

Automatic and semi-automatic detection of possible meteorite impact structures in the Fennoscandian shield using pattern recognition of spatial data

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Abstract. The search for impact structures in Norway is still in its infancy and compared to Sweden (6) and Finland (11) the number of discovered Norwegian structures (2) is low. This initiated a systematic search for possibly new impact structures in Norway by geographic information and image analysis on available regional geodata. Such data might be digital elevation models (DEM), satellite data (optical, radar), bedrock, lineaments and probably most promising, geophysical data (e.g. gravity, aeromagnetic). A matching algorithm using a DEM and impact crater templates has been performed, and a circular Hough transform algorithm is tested on the same data.

1 Introduction

The search for impact structures in Norway is still in its infancy and compared to Sweden (6) and Finland (11) the number of discovered Norwegian structures (2) is low [1]. This initiated a systematic search for new impact structures in Norway. Areas inhabiting impact structure characteristics, named here possible meteorite impact structures, are searched by geographic information and image analysis on regional geodata.

Impact structures are formed by collisions of comets and asteroids, with planets or moons, and these crater structures may be preserved for millions of years. Fresh impact craters are characterized by their circumform shape [8]. The active Earth (e.g. erosion, sedimentation, subduction) will eventually leave more poorly preserved impact structures [12], which can be hard to distinguish from their surroundings. The circular shape, even if less apparently, makes impact structures ideal objects for the applications of automatic detection methods. Candidates may be detected, but field observations are needed to determine if the structure has an impact origin (shock metamorphic features).

1.1 Joint project

The Norwegian search project is part of a cooperation program between the European Space Agency (ESA-ESTEC), the Universities of Oslo and Helsinki

along with the Geological Surveys of Norway and Finland. The project objectives are to develop a workable automatic search algorithm and to discover new impact structures in Fennoscandia.

2 Data

In order to detect candidates, available regional digital information will be explored for circular shapes. Such data might be digital elevation models (DEM), satellite data (optical, radar), bedrock, lineaments and probably most promising, geophysical data (e.g. gravity, aeromagnetic). Geophysical characteristics have been studied for many impact structures and a negative, often circular, gravity anomaly which changes density after impact, is common [9]. Magnetic anomalies display large variations across impact craters, but a magnetic low is often a dominant effect [9].

3 Methods

Two of several techniques in use to detect circular features in digital data are matching and voting algorithms. Variations of the Hough transform voting technique are the most common in the field of planetary impact crater counting, e.g. [2].

Using a matching algorithm, a first systematic search for possible Norwegian impact structures was based on an automatic scan of DEMs [7]. The DEM resolution applied were 100 m. Topographic crater templates (circular depressions), representing typical impact structures in the interval 5-10 km, were made based on depth/diameter relations from terrestrial impact structures [5] and lunar impact structures [8] [10]. The circular shaped templates of fixed diameters were cross-correlated with the DEM. The template matching output is an image the size of the DEM, consisting of a value of similarity between the template and the DEM in each pixel. The similarity is calculated by a correlation coefficient [4],

$$\gamma(s, t) = \frac{\sum_x \sum_y [f(x, y) - \bar{f}(x, y)][w(x - s, y - t) - \bar{w}]}{\left\{ \sum_x \sum_y [f(x, y) - \bar{f}(x, y)]^2 \sum_x \sum_y [w(x - s, y - t) - \bar{w}]^2 \right\}^{1/2}}, \quad (1)$$

where $w(x, y)$ is the template, $f(x, y)$ is, in this application, the DEM and the correlation is obtained at point (s, t) . A post-processing step, including a threshold to separate between low and high match pixels, grouping of high match pixels and a group classifier will gain areas of interest, potential impact structures.

The nature of the geophysical signatures of impact structures implies considering just the circumform shape and not a circular depression (the template matching), might be rewarding. A method that can solve this is the Hough transform. The Hough transform was developed to identify lines in digital images [6]. This technique, modified to identify circles, and by applying different

pre- and post-processing procedures (edge detection, result filtering), has shown promising results in detecting impact structures on satellite images and DEMs of planetary bodies, e.g. [2].

A circular Hough transform attend the problem of the probability that a set of pixels (from now on called gradient pixels) lies in a circular pattern. It is often an edge detection of an image that results in these gradient pixels. An advantage of the Hough transform is that if the circular object itself is a bit occluded, the transform still manages to detect the structure. It is also independent of position, rotation and scale [11]. Given an image of gradient pixels and a radius r , potential circle centres are calculated for each gradient pixel. The potential circle centre are all pixels a distance r away from the gradient pixel. These potential circle centres are accumulated in a matrix and the procedure is repeated for all gradient pixels. If the radius is not known, the Hough transform must be calculated for several values of radius. The circle accumulation matrix gets a dimensionality of three, each cell in the accumulation matrix categorized by a potential circle centre (a,b) , which must be inside the original image, and a radius r , inside a radius interval set prior to the analysis. This because a circle is parameterized by three parameters a,b,r ,

$$(x_1 - a)^2 + (x_2 - b)^2 = r^2, \quad (2)$$

where the circle has centre (a,b) and radius r [4], [11]. The frequency of the accumulated cells tell if several of the gradient pixels belong to the same circle. A high value indicate that a circle probably are present in the original image (Fig. 1).

4 Results

4.1 Template matching

A DEM covering a 7,000 km^2 area of Precambrian rocks in Finnmark resulted in 23 structures partly matching the templates, using a correlation coefficient of 36. They display different varieties of circular shapes (Fig. 2), and most likely have several different origins. The results detects more structures than what is the expected number of impact structures of this diameter interval in an area of this size.

4.2 Circular Hough transform

The analyses is performed on a gray level (8 bit) image, a shaded elevation model calculated from a part of the digital elevation model used in the template matching. The image is smoothed using a low pass filter and gradient pixels are found using the Sobel edge detection operator and a threshold of 80. A radius interval from 20 to 60 pixels (ca. 5-10 km) was set prior to the analyses and a threshold of 60 was applied to the accumulation matrix (Fig. 3 and 4).

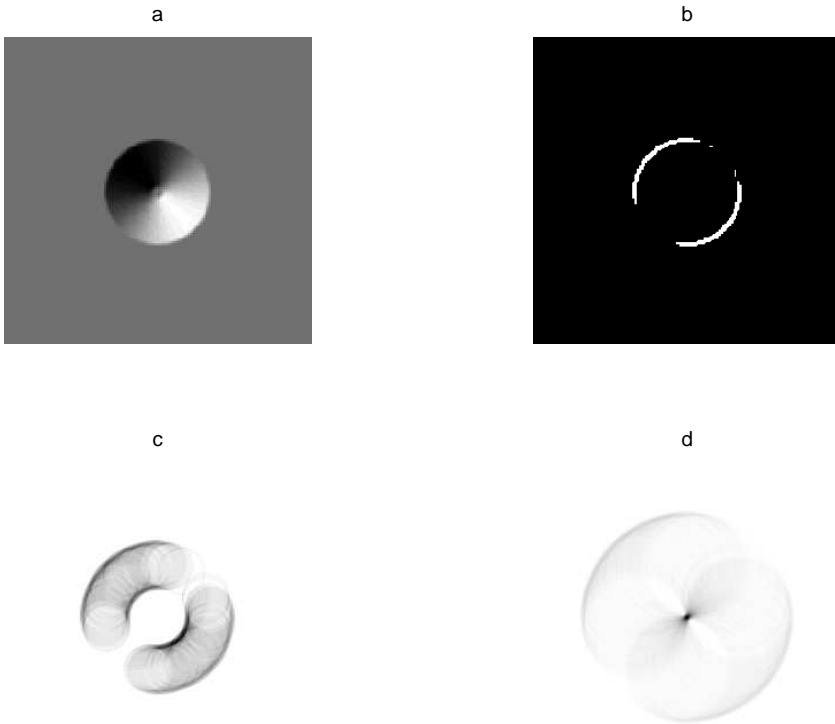


Fig. 1. A shaded elevation model of a synthetic circular depression made for the template matching analyses a), having a radius of approximately 45 pixels. b) displays a thresholded (threshold = 100) gradient image (white pixels are gradient pixels), and the results of a Hough transform with radius 20 and 45 pixels are shown in c) and d) respectively. The peak in Fig. d) have a larger value than the peaks in c), indicating that this peak is a probably circle centre.

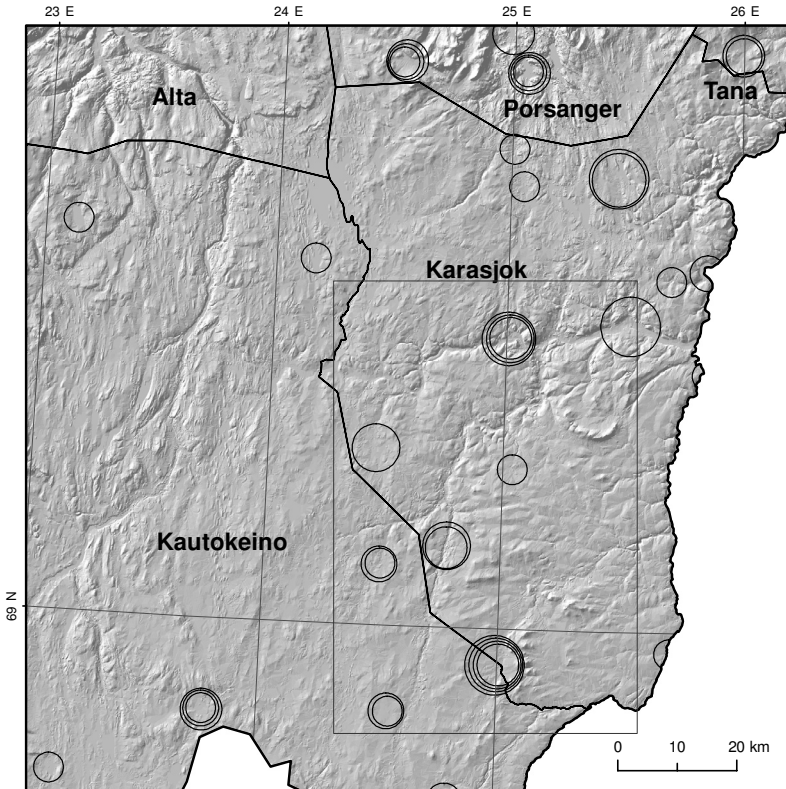


Fig. 2. An area of Finnmarksvidda displaying detected circular depressions [7]. The circular depressions are shown with circular symbols of diameters 5-10 km, the diameter referring to the template diameter detecting the individual structure. It shows 23 depressions, not counting overlaps between templates. The position of Fig. 3 and 4 is shown by the square. Map projection: UTM EUREF89/WGS84 zone 35.

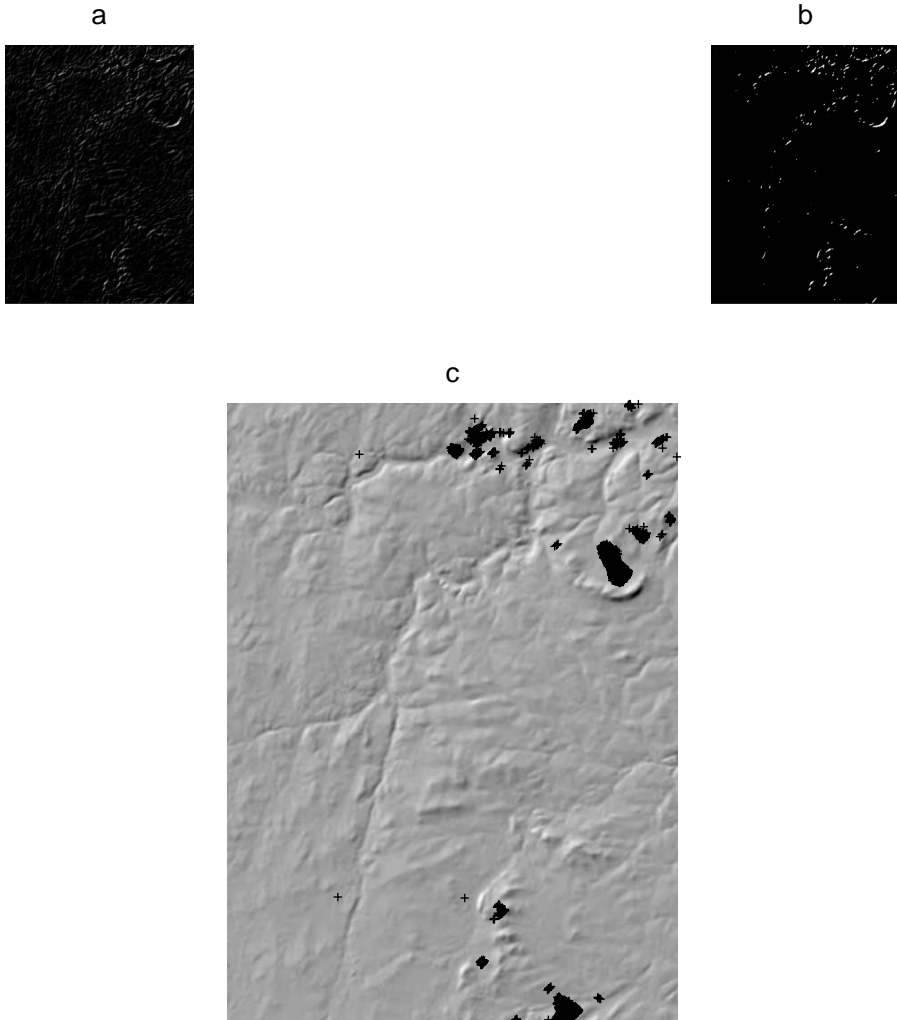


Fig. 3. A gradient image of part of the area of Finnmarksvidda displayed in (Fig. 2) calculated by the Sobel operator is shown in a), and results after a threshold of 80 on this image b). c) displays detected circular centres having a from 20 to 60 pixels, approximately 5-10 km in this resolution.

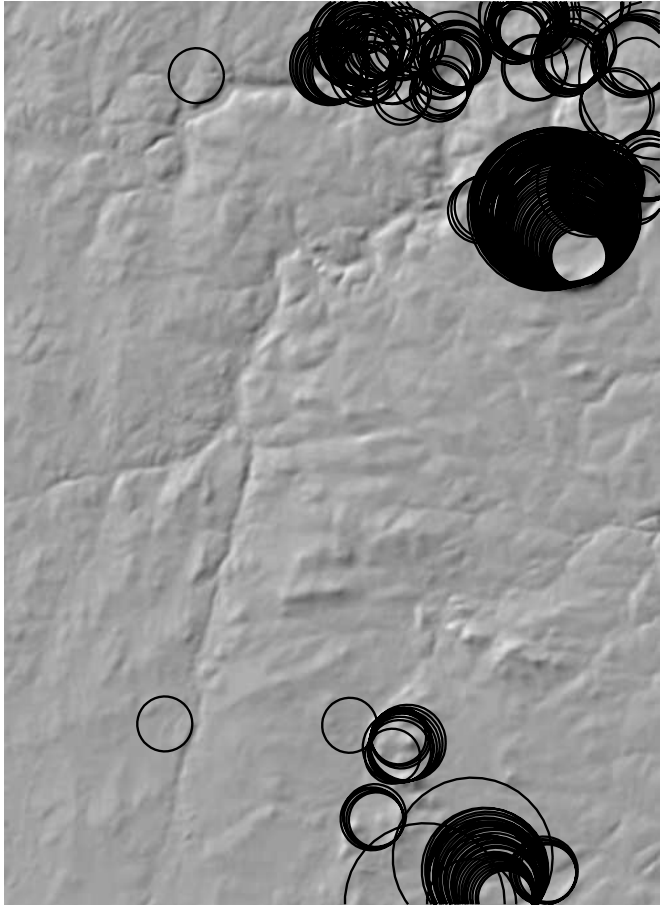


Fig. 4. Circles with radius r from circle centres (Fig. 3c). The clearly visible half circular structure in north east (Fig. 3c) is found by most radiuses, indicating that a stricter accumulation threshold could have been used, but on the expense of losing some of the other structures.

5 Discussion

The template matching detects a high number of possible meteorite impact structures, exceeding what could have been expected. The use of a higher correlation coefficient would have reduced this number, but the variability of the topography and impact structures defend such a low value.

The Hough transform enforce some decisions to be made, e.g. how to find proper gradient pixels (in addition to edge detection methods, terrain parameters like slope and curvature might be explored) and how to decide a threshold for the gradient image and the accumulation matrix. The thresholds in this Hough analyses was based on visual inspection. Global thresholds were used, but there exists locally adaptive threshold methods that might improve the results. Enough gradient pixels to capture structures are needed, but not to many. The threshold of the accumulation matrix settle whether a cell is a potentially circle centre or not. If a circle is occluded it will lead to a lesser cell value of that (a,b,r) combination, still it may be a high enough value to detect the circle. Gradient pixels of an uneven or noisy circle accumulate not only to a specific cell, but rather a cluster of cells, where the cluster mass centre may represent the circle centre.

The Hough transform analyses was performed on a gray level image, but a digital elevation intensity image might also be used, leading to other decisions and results. Generalized Hough transforms are developed to deal with more complex shapes, e.g. circles not exactly circular, and could be a future direction of the impact structure detection analyses.

Crater detection on e.g. Mars deals with more clearly visible structures. The Hough transform analysis showed that structures not clearly visible in the original image might not be detected. Applying this technique to terrestrial environments may force minor adjustments, but also enable the possibility to perform the analysis on a broad set of geodata. These results suggests further analysis, including incorporation of other methods, fusion of different data and combination of results.

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