Processing of aerial photographs for georeferencing of historical features

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Abstract: - Cropmarks offer a unique opportunity for visual discovery of buried historical (archaeological) features. These markings in landscape are mostly visible from proper perspective and overview. Aerial photographs are thus often used in a process of documentation of the features. Identification, characterization, and geographical localization of these objects currently require a high level of human interaction. The authors combine a specific knowledge from the fields of image processing, pattern recognition, and geographic information systems to design a robust procedure for semi-automated historical feature mapping. The main aim of this paper is to describe a technique for preprocessing high resolution aerial image data and to propose an intelligent system capable of recognition and classification of cropmarks. The cropmarks identified this way are consequently converted to polygons and mapped into a geographic information system (GIS). This research is an important step in automating the construction of archaeology-focused GIS, which supports the protection of cultural heritage.

Key-Words: - Archaeological feature detection, aerial image processing, cropmarks georeferencing

1 Introduction

Archaeological remote sensing (ARS) is currently one of the main pillars of modern non-destructive archaeology [1]. This discipline relies on two main sources of information – satellite images, and aerial photography. Both types of images can be acquired using a variety of devices, which can make certain feature of the land more pronounced, depending on the research subject and researchers’ choice. Several types of historical features can be observed using these devices, including those that are no longer visible even by the on-site observation. One of the most important techniques for the buried historical features detection relies on cropmarks (vegetation signs) in agricultural landscape.

Cropmarks have been used for remote sensing and detection of archaeological features in the United Kingdom since 1920s [2]. Discovering and documenting buried (under the arable layer) historical features using this natural phenomenon has thus a long tradition, in its parent country and Western Europe. After the fall of the Iron Curtain in 1989, it has been successfully implemented and developed in the post-soviet countries, too [3].

Mapping and georeferencing of buried features is very important for complex archaeological research. Interest-bearing historical deposits, the subject of later terrain archaeological research, can be pinpointed this way. It helps to confront the candidate features with existing domain knowledge, including historical maps and plans. This can enrich the knowledge about ancient settlement in the studied area [4].

Cropmarks make the shapes of buried man-made features visible, which makes it possible to localize them. They can be observed mainly in barley (Hordeum vulgare), wheat (Triticum aestivum), winter rape (Brassica napus), and lucerne (Medicago sativa) [5], [6], [7], [8]. There are two types of cropmarks – positive and negative – generally differentiable by their visual appearance. Positive cropmarks are characterized by a higher growth rate of plants contrary to their surroundings. Negative cropmarks work the other way round – plants above an ancient construction don’t reach the height of surrounding vegetation. Positive cropmarks represent around 98% of all the recorded cropmarks and negative ones only 2%. Both groups can also be characterized by slight difference in color of crops (lighter/darker) [9], [10], [1].

Positive cropmarks occur as a consequence of several factors. They take place above buried waste pits, graves, sunken dwellings and ditches. Thanks to the resulting soil with a higher concentration of
nutritionally rich sediments, low mechanical resistance and high porosity, the plants above such places can produce deeper roots, which have a positive effect on water and nutrient supply [1]. The improved nourishment is in turn reflected by the height and color of such plants. The negative cropmarks work following the opposite premises. However, the resulting difference of crop length and color cannot be properly seen from the ground perspective. To document this phenomenon, it is necessary to see these features from a higher position, which can be provided by the aerial survey. The actual distance (altitude) depends primarily on the size of observed feature [11], [12].

The transformation of aerial images into objects listed and mapped in a GIS currently requires an extensive work from a human expert; it is very time consuming. This article pays special attention to the first phase of a complex process of georeferencing of buried archaeological features. This phase consists of pre-processing of input photographs to the appearance suitable for further automatic shape detection, and consequent vectorisation. The final results of this process are mapped buried features, including their precise shape extracted from visible cropmarks placed in a coordinate system. Authors present a universally applicable set of steps that segments an input image into the state where resulting buried features are clearly visible for automatic shape detection systems.

2 Problem Formulation

A multitude of projects is currently underway in EU (including the Czech Republic) that focus on mapping the vanished archaeological features using sings in vegetation. In general, the processing of input image data and their entry into a GIS is performed manually. Non-orthogonal aerial photographs are primarily used within these projects for several reasons. The first reason is the insufficient spatial resolution of satellite images for specific need of archaeological georeferencing. The second reason is the inconsistent time period when satellite images are taken, because cropmarks are evident during a specific part of year (season) only. The most effective way to document cropmarks is taking pictures from a height of about 300m in the period from May to July (until harvest). These photos are therefore the only source of digital data in which are buried historical buildings clearly evident in their specific shape [4]. Aerial photographs are thus generally optimal for further processing needs, either manual or automated.

The complete procedure of mapping the historical features from aerial images to GIS consists of a series of interconnected steps. We have identified these essential steps and formalized them in Figure 1.

![Cropmark georeferencing procedure](image)

Fig. 1 – Cropmark georeferencing procedure

In comparison with satellite image analysis, the analysis of aerial photographs assumes, the candidate historical feature has already been discovered and its location is manually photographed from an appropriate perspective. The resulting images are transferred from a digital camera to a computer, the faulty photographs are removed, and individual image categorized by location. Certain level of manual interaction is therefore both required and acceptable, even in the consequent processing steps.

Various authors have already dealt with problems relevant for the proposed procedure, or solved analogous tasks. Lambers and Zingman describe the search of buried archaeological features in satellite images, and propose a procedure for detecting circle-shaped historical features based on template matching [13]. Sheikh and Mukhopadhyay designed a robust, noise tolerant method for differentiating between man-made objects and natural-scenes in natural images [14]. Several image pre-processing techniques have been adapted for this study, including histogram-based contrast enhancement [15], [16], image dilation [17], [18], and edge detection techniques. However, a comprehensive solution linking individual
approaches and automating the entire process is still missing.

In order to design a solution usable in archaeological practice, the precision of mapping is currently preferred over the computing overhead and performance. The interaction of the solution with human experts is also acceptable so far. In certain cases, it can dramatically reduce the processing time and improve the overall georeferencing precision.

2.1 Aerial image set

The basic material used for this research was a set of oblique high-definition aerial photos from the Institute of Archaeology of the Czech Academy of Sciences. The photographs were mainly acquired from Cessna 172 aircraft in 300-500m altitude. All the digital imagery was taken on various SLR cameras with minimum 12MP resolution between years 1992-2010. Photos with well-marked cropmarks were chosen for early research.

Although freely accessible satellite imagery (theoretically perfect for detecting cropmarks in landside because of the vertical character of photographs acquired) can be a good source of data, it does not contain the required level of detail to ensure accurate mapping of historical features on.

2.2 Image rectification

Oblique aerial photographs would be fully sufficient for the part of the georeferencing procedure associated with the shaped-based historical feature detection. However, in order to place vectorized buried features into a GIS, it is necessary to rectify the aerial images first [19], [20]. Authors therefore perform this operation before preprocessing the image any further. Unfortunately, rectification comes along with relatively high distance deviation of the final location from real coordinates. The level of distance deviation depends on several factors: quality and amount of source photographs, presence of referential points - solid objects (crossroads, buildings, electricity poles, etc.) around the observed feature contained in a base-map/satellite imagery, and importantly, preciseness and experience of the person who rectifies and places the image into the coordinate system, since this process is still traditionally manual.

The authors used Agisoft Photoscan Professional to eliminate the problem described above. This software creates a fully textured and high-detailed 3D model of the observed area from a set of several (6-15) oblique 2D photographs. A high-resolution vertical image can be rendered easily from textured 3D model. Agisoft Photoscan is able to process the GPS coordinates included in picture meta data and place the resulting model/image into the coordinate system, which is very useful for finalizing the described process of archaeological features mapping. To design a robust pre-processing algorithm, authors have further used both manually rectified imagery and Agisoft Photoscan Professional outputs.

2.3 Image preprocessing

For further automatic detection of buried historical features in rectified aerial images, an appropriate pre-processing and segmentation algorithm is a must. There are several problems, which must be addressed. Even though the difference between the cropmark and the rest of the field is evident to the human eye, from the computer vision point of view, the actual transition is very smooth (see Fig. 2). Another problem is the presence of several unfavourable objects, which occur as a consequence of a specific natural phenomena (subsoil and bedrock structure, water resources, etc.) or the agricultural activities pursued (plough furrows, field paths, country lanes, etc.). Following sections will discuss the proposed algorithm for making the cropmarks as pronounced and detached from the background as possible, whereas eliminating the noise, background, and as many unfavourable objects as possible.

3 Problem Solution

The above described image set focusing on cropmarks of various shapes and sizes was used as the main research material for further discussion. This original image set was consequently rectified and stored in/exported to JPEG format, using the RGB model (24 bits per pixel). As has already been mentioned before, in order to accomplish precise georeferencing, certain level of human interaction is acceptable. Hence, in the early research stages, the rectified image is manually focused on a visible outline of buried feature and cropped to include single feature and its near neighbourhood only. This modification reduces the problems with detection of existing construction, and false detection in general. The performance of the procedure is dramatically improved this way, while researchers maintain a significant level of control in deciding which objects are worth mapping.
In order to prepare an image suitable for template matching algorithms, a binary representation of the source image must be calculated, using suitable image processing and segmentation techniques, which will be discussed in following sections.

3.1 Image preprocessing and segmentation

The colours corresponding to cropmarks (from green, through yellow to light orange) occur in the wavelength interval of approx. 510-600nm. This wavelength interval is covered by the intensity edge of red channel; light orange (around 600nm) lies at the start point of the intensity drop of red channel on one side, and green (around 510nm) lies at the end of the intensity drop on the other side. It means that pure green shades appear the darkest while yellow/orange shades the lightest in red channel [21]. Therefore, the greyscale intensity map of the red channel has been used for further processing.

In order to make cropmarks more profound in comparison with background, the contrast-limited adaptive histogram equalization (CLAHE) technique was utilized on the red channel for local contrast enhancement. This technique operates on small regions in the image and balances the distribution of grey scale used, and makes hidden features of the image more visible [22]. The full grey spectrum is used to express the image, using the discrete formula Eq. 1,

\[
g = \left[ g_{\text{max}} - g_{\text{min}} \right] \star P(f) + g_{\text{min}}
\]

where \( g_{\text{min}} \) is the minimum pixel value (0 in this case), \( g_{\text{max}} \) is the maximum pixel value (255), and \( P(f) \) is the cumulative probability distribution.

To further sharpen the image, a downsampling of the image by bi-cubic method of pixel merging has been applied. This technique is beneficial for several reasons. Most importantly, the image noise is significantly reduced by taking the neighborhood of individual pixels as the core determinant of the output. The resulting image thus contains shapes, which are much better defined. Secondly, the computational overhead is decreased, and further processing improved, without significantly jeopardizing further georeferencing stages, including vectorisation.

The intensity scale of grey images is consequently reduced to 4 shades, using the global histogram equalization technique. This operation is based on separating the histogram of the original image into \( n \) region, which include approximately same number of pixels. The boundaries of each region are set as thresholding intervals, which are eventually used to convert the grey scale image into \( n \) intensity levels. This step has a massive effect of enlarging the differences among pixel intensities, which makes the cropmarks much clearer. The same procedure is repeated once again to transform the image into a binary form.

The last preprocessing step is application of a morphological dilation, which sets the values of all the pixels in the Moore neighborhood surrounding central pixel according to the dominant value. As a result, the neighboring regions are merged and form a uniform surface, which however keeps the general shape of features obvious and unchanged.

The following figure (Fig. 3) shows the red channel of selected images (a, b and c) containing an outline of historical features as inputs (1) and the resulting outputs (2) of the described pre-processing procedure.
In further stages of the georeferencing procedure, a template matching algorithm will be applied on the pre-processed images. The use of such technique is feasible, because the variation in shapes of cropmarks is generally limited. Gojda and Hejcman present the typical shapes of buried archaeological features [1], which can describe most of the observed cases.

4 Conclusion
This article discusses the aspects of georeferencing of buried archaeological features into a GIS. The importance of aerial images in ARS is discussed and the various benefits and drawbacks of this technology described. Authors have formalized the procedure of transferring the cropmark into an object in the GIS. Special emphasis is paid to the preprocessing stage of this procedure. An algorithm consisting of well established techniques of image processing is proposed and tested on the set of images containing buried historical features of various shapes. Further stages of this research will focus on template matching, object vectorisation, and mapping of buried historical features into a coordinate system of GIS.

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