Detection of burial mounds in high-resolution satellite images of agricultural land

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Keywords: Quickbird satellite images, template matching, contrast enhancement, crop marks, soil marks

ABSTRACT: Many archaeological sites are discovered during building and road construction work, prompting full excavations and delay in construction. In order to detect more cultural heritage sites in advance of construction work, the Norwegian Directorate for Cultural Heritage has taken an initiative to develop tools for early detection of potential cultural heritage sites in satellite images. The present work focuses on detecting the remains of burial mounds in agricultural fields.

The remains of destroyed burial mounds are sometimes visible in satellite images as circular soil marks or crop marks. At best, the marks are distinct, but tend to have less contrast to the background than many other patterns in the images. Consequently, reliable automated detection based on pattern recognition is challenging.

We have developed an approach with the following steps. First, the image is contrast enhanced, in order to make weak marks more distinct. The image is then convolved with ring templates of varying sizes, giving high absolute values at candidate ring locations. Finally, the ring candidates are presented to an operator, who may reject some of them.

We tested our method on Quickbird images from south-east Norway. Of the circular marks that were clearly visible in the images, 73% was detected, and of the ones that were fairly visible, 50% was detected. In addition, seven times as many false positives as true positives were detected. The number of false positives can be reduced, at the cost of reducing the number of true positives as well. For example, by reducing the number of false positives from 7 times to 0.5 times the number of true positives, the number of detected rings decreased from 64% to 32%.

Archaeologists state that the software tool will be helpful for locating potential cultural heritage sites. Although it makes many false detections, the interactive method to delete false detections is so efficient that, say, ten times as many false detections as true detections is not considered a problem by archaeologists.

1 INTRODUCTION

The increasingly intensive use and modification of the landscape resulting from modern demands for efficient infrastructure and land use (agricultural production, mining, energy sources, leisure/tourism facilities, etc.) exerts growing pressure on cultural heritage in the landscape. In order to match the political intentions of updated and sustainable cultural heritage management, it is necessary to develop a cost-effective method for locating and monitoring cultural heritage sites. Given the enormous costs of surveying the areas in question by traditional fieldwork, alternatives must be sought. The use of modern support technologies is imperative, if such rapid changes are to be balanced against the sustainable management of this resource. One possible approach is through the use of satellite images.

In recognition of this, the Norwegian Directorate for Cultural Heritage – in collaboration with the Norwegian Computing Center, the Norwegian Institute for Cultural Heritage Research, the Museum of Cultural History at the University of Oslo, and Vestfold County Administration – started in 2002 a project with the overall aim of developing a cost-effective method for surveying and monitoring cultural heritage sites on a regional and national scale. Important funding was provided by the Norwegian Space Centre.

Results obtained in a pilot project (Grøn, 2004) indicated the existence of a correlation between cultural heritage sites and variation in the chemical elements in the soil. A central focus in the early project years was the manual analysis of satellite images followed by chemical profiling of sites observed in these images in order to gain experience as to how cultural heritage sites really manifest themselves in satellite images. The results demonstrated that high-resolution geo-chemical sampling appears to be a promising field for the development of cultural heritage indicators. However, the costs involved demanded a need for funding which was difficult to obtain.

It was then suggested to focus on the development of automated methods, such as pattern recognition, for detecting and locating cultural heritage sites. The working assumption is that cultural heritage sites with no visual apparent manifestations above ground may be detectable in remote sensing images due to alterations in the spectral signature of the bare soil or of uniform vegetation growing there (crops).

The use of aerial imagery for this purpose is quite widespread (e.g., Campana, 2006a; Musson, 2006). In addition to airborne multispectral imaging, recent advances in airborne LIDAR also show great promise (e.g., Risbøl, 2006; Sittler, 2006). The collection of airborne imagery and LIDAR is nevertheless both time consuming and costly and this imposes severe limitations on the size of the areas that can be investigated. In this respect satellite imagery holds great promise. Satellite image based location, surveillance and monitoring of cultural heritage sites has been the subject of some recent research (e.g., Aurdal, 2006; Lasaponara, 2006; Campana, 2006b), but generally this field is not well explored.

Although the costs connected with acquiring and analyzing the satellite data will not be insignificant, and fieldwork will never be replaced entirely by high-technological methods, it seems plausible that an essentially cheaper and possibly even qualitatively better method for the surveying and monitoring of cultural heritage sites can be developed to target fieldwork to a degree not possible today.

2 THE CULTSEARCHER PROTOTYPE SYSTEM

The CultSearcher prototype system is currently analyzing soil-marked and crop-marked patterns. Soil-marked sites are typically the remains of a ditch or pit, buried walls, etc. A ditch or a pit would disturb the local soil profile, and refilled material usually has different characteristics, like density and composition. The refilled material is in most cases not so compact, and it might contain more humus components, making it look darker. The refilled material may also affect the soil texture with a grain-size distribution that differs from the undisturbed soil (usually larger number of smaller grain sizes). This results in improved water-storage capacity, so the soil would look darker under certain conditions.

Crop marks are an indirect effect of buried archaeological features. Their visibility depends on the soil, climate and vegetation. So-called positive marks are due to more available water, which makes plants grow higher and ripen later than the plants around. A colour-tonal contrast may be created because the vegetation stays green for a longer period and/or that the vegetation is darker green. Crop marks may also be due to a vegetation relief. Plants grow higher, enough to throw a shadow in slanting sunlight. So-called negative marks appear when plants grow over buried stones (e.g. walls) and run out of water sooner, ripen earlier and stay shorter. Almost any crop can develop marks, if conditions are well. Cereals react fast on a Soil Moisture Deficit (SMD) and are growing very close, making contrasts clearer.

Various types of remote sensing sensors, airborne and spaceborne, are useful for detecting remains or patterns due to cultural heritage sites. Soil- and crop-marked sites can be measured with high-resolution optical (visible and infrared) sensors. With the optimal selection of observation wavelengths, high contrast can be obtained (in particular appearing from reflectance contrasts due to soil moisture or vegetation density). The spatial resolution of these sensors should be of 1 m or better to be really useful. Therefore, the project has so far focused on images from Ikonos and Quickbird.

The aim of the software prototype described in this report is to provide computerized assistance to the operator in the analysis of satellite images. In particular, the software identifies circular structures, i.e., potential sites for the remains of bronze age burial mounds, for further inspection by an archaeologist. This means that the archaeologist may concentrate on analyzing the identified sites rather than the entire image. It is important to bear in mind that the system is designed to detect candidate sites and that no claim is made that these candidates are true cultural heritage sites. Even human specialists cannot make such an assertion based on satellite imagery alone. The verification of a potential site always depends on some kind of field inspection.

In order to detect as many circular marks as possible, while at the same time keeping the number of false positives at a minimum, variations of the following sequence of methods have been tried out: (1) band pass filtering in the frequency domain, (2) local contrast enhancement, (3) template matching, (4) feature extraction, and (5) decision tree-based classification

The details are given in (Trier 2008). Experiments in that study concluded that methods 2 and 3 were vital, whereas the three other methods gave no improvement in the recognition results. The resulting algorithm for ring structure detection can be summarized as follows.

1. Define masks of agricultural fields, either done interactively or by importing a GIS file.
2. Apply local contrast enhancement.
3. Search for rings: (a) construct ring templates of increasing sizes, (b) convolve image with a ring template, (c) threshold result of step b to find bright rings, (d) threshold result of step b to find dark rings, and (e) repeat steps b-d for all ring template sizes.

3 EXPERIMENTAL DATA

The data set consists of two Quickbird images from south-east Norway. One was taken on April 27, 2005 at 10:45AM, from the valley Lågendalen between Kongsberg and Larvik. The other was taken on July 29, 2003 at 10:23 AM, from an area surrounding, but not including, the Oslo Gardermoen airport. Both images consist of a four-band multi-spectral image and a panchromatic (grey scale) image. The panchromatic image has 0.6 m wide pixels, and the single band covers the 450-900 nm wavelengths. The multi-spectral image has 2.4 m wide pixels, and the bands are: blue (450-520 nm), green (520-600 nm), red (630-690 nm) and near-infrared (760-900 nm).

Many circular patterns are clearly visible in the panchromatic images, but can hardly be seen in the multi-spectral images. Recently, other research groups have used multi-spectral Quickbird (Lasaponara, 2007) or Ikonos (De Laet, 2007) images, but the objects they were looking for were much larger than the circular patterns in the present work. Since the circular patterns are difficult to spot visually in the multi-spectral images, we chose to use only the panchromatic images.

In the two images, archaeologists have identified 35 rings that they would like the system to recognize. We have visually classified 15 of these as “strong”, 10 as “fair” and 10 as “weak” (Figure 1). 11 subimages of 4096×4096 pixels were extracted for the experiments. These subimages included all 35 rings.

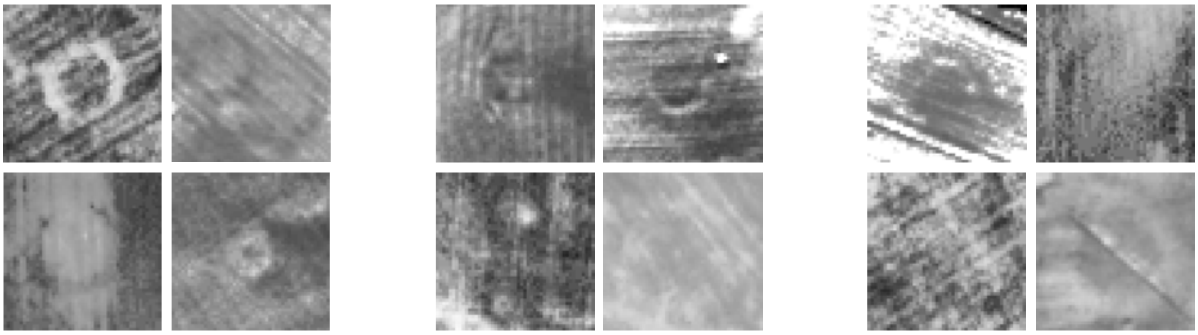

Figure 1 Example rings. Left: strong, center: fair, and right: weak.

4 EXPERIMENTAL RESULTS

The above algorithm was applied to the entire data set, that is, a collection of 11 sub-images of sizes 4096×4096 pixels, which together covered all the identified true rings.

The number of detected false rings varies dramatically with the correlation threshold (Table 1). A reasonable compromise between not detecting too many false rings and at the same time detect as many true rings as possible, might be when the number of false detections is approximately seven times the number of true detections (yellow line in Table 1). In this case, 11 out of 15, or 73%, of the strong rings were detected, and 5 out of 10, or 50%, of the fairly strong rings were detected. This is 16 out of 25 of the strong and fairly strong rings, or 64%.

The number of false positives can be reduced, at the cost of reducing the number of true positives as well. For example, by reducing the number of false positives from 7 times to less than half the number of true positives, the number of detected rings decreased from 64% to 32%. On the other hand, even if the correlation threshold is set so low that almost 30 times as many false rings as true rings are detected, many of the strong and fairly strong rings are not detected. Further, none of the weak rings are detected.

Table 1. Detection results

correlation threshold	strong rings	fair rings	weak rings	total true rings	false rings
0.3	11	5	0	16	450
0.33	11	5	0	16	109
0.35	10	2	0	12	39
0.4	8	0	0	8	3
Identified true rings	15	10	10	35	

5 DISCUSSION AND CONCLUSION

The experiments demonstrate that the proposed algorithm is able to detect many circular patterns. Still, many are also missed by the algorithm. If the goal is to detect each and every circular pattern, then the algorithm needs to be improved to be really useful.

For a thorough search in a limited area, a high number of false positives might be acceptable. On the other hand, for massive search through a large number of images, the number of false positives might be kept at a minimum, as long as *some* sites are detected. Some circular patterns may only be visible from time to time. In order to find these, one may have to process images from, say, a ten year period, and, say, 5-10 images per year. In this perspective, our approach can be used to process large volumes of satellite images that would otherwise not be inspected, thus detecting many new sites.

At present, only one parameter is varied for the different ring templates, namely the radius. One could also vary the thickness of the ring, and see if that enables us to use a high correlation threshold, possibly eliminating many of the false detections while at the same time detecting more true rings.

In this work, we have only used two satellite images, containing in total 35 identified rings. Many more satellite images and identified rings are needed to evaluate the current version of the system, spot weaknesses and experiment with possible enhancements.

Archaeologists state that the software tool will be helpful for locating potential cultural heritage sites. Although it makes many false detections, the interactive method to delete false detections is so efficient that, say, ten times as many false detections as true detections is not considered a problem by archaeologists.

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