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USE OF GABOR FILTERS FOR TEXTURE CLASSIFICATION OF AIRBORNE IMAGES AND LIDAR DATA

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ABSTRACT: In this paper, a texture approach is presented for building and vegetation extraction from LIDAR and aerial images. The texture is very important attribute in many image analysis or computer vision applications. The procedures developed for texture problem can be subdivided into four categories: structural approach, statistical approach, model based approach and filter based approach.

In this paper, different definitions of texture are described, but complete emphasis is given on filter based methods. Examples of filtering methods are Fourier transform, Gabor and wavelet transforms. Here, Gabor filter is studied and its implementation for texture analysis is explored. This approach is inspired by a multi-channel filtering theory for processing visual information in the human visual system. This theory holds that visual system decomposes the image into a number of filtered images of a specified frequency, amplitude and orientation.

The main objective of the article is to use Gabor filters for automatic urban object and tree detection. The first step is a definition of Gabor filter parameters: frequency, standard deviation and orientation. By varying these parameters, a filter bank is obtained that covers the frequency domain almost completely. These filters are used to aerial images and LIDAR data. The filtered images that possess a significant information about analyzed objects are selected, and the rest are discarded.

Then, an energy measure is defined on the filtered images in order to compute different texture features. The Gabor features are used to image segmentation using thresholding.

The tests were performed using set of images containing very different landscapes: urban area and vegetation of varying configurations, sizes and shapes of objects.

The performed studies revealed that textural algorithms have the ability to detect buildings and trees. This article is the attempt to use texture methods also to LIDAR data, resampling into regular grid cells. The obtained preliminary results are interesting.

1. INTRODUCTION

The texture is very important attribute in many image analysis or computer vision applications. Texture features play a very important role in pattern recognition. Texture applications include industrial inspection, ultrasonic imaging, computer vision, estimation of object range and orientation, shape analysis, satellite imaging, and medical diagnosis. Texture can be seen in many images from multispectral remote sensed data to microscopic photography. The variety of natural and artificial textures makes it impossible to give a universal definition of texture. Each texture analysis method characterizes image texture in terms of the features it extracts from the image. Quantitative approach is technical way of analysis texture. The procedures developed for texture problem can be subdivided into four categories: structural approach, statistical approach, model based approach and filter based approach.

In this paper, different definitions of texture are described, but complete emphasis is given on filter based methods. Examples of filtering methods are Fourier transform, Gabor and wavelet transforms. Here, Gabor filter is studied and its implementation for texture analysis is explored. This approach is inspired by a multi-channel filtering theory for processing visual information in the human visual system. This theory holds that visual system decomposes the image into a number of filtered images of a specified frequency, amplitude and orientation. Gabor filters have been used widely in image analysis due to their nature of spatial locality, orientation selectivity and frequency characteristic. A two-dimensional Gabor function consists of a sinusoidal plane wave of some frequency and orientation, modulated by a two-dimensional translated Gaussian envelope.

The main objective of the article is to use Gabor filters for automatic urban object and tree detection. The Gabor filters are used to aerial images and airborne laser scanner data. In order to use filters to LIDAR data, original data were resampled into a regular grid. To reduce falsification errors the Nearest Neighbour interpolation algorithm was applied to the original data.

The tests were performed using set of images containing different landscapes: urban area and vegetation of varying configurations, sizes and shapes of objects.

The performed studies revealed that textural algorithms have the ability to detect buildings and trees. This article is the attempt to use texture methods also to LIDAR data, resampling into regular grid cells.

2. MATERIALS AND METHODS

2.1 Method overview

The Gabor filters have been designed in MATLAB software. The first step is a definition of Gabor filter parameters: frequency, standard deviation and orientation. The choice of these parameters is crucial for the further studies. By varying these parameters, a filter bank is obtained that covers the frequency domain almost completely. These filters are used to aerial images and LIDAR data.

The next step is to select a group of significant filtered images. The filtered images that possess a significant information about analyzed objects are selected, and the rest are discarded.

Then, an energy measure is defined on the filtered images in order to compute different texture features. The measure calculates a sum of texture energies over a small window around each transformed pixel in the select filtered images. Using the energy measure as features, a vector of Gabor features is defined for each pixel in the original image. The Gabor features are used to image segmentation using thresholding.

2.2 Data description

The aerial images and LIDAR data were acquired in 2005. The aerial images were acquired with a digital camera Rolleiflex with CCD: 4080x4076. The resolution (ground sample distance) of these images was about 0.06 m. The average density of laser data is

20 points/m^2. From the raw laser data, both a DTM and DSM are generated. The nDSM is obtained by calculating difference between DSM and DTM. In order to use filters to LIDAR data, original data were resampled into a regular grid. To reduce falsification errors the Nearest Neighbour interpolation algorithm was applied to the original data.

3. FUNDAMENTALS OF TEXTURE

The texture is very important attribute in many image analysis or computer vision applications. The variety of natural and artificial textures makes it impossible to give a universal definition of texture. Quantitative approach is technical way of analysis texture. The procedures developed for texture problem can be subdivided into four categories: structural approach, statistical approach, model based approach and filter based approach.

Structural approaches assume that textures contain detectable primitives elements, which appear in quasi-periodic spatial arrangements. A primitive may be defined as a connected set of resolution cells characterized by a list of attributes (Haralick, 1982). The simplest primitive is the pixel, other primitive attributes include shape and uniformity of pixel intensity. This method is elementary and is mostly useful for moderate and highly periodic texture.

Statistical approaches use statistical characteristic derivable directly from the images such as mean, variance, entropy or other values obtained from the local pixel neighbourhood, as e.g. co–occurrences (Haralick, 1979). It is a second order of texture i.e. it does not operate on pixels directly but on a matrix derived from the window pixels.

Model based texture analysis methods are based on the construction of an image model that can be used not only to describe texture, but also to synthesize it (Chen et al., 1998). This approach tries to capture dependencies among neighbouring pixel values by assigning an analytical function to the textured images. For example: AR model, Gaussian Markow model, Gibbs model etc.

Filter based methods assume that the image function can be described in a frequency domain. Psychophysical research has given evidence that the human brain decomposes the image into a number of filtered images of a specified frequency, amplitude and orientation Texture is especially suited for this type of analysis because of its properties. Examples of filtering methods are Fourier, Gabor and wavelets transforms. The Fourier transform is an analysis of the global frequency content in the image. Many applications require the analysis to be localized in the spatial domain. This is usually handled by introducing spatial dependency into the Fourier analysis (Chen et al., 1998), the example of such an approach is Gabor transform.

4. TEXTURE ANALYSIS USING GABOR FILTER

4.1 The Gabor filter

This approach is inspired by a multi-channel filtering theory for processing visual information in the human visual system.

The Gabor filters were originally introduced by Dennis Gabor (Gabor, 1946). They have been used widely in image analysis due to their nature of spatial locality, orientation selectivity and frequency characteristic. A two-dimensional Gabor function *g(x,y)* consists of a sinusoidal plane wave of some frequency and orientation (carrier), modulated by a two-dimensional translated Gaussian envelope (Movellan, 2005).

$$g(x, y) = s(x, y) * w(x, y) \tag{1}$$

The carrier is a complex sinusoid:

$$s(x, y) = \cos(2\pi \cdot (u_0 \cdot x + v_0 \cdot y) + \varphi) + i \cdot \sin(2\pi \cdot (u_0 \cdot x + v_0 \cdot y) + \varphi) \tag{2}$$

where (u_0, v_0) – the spatial frequency of the complex sinusoid,
φ – the phase of the complex sinusoid,

The envelope is a Gaussian function:

$$w(x, y) = K \cdot \exp \cdot \left\{ -\pi \left(\frac{(x - x_0)_r^2}{\sigma_x^2} + \frac{(y - y_0)_r^2}{\sigma_y^2} \right) \right\} \tag{3}$$

where K – scales the magnitude of the Gaussian envelope,
σ_x, σ_y – scaling parameters of the two axis of the Gaussian envelope,
(x_0, y_0) – the peak of the Gaussian function,
θ – rotation angle of the Gaussian envelope (x_0, y_0)
$(x-x_0)_r = (x-x_0)\cos\theta + (y-y_0)\sin\theta$
$(y-y_0)_r = (x-x_0)\sin\theta + (y-y_0)\cos\theta$

The centre frequency of the Gabor function is defined by (u_0, v_0). The radial centre frequency is defined as $f_0 = \sqrt{u_0^2 + v_0^2}$ and the orientation as $\theta = \tan^{-1}(\frac{v_0}{u_0})$.

The 2D Fourier transform of *g(x,y)* is given by:

$$G(u, v) = \frac{K}{\sigma_x \sigma_y} \exp(j(-2\pi(x_0(u - u_0) + y_0(v - v_0)) + \varphi)) \\ \exp\left(-\pi \left(\frac{(u - u_0)_r^2}{\sigma_x^2} + \frac{(v - v_0)_r^2}{\sigma_y^2} \right) \right) \tag{4}$$

The Gabor function is most interesting when studied in the frequency domain. It is then a Gaussian function shifted in frequency to position (u_0, v_0) i.e. at a distance f_0 from the origin in the orientation θ (Bovik et al., 1990). Figure 1 shows an example of a Gabor filter.

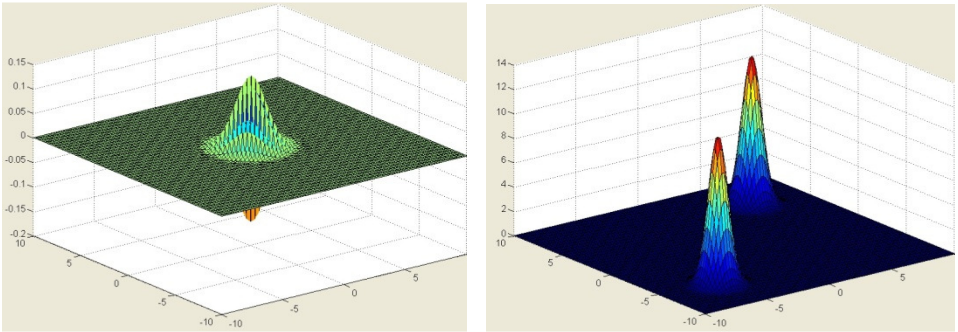

Fig. 1. Gabor filter in time and frequency domain (f_0=75, θ = 45°).

4.2 Filter selection

According to assumption each texture contains most of its energy in a narrow band of frequency and orientation. A Gabor filter encodes the textured images into multiple narrow frequency and orientation channels (Petkov, 1995). This filter acts as local bandpass filters. Each filter is fully determined by choosing the four parameters: θ, f, σ_x, σ_y (Jain et al., 1997).
The frequency (octave) and the orientation (radian) bandwidths of the Gabor filter is given by:

$$B = \log_2\left[\left(\frac{\pi f \sigma_x + \sqrt{\ln 2/2}}{\pi f \sigma_x - \sqrt{\ln 2/2}}\right)\right] \tag{5}$$

$$\Omega = \tan^{-1}\left[\frac{\sqrt{\ln 2/2}}{\pi f \sigma_y}\right] \tag{6}$$

The first step is a definition of Gabor filter parameters: frequency f, standard deviation: σ_x, σ_y and orientation θ. The choice of these parameters is crucial for the further studies. By varying these parameters, a filter bank is obtained that covers the frequency domain almost completely. Choice of the appropriate filter bank is a complex problem, which was analyzed in many publications (Recio Recio et al., 2005).

4.3 Feature extraction

The Gabor transform of an image *R(x,y)* is defined as the convolution of a Gabor filter *g(x,y)* with image *I(x,y)* (Lu et al., 1991):

$$R(x,y) = g(x,y) * I(x,y) = \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} g(m,n)\cdot I(x-m, y-n) \tag{7}$$

where * denotes two-dimensional linear convolution and *M* and *N* are the size of the Gabor filter mask.

The local energy of the filtered image *E(x,y)* is obtained by computing the absolute average deviation of the transformed values of the filtered images from the mean μ within a window *W* of size *MxMy* (Jain and Farrokhnia, 1991). The filtered images have zero mean, therefore, the texture energy *E(x,y)* is given by the equation:

$$E(x,y) = \frac{1}{M}\sum_{(a,b)\in W}\left|R(a,b) - \mu\right| \tag{8}$$

4.4 Thresholding

The simplest idea to obtain segmentation objects is to apply a threshold to the Gabor filter results (Andrysiak and Choraś, 2005), (Kruizinga et al., 1999). During the thresholding process, individual pixels in an image are marked as "object" pixels if their value is greater than some threshold value and as "background" pixels otherwise. This convention is known as threshold above (Shapiro and Stockman, 2001). The key parameter in the thresholding process is the choice of the threshold value. In this study the threshold values were chosen manually. It would be a significant improvement to compile an algorithm computing these values automatically.

5. OBJECT DETECTION USING IMAGES

The detection of objects is a well-studied but yet unresolved problem. A number of different techniques for solving this problem have been proposed. This paper is an attempt to use textural analysis for recognition of vegetation and buildings.

5.1 Scheme of the algorithm

Aerial imagery and LIDAR data are data sources used in the proposed method.
In this study the texture features were obtained as follows:

1. Use a bank of Gabor filters at multiple scales and orientations to obtain filtered images *R(x,y).*
2. The texture feature (energy) for each pixel is computed according to the equation 8.
3. Texture features were used in texture segmentation using thresholding described in chapter 4.4.

5.2 Examples of using of Gabor filters

The tests were performed using set of images containing very different landscapes: urban area and vegetation of varying configurations, sizes and shapes of objects.
The Gabor filters have been designed in MATLAB software.

Example 1
Site 1 is a dense forest with deciduous trees. Three different spatial frequency and four different orientation were used, resulting in a bank of 12 Gabor filters. Then, an energy measure is defined on the filtered images (Figure 2b). In order to enhance information an opening operator was used to the energy images (Figure 2c). Then, the segmentation was

applied to images using thresholding (Figure 2d). Results of the different stages are shown in Figure 2.

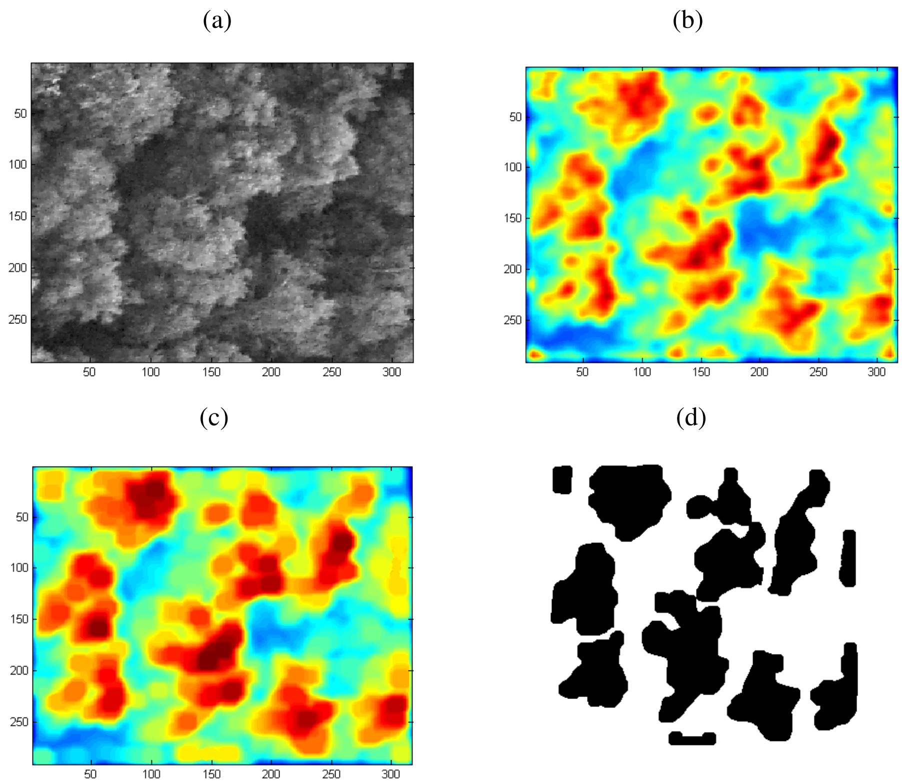

Fig. 2. A dense forest (a) , selected filtered image (f=5 cycles/images, θ = 0°) (b), the opening operator (c), result of segmentation (d).

The obtained results are fully satisfactory. The proposed algorithm has detected all the trees of the analyzed area. Also the size of the trees was determined correctly.

Example 2

Site 2 is a sparse forest. Stages of the analysis proceeded similarly as in the previous example.

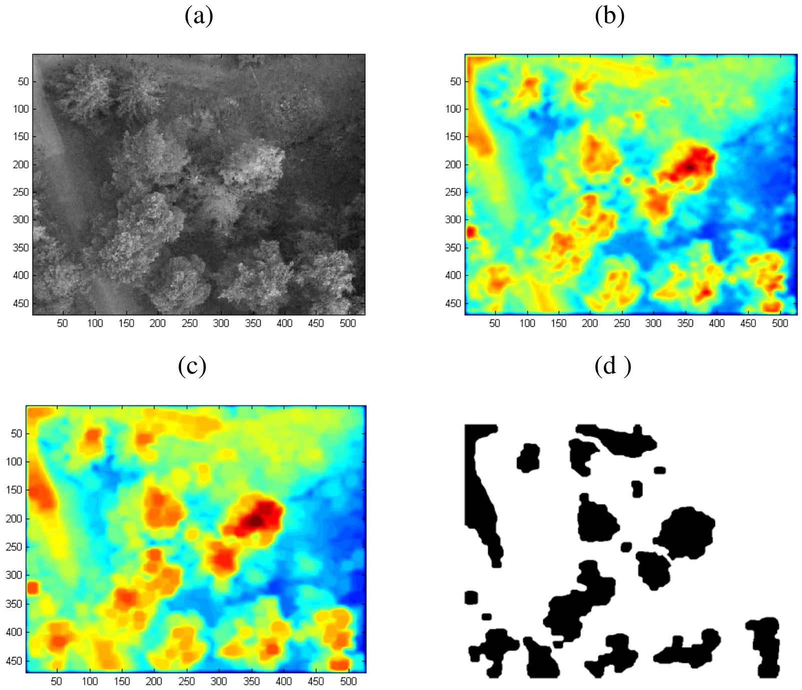

Fig. 3. A sparse forest (a), selected filtered image (f=5 cycles/images, θ= 0°) (b), the opening operator (c), result of segmentation (d).

The obtained results are partly correct. All the trees of the analyzed area were detected but their size has been underestimated. Some errors occurred on the fragment of the road, which was wrongly classified in the trees.

Example 3

Site 3 is an urban area. In the case of building, a Gabor filter was used as an edge filter. Depending on the parameter of orientation θ, the edges of different orientations are detected. For example, vertical edges receive strongest response in a vertical filtering output and weakest responses in a horizontal filtering output (Figure 4c). In Figure 4 selected results of filtering, by varying parameter θ, are shown. The long linear edges may contain elements of building. On the other hand, short and nonlinear edges may represent a noise. For most noise edges, filtering in different directions gives similar results (Xu et al., 2003). The resulting filter bank has allowed to generate a fusion image with defined edges of buildings (Figure 4d).

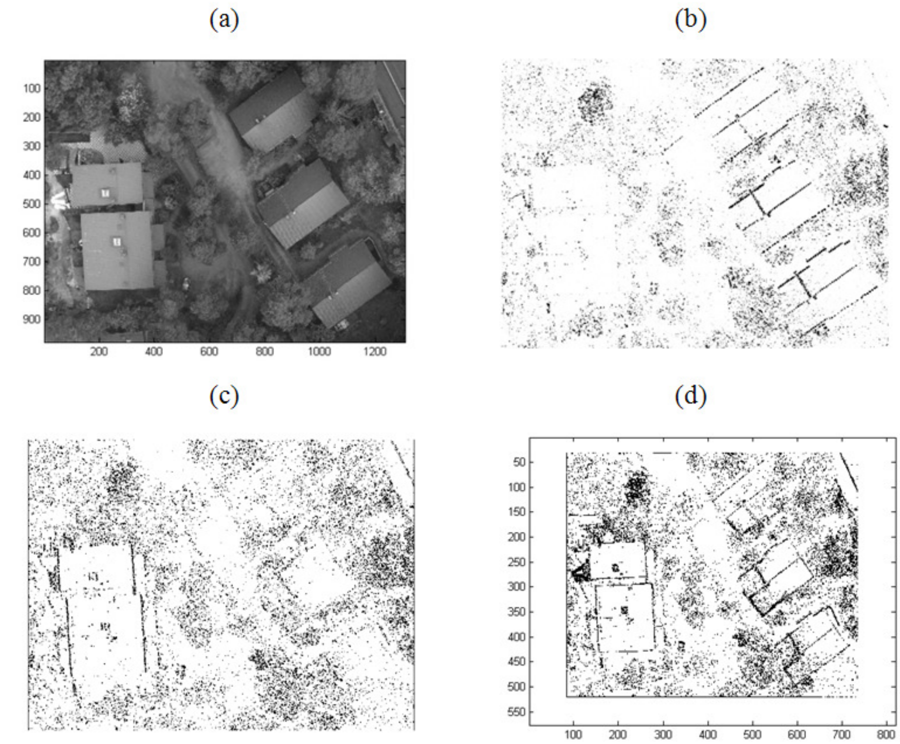

Fig. 4. An urban area (a) , selected filtered image (f=75 cycles/images, θ = - 35°) (b), selected filtered image (f=75 cycles/images, θ = 0°) (c), result of fusion (d).

6. OBJECT DETECTION USING LASER DATA

There have already been some attempts to use Gabor filters to airborne laser data. In (Wei and Bartels, 2006) an algorithm, based on the Gabor filter, has been developed to segment ground (e.g. building and high vegetation) and non-ground in LIDAR data.

In this study Gabor filters are used to recognition vegetation and buildings from LIDAR data. Test sites used at this stage were the same as in the case of aerial images. All the analysis were carried out on the nDSM, calculated as the difference between DSM and DTM. In order to use Gabor filters to LIDAR data, original data were resampled into a regular grid. To reduce falsification errors the Nearest Neighbour interpolation algorithm was applied to the original data.

Example 1

Site 1 is a dense forest with deciduous trees.

It was impossible to separate trees in a dense forest using LIDAR data. Dense deciduous trees blocked off the laser pulses reflected from the topographic surface. Only single pulses reach the ground surface, but it was not enough for the textural analysis.

Example 2

Site 2 is a sparse forest.
The Gabor filter bank consisted of 12 filters: three spatial frequency and four orientation. Then, an energy measure is defined on the filtered images. In the last stage the segmentation was applied to images using thresholding. The final results are shown in Figure 5.

(a) **(b)**

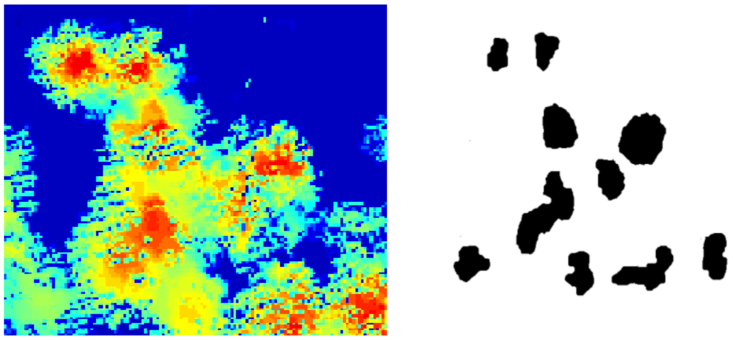

Fig. 5. The nDSM for a sparse forest (a), result of segmentation (b).

For this area, the process of tree detection proceeded correctly. All trees were identified, but their size, by analogy to aerial images, has been underestimated. The advantage of using laser data is to eliminate wrongly classified part of the road. In this case, the road had a significantly lower textural energy than the trees and in the process of tree segmentation it was correctly removed.

Example 3

Site 3 is an urban area. The test procedure proceeded analogously to Example 2.

(a) **(b)**

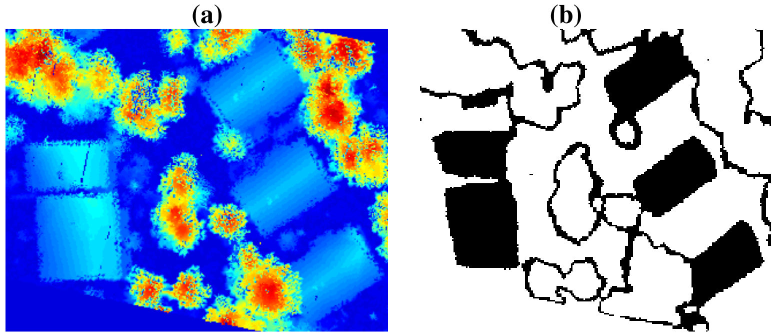

Fig. 6. The nDSM for an urban area (a), result of segmentation (b).

The obtained results are satisfactory. All buildings were detected correctly, but their edges are not completely proper. It is a known problem of laser data that an identification of the edges is not explicit, due to the laser pulse discontinuousness.

7. CONCLUSIONS

In this paper problem of detection objects was studied on several aerial images and LIDAR data. The proposed approach is based on texture analysis. A Gabor filter encodes the textured images into multiple narrow frequency and orientation channels.
The obtained preliminary results are interesting. Texture analysis can be used in the process of object detection.
In the case of aerial images, the trees have been detected correctly, but their size has been underestimated. Building elements have been detected using Gabor filter, as the edge filter. It would be interesting to compare this method with other known methods of edge extraction.
In the case of LIDAR data, it was impossible to detect the trees in a dense forest. Only single pulses reach the ground surface, but it was not enough for the textural analysis. The building detection was quite good, but determination of edges is not always clear.
The performed studies once again revealed that the integration of photogrammetric and laser data will be the basis to solve many of research problems. These data are complementary and cumulative use of this information and can improve the obtained results of object detection.

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