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RESEARCH ARTICLE

Comparison of standard image edge detection techniques and of method based on wavelet transform

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Abstract

Image edge detection is in the forefront of image processing. There are lots of various edge detection methods. However the choice of a certain image edge detection technique still remains topical and this issue is constantly in focus for the researchers. This owes to both the specifics of implementing certain image edge detection technique and to the specifics of obtaining and presenting images for further processing. Based on this, in this paper, the comparison of standard image edge detection techniques (Canny, Prewitt, Robert, Sobel) and methods based on wavelet transform are studied. Quantitative measures for evaluating edge detection quality and simple visual comparison of the obtained edge maps of the original image are used for comparison. The advantages and disadvantages of these edge detection techniques have been shown.

Introduction

Visual objects are one of the most important sources for receiving information about the outworld. Therefore, behind the creation of artificial intelligence systems there are also subsystems that are capable of processing and analyzing images, with special attention paid to imagery interpretation obtained while processing source images. An example of such symbolic thinking is the implementation of spatial intelligence on basis of 3-D models and 2-D images analysis (Brooks, 1981). At the same time, there is an overview in Binford's work (1982) of already classic image analysis models that can be used in artificial intelligence systems. Direct application on image processing and analysis as part of artificial intelligence system is considered in Vyborny et al. (1994) as methods of digital image analysis in mammography. Application of artificial intelligence methods based on image analysis are also defined in the following papers:

Cucchiara et al. (2000), which analyzes the efficiency of traffic monitoring system for public transportation based on the analysis of urban scenes using image analysis methods and sets of rule-based reasoning for urban traffic monitoring;

Moeslund et al. (2001), the results of this work are useful for creating intelligence systems analyzing human motion;

Aitkenhead et al. (2003), which examines the development of visual method for weed and crop discrimination in automated control system for weed chemical treatment;

Ramos et al. (2008), which deals with the issues of computer vision while creating ambient intelligence as the next step in the development of artificial intelligence.

Thereby, processing and analysis of the obtained images can be based on various methods: from image preprocessing methods (Yang et al., 1996; Van De Ville et al., 2003; Ji et al., 2008), that allow enhancing perceptivity of the received information to the methods of segmentation and recognition of image patterns (Felzenszwalb et al., 2004; Grady, 2006; Shotton et al., 2013).

At the same time, a special place among various image processing and analysis methods take techniques for image edge detection.

Edge detection task is in defining and tracing image boundaries and selecting uniform (homogeneous) regions. Image contour is a line which is the transition boundary from the object to the background with its width of at least one pixel. If the image is noisy, then it is possible that after processing false edges may appear, that are not boundaries of the objects.

Such attention to the image edge detection techniques is due to that fact that on the one hand, image edge detection is fundamental for further image analysis. For example, for analysis based on obtaining and comparing geometric characteristics of separate image objects, which is an important research line when using topological methods of image analysis (Peters et al., 2014). For generating tracking algorithms (Sobottka et al., 1998), recognition (He et al., 2008), image compression and their transmission Xiao et al., 2001);

On the other hand, edge detection and further work with this contour reduces the amount of time for further image analysis, as well as the amount of memory required for storing and transmitting images.

However, at the same time, when considering the necessity of image edge detection, one faces the selection problem of such techniques, based on the qualitative characteristics of the applied edge detection techniques as well as on their computational complexity. In this case, based on the diversity of the relevant studies, this choice is not only important, but also uncertain.

In particular Zhang (2001) work provides an overview of various evaluation methods to compare image edge detection methods taking into account image generation in various conditions.

However, Maini et al. (2009) analyzes the use of classic approaches to edge detection under the condition of various artifacts.

Thus Senthilkumaran et al. (2009) and Shrivakshan et al. (2012) not only compare classical edge detection techniques, but also give such a comparison in the context of soft computing approaches application for such a procedure.

Hence, the available variety of comparison analysis of different image edge detection techniques suggests the practicability of the subsequent comparison in the context of various methods used for these purposes. This is due o the fact than the comparison of image edge detection techniques will result in the selection of the best one both according to different aspects of this comparison and to conditions for generating images studied. It is for these reasons that the subject for this research has been selected, which ultimately determines the purpose of such research.

Material and Methods

Classic image edge detection methods

To conduct the selected direction of the research for this work it is necessary to concentrate on the edge detection techniques being compared and on characteristics of such comparison.

Talking about the selection of the compared edge detection techniques, one should first of all focus on the classic approaches which include image edge detection using the Roberts, Sobel, Prewitt, and Canny operators. These techniques are simple to implement and provide generally good results for edge detection. Moreover, these techniques are quite often used for analysis by different researchers (Juneja et al., 2009; Maini et al., 2009; Senthilkumaran et al., 2009; Shrivakshan et al., 2012).

At the Roberts, Sobel, Prewitt, and Canny methods' core is the application of masks of a certain type to the incoming studied image, where new values of separate image points are determined by its convolution between the values of separate points of the incoming image with the masks under review. The difference between such operators is in the size of the masks used for edge detection, parameters of these masks, as well as in the methodology applied for mask and original image convolution. The classical description if such masks and methods can be found in the works of Juneja et al. (2009), Maini et al. (2009), Senthilkumaran et al. (2009), and Shrivakshan et al. (2012). Therefore, we would omit their detailed description in this paper. It should only be noted, that among disadvantages of edge detection techniques listed above are the following: dependence of edge detection quality on the changes of image brightness value and on differences between the potential zones of edge detection, which, in general, is associated with the lack of the ability to automatically select a threshold for conducting the appropriate convolutions. In some way, this problem can be solved by using continuous wavelet transform (Heil et al., 1989).

Edge detection based on wavelet transforms

Wavelet transform is a division of a signal by wavelets system. Wavelets result from the oscillation and scaling of one function – generating wavelet (Kingsbury, 1999). In such case, wavelet is a function rapidly decreasing at infinity with its average value equal to zero. For example, unlike Fourier analysis, each scale value of wavelet analysis corresponds to the infinite number of shifted relative to one another spatially localized functions. If there is a wave discontinuity, then only those wavelets will have high amplitudes, whose maximum will be located near the point of discontinuity. A discontinuity is a sharp intermittent transition during any process. Quantity-related, it can be estimated by the value of the first derivative of such process. The first derivative is very large in the areas with rapid change. If the step function is n the form of discontinuity, then the first derivative tends to infinity. However, actual processes measured by real devices cannot have perfect discontinuities. In fact, measured fractal transitions are characterized by the final value of the derivative. The sharper the discontinuity, the greater the value of the derivative is. Smooth transitions will have small derivative values. This makes it possible to determine the availability of signal indications, as well as its position point.

The basis of formal characterization of the continuous wavelet transform (IWT) is in the use of two functions – continuous and integrated along the whole t axis (Heil et al., 1989; Kingsbury, 1999):

– wavelet – $\phi(t)$ functions with zero integral value

$$\int_{-\infty}^{\infty}\phi(t)dt = 0 \text{ , (1)}$$

that determines signal details and generates the detail coefficients;

– scaling functions $\varphi(t)$ with a single integral value

$$\int_{-\infty}^{\infty}\varphi(t)dt = 1 \text{, (2)}$$

that determines rough approximation of signal and generates approximation coefficients.

However, the CWT function can be applied only to one-dimensional signal, and image is a two-dimensional signal. Therefore, in order to be able to apply CWT for image edge detection it is suggested to consider the following analysis edge detection procedure:

– let's perform the calculation for horizontal discontinuities of the original image F, presented in the form of matrix set by its readings $f_{ij} \in \{0,1,\ldots,P\}, i = 1,2,\ldots,N, j = 1,2,\ldots,M$ on a square heads $N \times M$. For these purposes, let's use the following expression to obtain the so-called wavelet-spectrogram matrix W (based on the sequential processing of each line of the original image F):

$$W[f_{ij}] = \frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty} f_{ij}\phi(\frac{t-b}{a})dt \text{ , (3)}$$

where $\phi(\frac{t-b}{a})$ – is a mother wavelet satisfying condition (1); a, b – scale and center of time localization, that determine the scale and $\phi(t)$ function offset in accordance with the scaling conditions (2); $\lfloor f_{ij} \rfloor$ – denotes the number of the processed line of the original image F to obtain the range of values of its wavelet-spectrogram W. The parameters a, b are chosen in such a way, so that the corresponding matrix dimensions of wavelet-spectrogram W correlate with the linear dimensions of the original image F.

Then based on the analysis of the received spectrogram (W for each line of the original image F), we select its certain line NN based on the condition:

$$NN = \max(\frac{1}{N}\sum_{i=1}^{N} w_{ij}) \text{ , (4)}$$

where w_{ij} – wavelet spectrogram element of the analyzed line of the original image F.

Such choice is determined by the fact that we select the spectrum part of the original image row, which corresponds to the largest discontinuity of the original signal between its readings (see the remarks above).

The row selected in such a way will correspond to the line in matrix F_g, that characterizes the matrix of horizontal discontinuities of the original image F.

The processing of all lines of the original image F allows, as a result, obtaining a matrix of horizontal discontinuities F_g due to the following sequence of transformations:

$$F \xrightarrow{\text{rows CWT}} W \xrightarrow{\text{row selection}} F_g .$$

– likewise, the computation of vertical discontinuities of the original image F is conducted for each column. Equation (3) is used for this, as well as equation analogue to equation (4) to select certain column from the obtained wavelet-spectrograms for each column of the original image F.

$$MM = \max\left(\frac{1}{M}\sum_{i=1}^{M} w_{ij}\right) . \quad (5)$$

Processing of all columns of the original image F allows, as a result, obtaining the matrix of vertical discontinuities F_v, due to the following sequence of transformations:

$$F \xrightarrow{\text{column CWT}} W \xrightarrow{\text{column selection}} F_v .$$

– addition of matrices of both vertical and horizontal discontinuities into one matrix is conducted, which displays the edge of the original image based on CWT method. For visual expression, matrices of vertical and horizontal discontinuities, as well as generalized matrix depicting the edge of the original image, can be inverted.

Comparison measures for image edge detection techniques

To compare the image edge detection techniques under study, a variety of approaches can be used.

One of the most common approaches to estimating the quality of the detected edge is based on a simple visualization. As a result, the quality of different edge detection techniques is being compared visually. Edge completeness is also compared. However, this method does not allow automating the selection of the most accurate procedure. In particular, this approaches is studied in the work of Juneja et al. (2009). At the same time, Juneja et al. (2009) also study the statistical characteristics of how the selected edges match using various techniques. This allows comparing the quality of the detected edges between different techniques used for these purposes. However, in this case we deal with the issue of the selection of reference standard for comparison, which is eventually selected on the basis of the initial simple visual comparison of the obtained edges.

Comparing various image edge detection techniques Prieto et al. (2003) talk about the necessity to consider several comparison measured, which then can be combined as some integral estimation. But as it has been stressed by Román-Roldán et al. (2001), the use of a single method to compare the quality of various image edge detection techniques is difficult. This is due to the difference in the complexity of the images, how they were produced, their preprocessing, which points to the necessity to correctly apply any quality measures to compare the considered image edge detection techniques.

Nevertheless, the most frequently used quality comparison of edge detection techniques can be the following (Gonzales et al., 2002):

error of the first kind (O1), which is characterized by the ratio of incorrectly allocated contour points to the total number of points that don’t belong to the contour (edge). Talking about the quality of edge detection, it should be noted that the value of such measures should tend to zero,

error of the second kind (O2), which is characterized by the ratio of the unselected contour point to the total number of contour points. This measure should also tend to zero,

the ratio of correctly selected the contour points to the total number of contour points (K1). This measure should tend to 1,

the ration of the selected non-edge points to the total number of non-edge points (K2). This measure can also tend to 1, but it should be less than the K1 measure value. Thus various correlations of K1 and K2 measure values indicate the complexity of the image.

An important factor in comparing different image edge detection techniques is their computational complexity.

Result and Discussion

For the comparative analysis of classical image edge detection techniques with the one based on wavelet transforms, let's take a half-tone image shown on fig. 1. The image on fig. 1 is a real photograph without any preprocessing on the computer. First of all, the object we need to generate edge for is a bus. Though, we don't have the ability to previously select the image of the bus from the total image view.

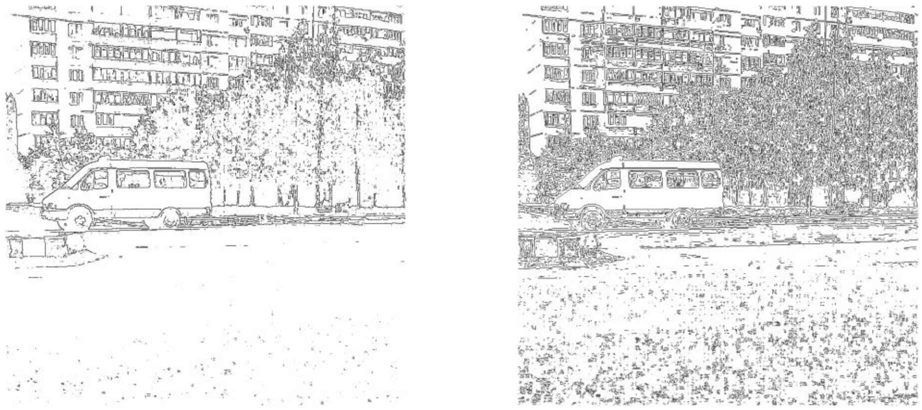
At the same time, we are going to view all other details as separate objects in the picture, including the house and trees.

So, we will comparing the quality of these techniques for image edge detection taking into account all the details, the displayed image, and only with possibility of edge detection for the bus.

Fig. 1 Original half-tone image

The results of edge detection using the described above classical edge detection techniques are shown in fig. 2. Edge detection has been realized using mathematical package MatLab with function edge(). As it can be seen on fig. 2, the obtained results, based on the complexity of the original image, include all the elements and object details. This is due to the fact that brightness of the objects in the picture plays a significant role in detecting edges.

a) b)



c) d)

Fig. 2 Results of classical image edge detection techniques
a) – Canny; b) – Prewitt; c) – Roberts; d) – Sobel

Fig. 3 displays the results for CWT edge detection technique.

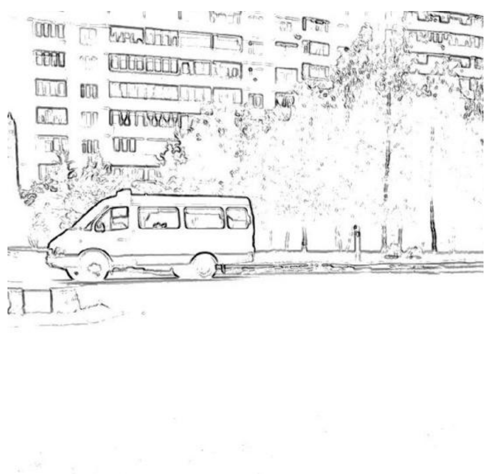


Fig. 3 Results for CWT edge detection technique

Simple visual comparison of the results for image edge detection using classical and CWT techniques shows that image contour can be more sharply defined using CWT technique under conditions that a significant part of image is a background.

In case we need to detect edges of all image details, from the visual point of view, good results are first of all provided when using Canny and CWT techniques. Following are approximately the same results suing Prewitt and Roberts techniques.

In case of detecting the edge of a bus (from the visual point of view) the results obtained can be distributed in the following way: CWT, Roberts method, Canny, Prewitt, and Sobel techniques.

Quantitative estimates (based on the above described errors of the first and of the second kind – O1 and O2, as well as on the ratios of various correctly detected points – K1 and K2) of the quality for edge detection using different techniques are provided in table 1 and table 2. Table 1 provides the quantitative evaluation with consideration of all the details of the original image. Table 2 provides the quantitative evaluation with consideration of the bus edge quality.

Table 1: Analysis of image edge detection quality based on Fig. 1 with all the details of the original image

Edge detection technique	Quality evaluation for edge detection			
	O1	O2	K1	K2
Canny	0,0619	0,0197	0,8743	0,5710
Prewitt	0,0564	0,0271	0,7238	0,6053
Roberts	0,0501	0,0214	0,7610	0,5831
Sobel	0,3418	0,0342	0,8109	0,9021
CWT	0,0062	0,0103	0,9234	0,2687

Table 2: Analysis of image edge detection quality based on Fig. 1 considering the quality of edge detection for the bus

Edge detection technique	Quality evaluation for edge detection			
	O1	O2	K1	K2
Canny	0,0134	0,0401	0,8901	0,7720
Prewitt	0,0207	0,0452	0,8971	0,7219
Roberts	0,0097	0,0392	0,9127	0,6931
Sobel	0,1092	0,0277	0,8701	0,8213
CWT	0,0013	0,0319	0,9671	0,2390

The results shown in tables 1 and 2 are generally comparable with the results of visual analysis for the edges obtained for the original image using various techniques. Specific distinction between quantitative estimate for the quality of image detected edges presented in table 1 and 2 are small values for quality measure K2 for CWT edge detection technique in comparison with K2 values for other edge detection techniques. This means that CWT edge detection technique can work as a filter that suppresses minor local noise and homogeneous areas which are not object for detecting contour points.

Talking about computational complexity of the techniques described above for image edge detection, which is first of all connected with time-response characteristics of their implementation, it should be noted that:

- classical image edge detection techniques provide computational simplicity in their implementation. The key point in the time for their implementation is the number of possible enumerations for calculating convolutions between the masks of specific edge detection operators and various image areas;
- CWT technique for edge detection doesn't require a large number of enumerations in order to generate image contour, as it allows working as a whole, both with columns and with rows of the original image matrix. However, the real computational complexity of the CWT technique that influences the time required for image edge detection is the wavelet transform technique itself – for each column and row of the original image. Therefore, in order to reduce time for implementation of the CWT method for image edge detection, it is necessary to study the issue of generating image contour using the levels of wavelet transform.

At the same time, it should be noted that as compared to the classical methods, CWT technique has the following advantages:

- the processing is conducted not on the image display area, but consequentially by columns (rows) of the image matrix, which allows to accurately identify gradients on each column (row), and therefore, increase the quality of edge detection;

- for processing columns (rows) of the image matrix to identify boundaries of object on the image high-sensitivity wavelet spectral analysis has been used. This can be considered as the main advantage of CWT technique, since only wavelets can allocate even small discontinuities on one-dimensional signals in the most accurate way, which are interpreted as object boundaries in this case.

Conclusions

Hence, this paper provides a study and comparative analysis of various approaches for edge detection. Among such techniques are classic edge detection techniques (Canny, Prewitt, Robert, and Sobel operators) and continuous wavelet transform technique. To compare the quality of image detected edge the following criteria were used:
simple visual analysis methodology,

quality measures that are based on the comparison of the selected image points with those image points that belong to the contour (edge) and doesn't belong to the contour (edge) of different image details,
computational complexity of the techniques.
It has been also noted that classical edge detection techniques are more effective from the computational effort point of view, than edge detection technique based on continuous wavelet transform. At the same time, the quality of edge detection using the continuous wavelet transform is not worse, and even better in comparison with the classical edge detection techniques that were considered in the paper.
To improve computational characteristics of the continuous wavelet transform for edge detection, it has been suggested to study this technique in terms of separate levels of wavelet transforms.

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