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Automatic detection of forest regions on scanned old maps

Abstract. *The paper presents the image processing method for detection forest regions from digitized old maps. The proposed scheme consists of two principal steps. In the first one the input color image is filtered using averaging filter and binarized by thresholding in the HLS color space. The second step is based on morphological image processing of binary images and results in smoothening of contours of forest regions and removing unnecessary objects. As experiments are showing, the proposed method produces correct results of segmentation, allowing extraction of forest regions that can be further effectively processed and analysed.*

Streszczenie. *W artykule przedstawiono metodę segmentacji obrazów cyfrowych przedstawiających skanowane mapy historyczne. Celem segmentacji jest wykrycie i wyodrębnienie obszarów leśnych. Zaproponowna metoda składa się z dwóch etapów. Na pierwszym, wejściowy obraz kolorowy jest filtrowany i binaryzowany przez progowanie w przestrzeni kolorów HLS. Drugi etap polega na zastosowaniu filtrów morfologicznych w celu wygładzenia konturów obszarów leśnych oraz usunięcia obszarów zbędnych. Jak pokazały przeprowadzone eksperymenty, zaproponowana metoda pozwala na uzyskanie prawidłowych wyników segmentacji, dzięki czemu wyodrębnione obszary leśne mogą być następnie skutecznie przetwarzane i analizowane (***Automatyczna detekcja obszarów leśnych na skanowanych mapach historycznych***).*

Keywords: image segmentation, morphological image processing, old maps
Słowa kluczowe: segmentacja obrazów, morfologiczne przetwarzanie obrazów, mapy historyczne

Introduction

In the digital era, almost all the information is produced in digital form that can be further processed automatically according to user's needs. However, the information resources published years ago are stored in classic, paper-based forms. In order to make them compatible with modern information sources the digitalization is performed. In most of the cases, the digitalization product is just the raster image showing the original publication. To understand the content of such piece of information, scanning result must be further processed using image processing and pattern recognition approaches. One of the elements of such processing is image segmentation which aims at extracting the necessary user-defined information from the original image.

Old maps are the major source of spatial information available before the onset of photogrammetry and remote sensing in the 20th century frequently used to study changes in land use and land cover over the last centuries [1, 7, 8]. Typically, due to the complex nature of map content, the specific information is extracted via visual interpretation and manual vectorization. This process requires enormous work load of skilled operators. Automation of map information / feature extraction is rare; typically, it relates to linear and point features or text [2] and has not been implemented on a large scale in geographical studies.

The paper presents the image processing method for detecting and extracting forest regions from digitized old maps. Four subsets of P51 S30 sheet ("Zakopane", 1934) of the Polish Topographical Map published by the Polish Military Geographic Institute (WIG, Wojskowy Instytut Geograficzny) in the inter-war period were used for testing (Fig. 1). The WIG maps cover all territory of Poland and have frequently been used to document long-term changes of land cover in Poland (e.g. [3, 5]) using a manual vectorization. On WIG maps, forests are marked light green with a dotted black outline; the forest area is obscured by a variety of additional symbols, gridlines and text (see Fig. 2(a)), color variations are also related to terrain shading visible on steep mountain slopes.

The proposed automatic detection scheme is divided into two principal steps. The first step consists of three stages. First, the image is filtered in order to remove small pixel-scale variations of colors. Next the image color space is transformed from Cartesian RGB (red-green-blue) into cylindrical HSV (hue-saturation-value) and finally the thresholding in the latter space is performed. As a result a binary image

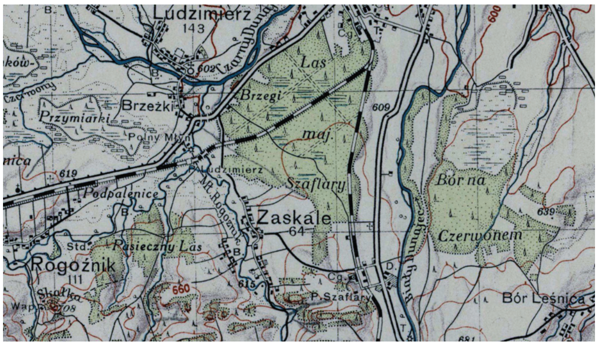


Fig. 1. Example of scanned topographic map.

containing preliminary forest regions is obtained. This result suffers however from some important imperfections that appear as salt and pepper noise consisting of grains of various sizes or as inaccurate soutline of forest regions. In order to improve the quality of such binary forest mask, the second step of the method is executed. It is based on morphological image processing of binary images and consist of two stages. The first one is based on morphological filters of opening and closing which smoothen contours of forest regions and remove unnecessary objects. The second stage is based on morphological reconstructive filters and continue removing unnecessary objects but this time without smoothening the contours.

Color image segmentation in cylindrical color space

The first step of processing aims at converting color input image into a binary one. In the current study this step consists of three steps: low-pass filtering, color space conversion and thresholding.

The aim of the first stage – low pass filtering is to smoothen the image and to remove small, local variations of color values. In order to perform this filtering, the averging filter is applied:

$$\text{(1)}\quad \forall_{(x,y)} f'(x,y) = \frac{1}{(2n+1)^2} \sum_{i=-n}^{n} \sum_{j=-n}^{n} f(x+i, y+j),$$

where n stands for the size of filter and f, f' for input and output images, respectively. The choice of filter size n is restricted by two constaints. On one hand the smoothening of forest regions should be as strong as possible, on the other

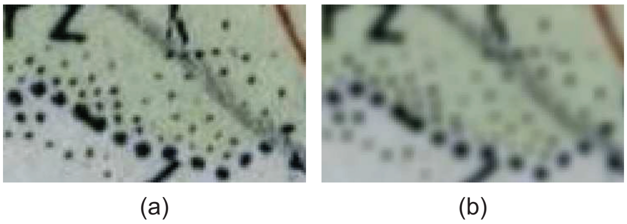


Fig. 2. Fragment of image before (a) and after (b) low-pass filtering.

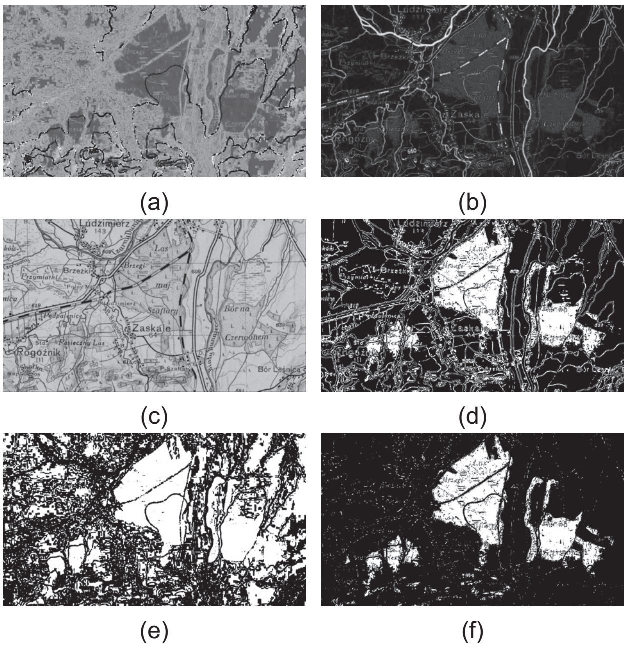


Fig. 3. Input image (see Fig. 1) splitted into HSV components (resp.(a),(b),(c)), thresholding results: of hue (d), of saturation (e) and the intersection of all three thresholding results (f).

– the blurring of their boundaries needs to be as small as possible. Experiments showed that size $n = 2$ is the optimal one. The result of filtering is shown in Fig. 2.

To obtain binary image with forest regions of interests, the filtered image is thresholded in HSV color space. The extraction of regions of interest is driven by region color. The differences between color variations within the forest area are visible as disturbances in pixel lightness and/or saturation rather than in hue. Since original, color components in RGB color space (in which scanned images are originally registered) do not reflect these color properties, in order to get proper extraction of forest regions, the color space transformation must be performed. The original RGB color image is thus transformed into HSV color space and the thesholding is performed on three bands of HSV image: hue, saturation and luminance (value). As a result of thresholding, the intersection of results of three above thresholds is taken:

$$(2)\quad F = \mathcal{T}_{[H_{lo},H_{hi}]}(f'_H) \cap \mathcal{T}_{[S_{lo},S_{hi}]}(f'_S) \cap \mathcal{T}_{[V_{lo},V_{hi}]}(f'_V),$$

where $f' = [f'_H, f'_S, f'_V]$ stands for the filtered image transformed into HSV color space and $H_{lo}, H_{hi}, S_{lo}, S_{hi}, V_{lo}, V_{hi}$ are lower and upper thresholds on hue, saturation and value, respectively. The example of color space transformation and thresholding is shown in Fig. 3.

Morphological filtering

The result of thresholding is a binary image containing objects that most likely belong to forest regions. Unfortunately these objects do not match precisely the real forest regions. There exist not only some objects outside forest regions (false-positives), but also within the forest regions one can observe some defects (false-negatives). The latter are visible as holes inside objects or improper outline of regions. What is important, these imperfections appeared in spite of correct color segmentation results. It means that they cannot be removed by adjusting the thresholds, as the reason of their appearance is color distribution on the input image. The disturbances of particular colors within regions when observed by humans are easily neglected thanks to a priori knowledge (e.g., proper recognition of elevation contour lines, text symbols, shading intersecting the forest area). Thresholding however does not make use of such knowledge and consequently one has to use other means to improve segmentation results. Such improvement requires smart modification of the content of binary image. The filtering phase is divided into two parts: region shape smoothening and removing of false ones.

Introduction to morphological filtering

Let X be the binary image. Two base morphological operators are *erosion* and *dilation* [4, 6, 10], are defined for binary images as, respectively:

$$(3)\quad X \ominus B = \cap_{b\in B} X_{-b}\ ;\ X \oplus B = \cup_{b\in B} X_{-b},$$

where $X_b = \{x + b, x \in X\}$ and B is structuring element. Operators of erosion and dilation are, for each pixel, searching for the lowlest (in case of erosion) and highest (in the dilation case) value among all pixels located within the pixel's neighborhood defined by B. Structuring element B can consist of any subset of pixels, but in most of cases several standarized elements are in use. The most popular are 4- and 8-connected elementary structuring elements (denoted as $B = \mathcal{N}_4$ and $B = \mathcal{N}_8$ resp.) that consists of a pixel plus their either 4 or 8 closest neighbors. Also, their multiples are in common use.

Morphological reconstruction allows extracting from the binary image selected objects (connected components). It is defined in an iterative way as follows:

$$(4)\quad Y \triangle_B X = \underbrace{(...(((X \oplus B) \cap Y) \oplus B) \cap Y)... \cap Y)}_{k-times},$$

where k stand for such number of iterations after which the image stops to change. It is usually assumed that either $B = \mathcal{N}_4$ or $B = \mathcal{N}_8$. The morphological reconstruction can also be computed using fast algorithms [9].

By combining erosion and dilation, two pricipal morphological filters of *opening* and *closing* are defined respectively as:

$$(5)\quad X \circ B = (X \ominus B) \oplus B^T\ ;\ X \bullet B = (X \oplus B) \ominus B^T,$$

where $B^T = \{p : -p \in B\}$ is the transposed structuring element. Opening and closing are modyfing an image in such a way that object smaller than the structuring element belonging either to the foreground (in case of opening) or to the background (in case of closing) are removed. Apart from effect of removing unwanted objects, both operators are also modyfying the shape of the remaining image objects, so that their outlines become smoother.

Morphological filters of *opening by reconstruction* and *closing by reconstruction* are defined as, respectively:

(6)

$$X \circ_{B_1} B_2 = X \triangle_{B_1} (X \ominus B_2)\ ;\ X \bullet_{B_1} B_2 = \overline{\overline{X} \triangle_{B_1} \overline{(X \oplus B_2)}}.$$

These two filters are removing objects smaller than structuring element B_2, but without modifying the rest of the image, which makes them very powerful image filters. The second structuring element B_1 is used by the reconstruction operator and ususally $B_1 = \mathcal{N}_4$ or $B_1 = \mathcal{N}_8$.

Forest regions shape smoothening

The shape of forest regions – objects present on thresholding results – suffer from some imperfections. They are appearing due to the nature of color input image, the scanning process, and sometimes also poor quality of old paper. One can observe that there is a lot of salt-and pepper noise (see e.g. Fig. 3). It is caused by pixels of color similar to the color of forest regions, but located elsewhere (“salt” noise) and by pixels of color different to typical of forest regions located within such regions (“pepper” noise). What is even more important, the forest regions refering to the same real forest area, are represented by disjoint objects (separated by e.g. various linear objects like roads, elevation contour lines, etc.). Such discontinuities deforms the actual shape of forest regions. In order to solve both problems at once, the combination of morphological filters of opening and closing is applied. These filters remove noise and smoothen object contours. To combine both types of filters, so called morphological alternating filters are used:

(7) $$F_1 = (((F \circ S_1) \bullet S_2) \circ S_3)\,,$$

where F stands for the result of thresholding (eq. 2), and S_1, S_2, S_3 are structuring elements of the first opening, closing and the second opening, respectively. These structruring elements must be chosen considering the fact that primary goal of this stage of fitlering is to smoothen the contours of regions. Using of too small structuring element would result in poor smoothening, while too large would cause such modificaton of regions’ shape that it would not be consistent with the real forest area.

Removing of false regions

The problem with the result of the first stage of filtering is presence of false-positive and false-negative regions, which still should be removed. When considering removal of image objects, one have to consider the criterion based on which this removal is performed. In the current case, the size criterion will be used. Consequently, object smaller than given size will be removed as well as holes inside objects. To perform this removal precisely, without disturbing the shape of remaining parts of the image, the morphological filters by reconstruction will be applied. To remove small objects, the opening by reconstruction filter is applied. Holes inside object are, in other words, background objects inside foreground regions. To remove them the morphological filter of closing by reconstruction is used. The order of performing above two operators for some configuration plays important role. For example small object with a hole inside may be removed by the opening by reconstruction if such operation is performed first. But in the opposite case, when it is preceeded by the closing by reconstruction, it may happen that in result of closing the hole disappears and the size of object increases. Consequently, the enlarged object would not be removed as in the first case. To allow both orders of applying filters by reconstruction, the following chain of operations is proposed:

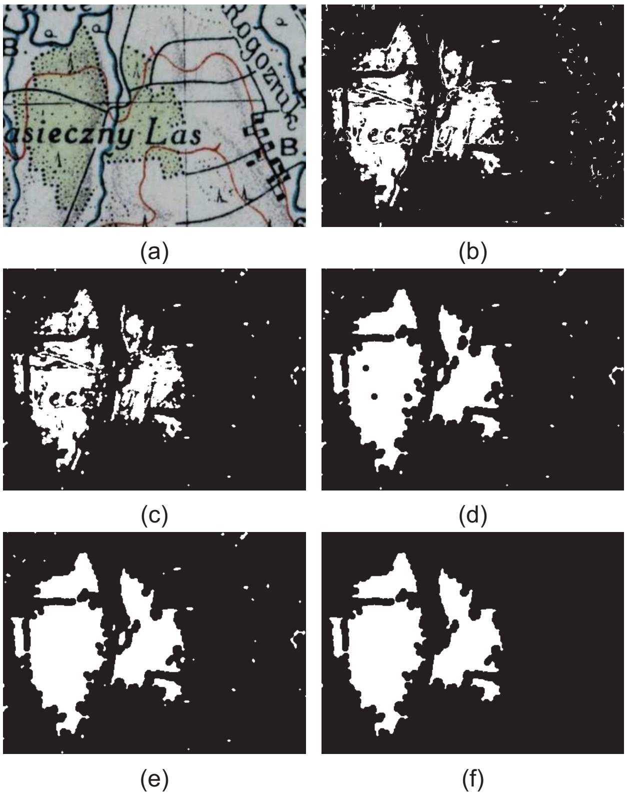


Fig. 4. Fragment of the input image (a), its binarisation (b) and results of morphological operators: opening (c), closing (d), closing by recostruction (e) and opening by reconstruction (f).

(8) $$F_1 = (((F \circ_{\mathcal{N}_8} S_4) \bullet_{\mathcal{N}_8} S_5) \circ_{\mathcal{N}_8} S_6)\,,$$

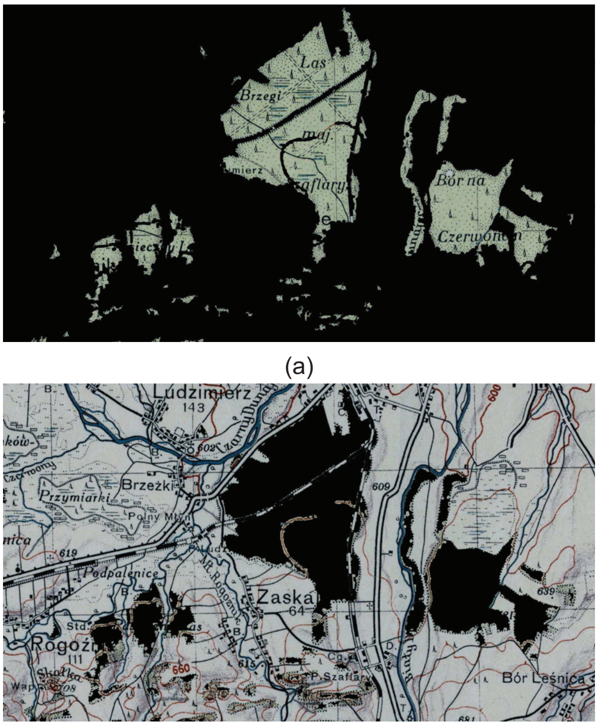
where S_4, S_5, S_6 are structuring elements used by reconstruction filters: first opening, closing and the second opening, respectively. The size of objects or holes removed during this stage of filtering depends on these three structuring elements. Example results of the first stage of filtering are shown in Fig. 4.

Results

The method was applied on various scans showing different sections of one map sheet. Each time the parameters have to be adjusted to specific conditions, e.g., presence/absence of shading and density of elevation contour lines, nature of forest neighbourhood (rural/urban), forest fragmentation). The preliminary results, as evaluated visually, are in the majority of subsets correct, and the forest mask obtained using the proposed method follows well the cartographic representation of forest regions. Results are shown in Fig. 5 and 6.

Conclusions

In the paper, a method for extracting forest regions from digitized old maps was presented. It is based on color image segmentation (with convolution filtering and thresholding in HSV color space) followed by two-stage morphological filtering process. The proposed method can be successively applied into a series of images containing scans of old digitized maps. The example of segmentation results are shown in Figs. 6. These results indicate the potential applicability of the proposed method in cartographic research and the need of further testing. This approach can be applied also to extract regions of other characteristics on digitized maps, remote sensing data or other types of images. In general the



(a)

(b)

Fig. 5. Forest (a) and non-forest region (b) of the image shown in Fig. 1.

proposed scheme may be applied to segment color images containing perceptually homogenous regions but producing noisy thresholding results.

BIBLIOGRAPHY

[1] Gimmi U., Lachat T., Bürgi M., “Reconstructing the collapse of wetland networks in the Swiss lowlands 1850-2000”, *Landscapy Ecology*, 2011,

[2] Pezeshk A., Tutwiler R.L. “Automatic Feature Extraction and Text Recognition From Scanned Topographic Maps”, *IEEE Transactions on Geoscience and Remote Sensing*, vol.PP, pp. 1-17, 2011,

[3] Ostafin K., “Zmiany granicy rolno-leśnej w środkowej części Beskidu Średniego od połowy XIX w. do 2005 r.” Wydawnictwo Uniwersytetu Jagiellońskiego, Kraków, 2009

[4] Iwanowski M. “Metody morfologiczne w przetwarzaniu obrazów cyfrowych”, EXIT, Warszawa 2009

[5] Kozak J, Estreguil C, Troll M “Forest cover changes in the northern Carpathians in the 20th century: a slow transition”. *Journal of Land Use Science* 2, pp.127-146, 2007

[6] Soille P. “Morphological image analysis” *Springer Verlag*, 1999, 2004

[7] Bielecka E., Ciołkosz A., “Land use changes during the 19th and 20th centuries. The Case of the Odra River Catchment Area”. *Geographia Polonica* 75, 1, pp.67-83, 2002.

[8] Petit C. C., Lambin E. F., “Impact of data integration technique on historical land-use / land-cover change: Comparing historical maps with remote sensing data in the Belgian Ardennes” *Landscape Ecology* 17, pp.117-132, 2002

[9] Vincent L., “Morphological grayscale reconstruction in image analysis: applications and efficient algorithms”, *IEEE Trans. on Image Processing*, Vol.2, No.2, April 1993.

[10] Serra J. ”Image analysis and mathematical morphology”, vol.1,*Academic Press*, 1983

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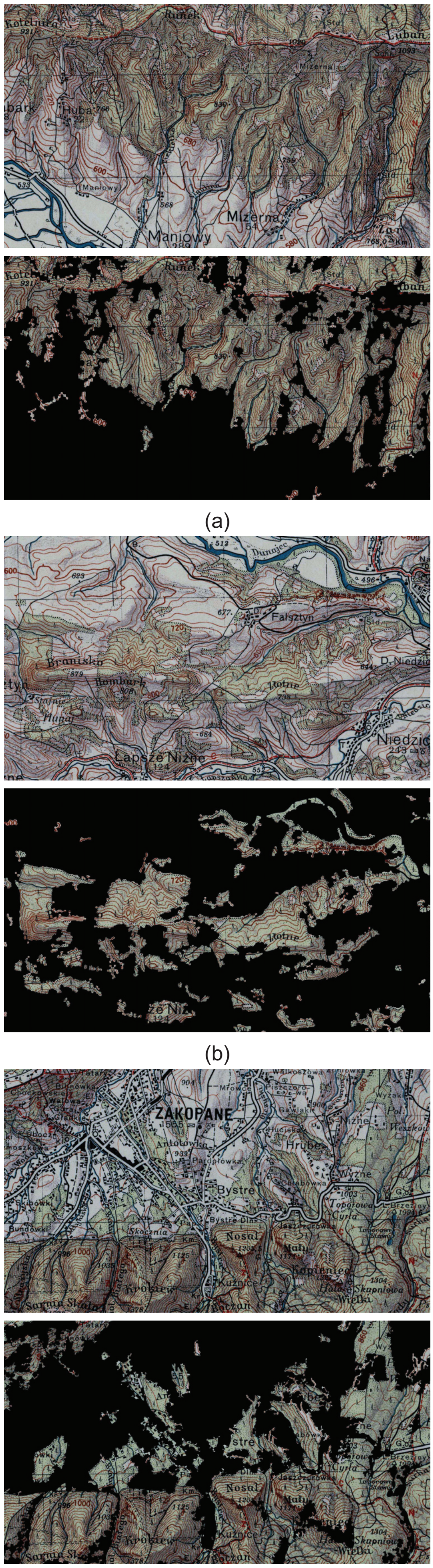

(a)

(b)

(c)

Fig. 6. Final results on three example fragments of maps – subsets of P51 S30 sheet.