is define their diameter and position by tracing a line on the photograph on the screen with the computer mouse. This option is not merely useful for correcting errors but also allows the forester to test various blazing scenarios and to see immediately the effect on the percentage of forest cover.
The processing software differentiates trees very well from the other objects which appear on the image. It can be seen in Figure 18 that all the trees are processed but that the house and the power transmission poles are correctly factored out.

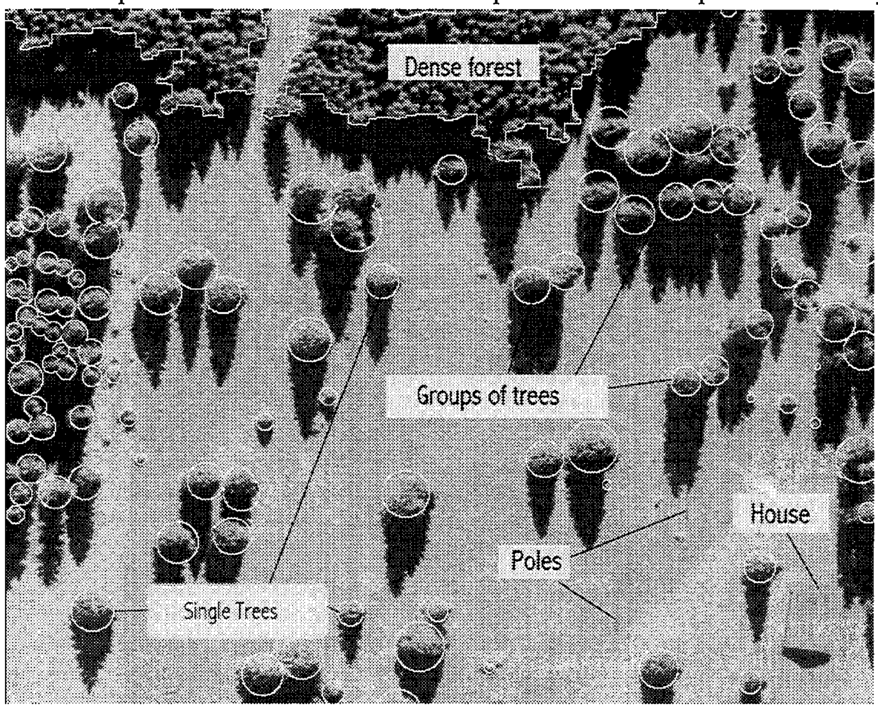

Fig. 18: Result of image processing

4. PROSPECTS

The CLAPA software opens up a vast number of potential uses. However, it is currently still at the prototype stage and not yet ready for practical application. The improvements that need to be made can only be achieved through substantial research work and numerous tests.

4.1 Improvements to be made to the software

Research must now follow two major routes:

- To achieve the greatest impact possible, the software must be able to process different types of coniferous and broadleaved trees. The process needs to be made more sophisticated and the other most common species of tree integrated. CLAPA should be capable of at least differentiating conifers from broadleaved trees, and even of differentiating between different species.

- CLAPA is currently particularly successful in open forest zones. In dense forest, because of the fairly coarse expansion/hole-filling procedure (Figs 8 and 9), it only recognizes the outlines. This is in itself extremely useful if, for instance, we consider all the problems relating to the forest edge in the context of forest policy (construction close to the forest, forest land registry, etc.). However, the software must also be developed to provide information on the structure and texture of the forest interior. This will make CLAPA the kind of "universal" tool which is essential in forest planning in the broad sense. In relation to mountain forests, by merging forest avalanche and rockfall models it would provide the data needed to assess stability factors, as well the necessary basis for targeted sylvicultural processing.

The tests conducted with CLAPA on different aerial photographs related to zones of limited area in the Jura, the Pre-Alps and the Alps. Other tests now need to be undertaken on larger portions of photographs and in mixed zones where different structures and types of forest alternate. What must be aimed for is a stricter automatic monitoring of the errors made and a better understanding of these errors with a view to improving the software.

4.2 Prospects for use of the software

Various possible uses of the software have been mentioned. Two possible applications of the CLAPA software at its current state of development are discussed in greater depth below.

4.2.1 Forested pastureland and other open forest populations

The percentage of forest cover and the texture and structure of forested pastureland are items of information which cannot be overlooked, whether in research or in management. The significant PATUBOIS study (Gallendat *et al.* 1995) carried out on behalf of the forestry departments of the cantons of Berne, Jura, Neuchâtel and Vaud and the Federal Government by the Plant Ecology and Plant Sociology Laboratory of the University of Neuchâtel made copious use of aerial photographs.
Pre-zoning of four large types of phytocoenosis were defined from the percentages of forest cover (understood as the covering of the ligneous layers) and the texture of the woodland assessed visually on the basis of aerial photographs:

- non-forested pastureland: percentage of forest cover zero or less than 1%,
- pastureland with little forest: percentage of forest cover between 1 and 20%, fine texture (single trees),
- highly forested pastureland: percentage of forest cover between 20 and 70%, coarse texture (trees in groups),
- grazed and non-grazed woodland: percentage of forest cover higher than 70%, any texture.

The phytocoenoses were mapped by digitizing the aerial photographs and manually tracing their provisional outlines using drawing software. These first maps were then added to and refined on the ground by transferring final outlines. Linking to a digital altitude model in a GIS allowed a spatial reference to be found which was calibrated to a broadly more precise scale.

In the regeneration survey, an estimate first had to be made of the density of the sampling inventories based on the degree of cover of the trees. In this kind of application, precise visual assessment of the percentage of forest cover from aerial photographs is difficult. It calls for a level of experience which would allow the shadows cast by the trees - a classic trap for the novice - to be largely disregarded because they interfere greatly with visual appraisal and lead to considerable overestimation of the percentage of forest cover.

Time analysis of existing aerial photographs provides essential information which allows the dynamics in progress to be understood and if necessary corrected, using the models developed under PATUBOIS.

As forested pastureland is classified as forest (Section 2 Subsection 2 of the Forests Act), it is subject to forestry management. This dictates the appropriate sylvicultural measures - i.e. chiefly for the purposes of landscape conservation, but also for agricultural use. The forestry practitioner needs to assess the percentage of forested area in zones which are as homogeneous as possible; this again plays a key role. The woodland cover and the quality of grazing land are closely related; Schumacher and Nebiker (1994) demonstrated this relationship for orchards on grassland, and the Federal Agronomic Research Station at Changins is currently studying it with reference to forested pastureland (Troxler, 1992).
Determination of the percentage of forested area on the basis of aerial photographs can sometimes be centralized within the cantonal department, and is in any case rarely done at national level because it is a tedious procedure which necessitates following a routine difficult to acquire. Once again, analogue analysis is a difficult process which should be treated with caution as it is imprecise and consequently not commonly used. It cannot be repeated simply, reliably and objectively on a series of diachronic photographs.
In practice the manager will instead opt for visual assessment on the ground. Although this is common practice, it is very approximative because of the difference in scale between man and tree and the disparities in estimates made by different observers.

Estimating the percentage of forested area, a key element in the management of forested pastureland in the absence of other more efficient ways of determining it, has thus to date always involved visual assessment on the ground or from aerial photographs. Given how much work is required to make it a reliable method of assessment, it has all too often been neglected.

The CLAPA software, which automatically recognizes single trees or groups of trees and dense forest, allows problems of this kind to be solved objectively and cost-effectively, and any systematic error can be easily checked. Development of the CLAPA software will focus on all more or less open forest populations. Simple and rapid automated analysis of such populations - ideally using commercially available computer systems - is seen as an attractive vision of the future by those concerned. In the context of our study we have brought together forestry practitioners and various scientific groupings. They have been unanimous in recognizing the benefit of this research. They have also supplied us with a number of suggestions for applications, not all of which have as yet found a place in the current software prototype.

4.2.2 The timber line and climate change

Although they are very attractive and of great and undeniable scientific interest, forest populations of the subalpine stage and the protection zone ultimately are fairly poorly known, among other things with regard to their precise geographical situation, their dynamics and their precise composition in terms of area (Bodmer *et al.* 1994).
These forest ecosystems are of no direct economic value in terms of timber production since exploitation there is generally loss-making. However, exploitation is often essential to ensure that they continue to play a protective role against avalanches, rockfalls and landslides, to mention only those aspects which have long been recognized and appreciated. Their ecological value is also vast, as they represent the last zones where human activity has remained very limited, except for those affected by grazing from long ago or by more recent tourist activities.
The factor of heat is crucial to the growth of tree vegetation. Many questions are currently arising in relation to climate change. A consensus appears to be forming within the international scientific community that global climate change is taking place as a result of the greenhouse effect (Haughton *et al.*, 1990, 1992). In this context, Bugmann (1994) suggests that mountain forests close to the timber line could be particularly sensitive to global climate change.
Looking at Switzerland, Brzeziecki *et al.* (1995) have modelled the potential impact that various global climatic change scenarios have on the spatial distribution of forest vegetation by altitude zone. The long-term adaptation potential of vegetation has also been evaluated (Kienast *et al.*, 1996). A rise in annual mean temperature of 2 to 3°C would cause one type of altitude vegetation to be replaced by that immediately below it. On the other hand, it has not been possible in the context of this research to make a statement on the capacity of the forest ecosystems concerned to respond to changes, nor on the time which would be necessary to adapt.
Could a marked tendency towards warming, like a cooling elsewhere, pass by unnoticed for vegetation at the upper limit of the forest and for how long?

Thanks to existing aerial photographs stretching back over more than 40 years, a diachronic study consisting of sampling the spatial dynamics of chosen altitude forest ecosystems (i.e. the targeted elimination of noise, particularly the influence of cattle pasture) from the south to the north of the Alps would enable the dynamics of forest vegetation to be captured with precision. There is plenty of material as the timber line and the protection zone extend over tens of thousands of kilometres in Switzerland. The land-area statistics (hectometre grid) (OFS, 1985) give a figure of around 6000 km for the cantons of Appenzell and St. Gallen alone (Kienast, verbal communication). A study of this kind can only be carried out at present at great expense, and on very limited parts of the national territory, because analysis of the photographs is still dependent on the analogue work of an operator. With an automated system for the recognition of single trees, trees in groups or dense forest, the prospects for research covering a large transect should at least be reconsidered.

5. CONCLUSIONS

CLAPA development work to date has produced some extremely promising software which is close to being operational. In view of the vast potential for its use and the very many needs which it meets, it is planned to continue pursuing a research programme that combines development in microtechnological vision with environmental knowhow, particularly in the field of forestry.

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