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REVIEW OF EDGE DETECTION METHODS IN IMAGES: BENEFITS, LIMITATIONS AND DEVELOPMENT PROSPECTS

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Abstract

This article outlines the procedures involved in an edge detection system in particular. The review details the fundamental concepts of edge detection, from the choice of the detection method to the differentiation and to the reason why a particular derivative is used. In edge detection many researchers hold on scientific work to enhance clearness and accurateness in order to be efficient foundation in face recognition, license plate detection and others. There are many existing edge detection methods like Canny, Sobel, Arbelaz and others are considered.

Keywords: Edge detection, Feature Similarity Index (FSIM), Neural networks and segmentation.

Introduction

Edge detection is an important and widely studied aspect of image processing. Edges represent pixel intensity transitions in an image and are key features for understanding the shape, structure, and contours of objects in an image. Accurate edge detection is of great importance in many areas, including computer vision, image processing, data visualization, video analysis, image quality assessment, and object detection.

In this paper, we will look at the various methods and operators of edge detection, their principles of operation, advantages and limitations. We will also look at the application of edge detection in various fields such as image processing, computer vision, and image quality assessment.

One of the most famous and widely used edge detection techniques is operator Canny, proposed in 1986 by John Canny[1]. The Canny operator provides accurate edge detection by combining several steps: image blur, intensity gradient computation, non-maximum suppression, and threshold filtering. This method has become widely used and has been used in many image processing and computer vision applications. Edge detection is a complex task with which certain problems

are associated. Some of these issues include noise, uneven lighting, blur and blurred images. All these factors can adversely affect the accuracy and reliability of edge detection.

Several new edge detection approaches have been proposed in recent years that seek to overcome these challenges and improve detection accuracy. Some of these approaches include the use of structured forests, anisotropic diffusion, multi-scale combinatorial grouping, and deep learning. It is also worth noting that edge detection is just one step in the process of analyzing and processing images. It can be integrated into more sophisticated algorithms and computer vision systems that include other operations such as segmentation, classification, tracking, and object detection.

The purpose of this work is to review existing edge detection approaches and methods, compare them, analyze and evaluate their effectiveness. We will also look at the prospects and directions for the development of this area and the possibilities for improving edge detection in future studies. In the following sections, we will provide an overview and analysis of the selected edge detection methods and operators, and consider their application in various applications. After that, we will discuss the results and conclusions, as well as opportunities for future research into edge detection in images.

I. Edge definition

Image edge detection is an important task in the field of computer vision and image processing. It allows you to select the contours of objects in the image and is an important step in tasks such as pattern recognition, image segmentation and object detection. In this section, we will review the various methods of edge detection and review some of the key works presented in the reference list.

One of the most widely used methods of edge detection is the Canny operator, proposed in 1986 by John Canny [1]. The Canny operator is based on the use of a pixel intensity gradient and is one of the most accurate methods for detecting the edges of objects in an image. It suppresses noise well and allows for clear and precise contours.

Another known method is the Sobel operator proposed by Irwin Sobel and Gary Feldman [2]. The Sobel operator uses a 3x3 gradient operator to detect boundaries in an image (Figure-1). It has ease of implementation and effectively highlights the edges of objects.

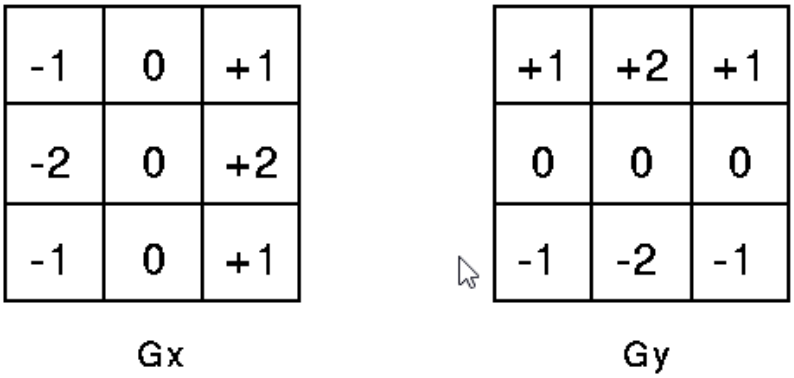

Figure-1. 3x3 Gradient operator to detect boundaries in the image.

Study presents a method of contour detection and hierarchical image segmentation [2]. This method combines different features and produces more accurate segmentation results. Work offers an edge detection method based on image scaling and diffusion. This method is resistant to noise and large-scale changes and provides accurate selection of object contours [4].

Dollar and Zitnik proposed a method for detecting edges based on structured forests. This method has high efficiency and accuracy and can be used in real time [5]. It finds its application in tasks such as object detection and image quality measurement.

The author's work presents a database of segmented natural images, which is important for evaluating segmentation algorithms and measuring environmental characteristics [6]. This allows researchers to develop and compare different methods of edge detection and object segmentation.

The method proposed by Hu L and other authors is based on minimizing the L0 gradient and is used for image smoothing [7]. This method eliminates noise and stores edge details in the image, which is important for accurate object detection and analysis.

Jane's work is a fundamental source of information on digital image processing, including edge detection techniques [8]. She offers basic principles and methods that are useful for understanding and implementing image processing algorithms, including edge detection techniques.

The work of the authors presents fast pyramids of features for object detection [11]. This method allows efficient detection of edges and contours of objects in an image and can be used in tasks such as detection of pedestrians or objects of interest.

The work of other authors proposes a method of multi-scale combinatorial grouping, which detects the edges and boundaries of objects in the image [12]. This method

allows you to effectively segment images and select different objects based on their contours.

Other works such as also contribute to the field of edge detection and propose different approaches and methods to improve the accuracy and effectiveness of this task [13-18].

II. Edge detection methods

Edge detection techniques are an important component of image processing and computer vision. They allow you to select the boundaries and contours of objects in the image, which is the basis for many tasks, such as pattern recognition, object segmentation and detection of objects of interest. In this article, we will review several image edge detection techniques presented in our reference list.

One of the most widely used methods is the Canny operator proposed in Canny's work [1]. It is based on edge isolation with a highly sensitive gradient filter and the subsequent application of threshold processing and suppression of non-maximums to produce clear and precise boundaries. This method has a good ability to suppress noise and accurately detect edges, and therefore it is widely used in various computer vision problems.

Another popular method is the Sobel operator proposed in Sobel and Feldman [2]. It is based on the approximation of the brightness gradient using small-sized filters. The Sobel operator allows the detection of horizontal and vertical boundaries in an image and can be easily implemented by convolution. This method provides fast processing and good sensitivity to boundaries.

Arbelaz presents a method for detecting contours and hierarchical segmentation of images [3]. It relies on constructing a contour map using non-maximum suppression and threshold processing, and then applies a hierarchical segmentation method to divide the image into semantically related regions. This method has the ability to highlight complex structures in an image and provides higher segmentation accuracy.

The work of Peron and Malik proposes a method for detecting edges using anisotropic diffusion [4]. This method is based on the idea of applying diffusion processes to eliminate noise and preserve contours. It offers a regularized diffusion algorithm that provides image smoothness along boundaries and noise suppression. The use of anisotropic diffusion makes it possible to obtain clearer and more contrasting boundaries of objects.

Another interesting method is proposed in Dollar and Zitnik and is called “structured forests for quick detection of edges” [5]. This method uses a combination of random

forest-based classifiers to efficiently detect edges (Figure-2). It applies a set of filters of different orientations and scales to produce an edge map, and then uses structured forests to refine and filter edges. This method shows high processing speed and good edge detection accuracy.

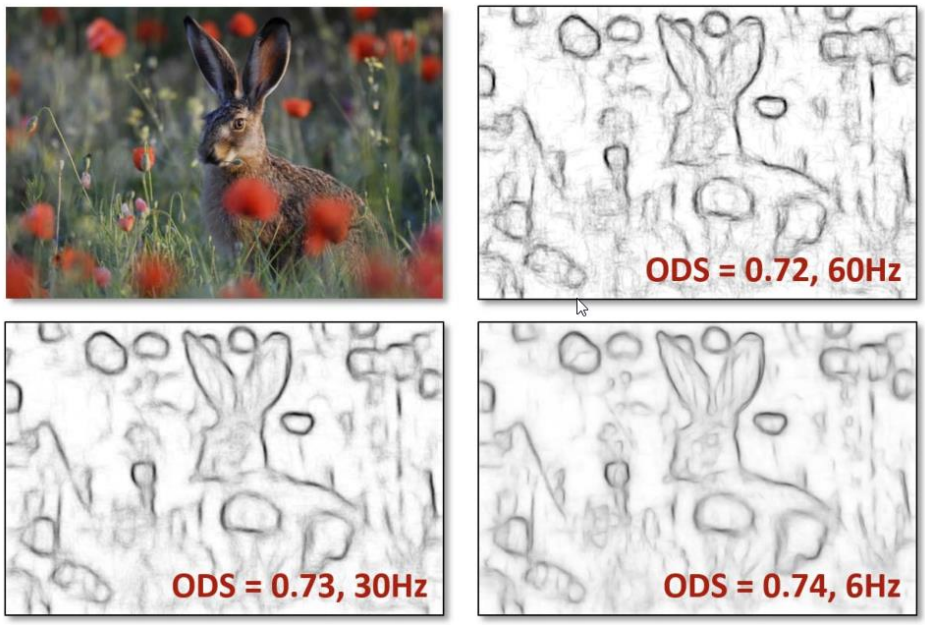

Figure-2. Edge detection results using three versions of our Structured Edge (SE) detector, demonstrating a trade-off between accuracy and runtime.

Edge detection techniques have also been used to develop new approaches to image segmentation. Arbelaz presents a method of segmentation based on regions and parts [12]. It combines image boundary and texture information to divide it into semantically related regions and parts of objects. This method provides more accurate and semantically meaningful image segmentation.

An interesting approach to edge detection is proposed in Bai X, where the authors present a method for extracting a skeleton from noisy binary images [13]. It is based on constructing a graph representing the relationships between pixels and using graph algorithms to determine the image skeleton. This method retrieves the principal axes of objects and detects their structural information.

An important aspect of edge detection is also the assessment of the quality of the detected edges. Zang K presents the Feature Similarity Index (FSIM), which makes it possible to assess the quality of detected edges based on the similarity with the original image [14]. This index takes into account contrast, structure, and boundary information and allows comparison of different edge detection methods.

The Canny operator is proposed in Canny and is one of the most widely used methods [1]. It provides high accuracy and clarity in edge detection by applying a

gradient filter, threshold processing, and non-maximum suppression.

The Sobel operator proposed in Sobel and Feldman is a simple and effective method for extracting horizontal and vertical boundaries in an image using gradient filters [2].

The method proposed by Arbelaz combines contour detection and hierarchical image segmentation [3]. It uses non-maximum suppression and threshold processing to create a contour map, and then applies hierarchical segmentation to divide the image into related regions.

The anisotropic diffusion proposed by Peron and Malik uses diffusion processes to smooth the image and preserve the contours. It provides good clarity and smoothness of the boundaries of objects [4].

The Structured Forests for Fast Edge Detection method proposed in Dollar and Zitnik combines random forest-based classifiers to quickly and accurately detect edges in an image [5].

The authors' work presents a segmentation method based on regions and parts, which combines information on the boundaries and texture of an image to divide it into semantically related regions and parts of objects [12].

The method of image skeleton extraction proposed in the authors' work is based on graph construction and application of graph algorithms for determination of skeleton and structural information of objects [13].

The Canny operator is a widely used method that provides high accuracy and clarity in edge detection. The Sobel operator is simple and efficient in highlighting horizontal and vertical boundaries in an image. The Arbelaz method combines contour detection and hierarchical segmentation to obtain semantically related regions in an image. Anisotropic diffusion provides smoothness and preservation of object contours. The "structured forests for rapid edge detection" method combines random forest-based classifiers for accurate edge detection. The region and part segmentation method divides the image into semantically related regions and parts of objects. The image skeleton extraction method defines the principal axes of objects and structural information. The Feature Similarity Index (FSIM) provides an estimate of the quality of the detected edges based on the similarity to the original image.

All of these methods have advantages and are applied in various fields of computer vision, such as pattern recognition, object segmentation, object of interest detection, and much more. The choice of edge detection method depends on the specific task and accuracy and efficiency requirements.

Each of these methods has its own uniqueness and is suitable for different image processing scenarios. The Canny operator provides accurate edge detection taking into account gradient and threshold processing, making it applicable in tasks requiring high accuracy, such as medical diagnosis or automatic facial recognition. The Sobel operator is easy to implement and provides fast processing, making it preferable for real-time and embedded systems where speed plays an important role. The Arbelaz method, which combines contour detection and hierarchical segmentation, is useful for segmentation and scene analysis problems where image separation into semantically related regions is required. Anisotropic diffusion is used to improve image quality by eliminating noise and preserving contours, which is useful in image processing tasks such as image recovery or photo quality improvement.

The "structured forests for fast edge detection" method provides high processing speed and accuracy in detecting edges in an image. It can be applied to a wide range of tasks, including robotics, automatic driving and video processing.

The region and part segmentation method provides more detailed and semantically meaningful image segmentation, which is useful in scene analysis and object recognition tasks. The method of extracting the skeleton of an image allows you to determine the main axes of objects and highlight their structural information, which can be useful in shape analysis and robotics tasks.

Table 1. Comparative analysis of image edge detection methods

№	Method	Description	Advantages	Restrictions
	Canny [1]	Computer-based approach to edge detection.	High accuracy of edge detection.	High computational complexity.
	Sobel [2]	Isotropic gradient 3x3 operator for image processing.	Ease of implementation.	Noise sensitivity.
	Arbelase [3]	Contour detection and hierarchical image segmentation.	Pinpoints the contours of objects.	Constraints when processing complex scenes with multiple intersecting paths.
	Perona and Malik [4]	Scale-spatial and edge detection using anisotropic diffusion.	Resistance to noise and texture.	Tendency to blur and lose details in complex images.
	Dollar and Zitnik [5]	Structured forests for quick edge detection.	High rate of edge detection.	Constraints when processing complex scenes with multiple intersecting paths.
	Hyu L [7]	Smoothing images by minimizing the L0 gradient.	Saves the boundaries of objects when smoothing.	High computational complexity.
	Jane A [8]	Fundamentals of digital image processing.	Provides basic concepts and approaches in the	Not a specific method of edge detection.

			field of image processing.	
	Shen S [9]	Detects and aligns objects through repeating the structure boundary.	Accurately highlights the contours of objects.	Constraints when processing complex scenes with multiple intersecting paths.
	Ren and Malik [10]	Training the classification model for segmentation.	Application of machine learning for image segmentation.	Pre-training of the model is required.

III. Application of edge detection

The application of edge detection in the field of computer vision and image processing has a wide range of applications and significance in various fields. In this article, we look at some of the main applications of edge detection techniques and their relationship to the literature on your list.

Medical diagnosis: Edge detection plays an important role in the processing of medical images such as X-ray, MRI and CT scans. Methods such as the Canny operator and anisotropic diffusion are used to detect contours and improve image quality for accurate diagnosis and analysis [1-4].

Object Recognition: Object recognition tasks use edge detection to highlight the boundaries of objects and define their shape. Methods such as Sobel operator, Canny operator, and structured forests provide the high precision and processing speed required to recognize and classify objects [2-5].

Robotics: Edge detection plays an important role in autonomous robot navigation and environmental perception. Methods such as the Canny operator, multiscale combinatorial grouping, and skeletal detection are used to detect obstacles, isolate boundaries, and extract structural information from the environment [19-13]. For robotics and autonomous navigation tasks, the methods described in are used [7,12]. They offer techniques that allow for the detection of obstacles, the identification of boundaries and the extraction of structural information from the environment for more accurate navigation of robots.

Video processing: Edge detection in video images is used to highlight moving objects, define contours, and segment video. Methods such as the Canny operator, region and part-based edge detection, and object boundaries provide efficient video processing for a variety of tasks, including moving object tracking and scene analysis [12-20].

Data analysis: Edge detection techniques are also applied in the field of data analysis, especially in image processing and information visualization. For example, the Canny operator, Sobel operator and gradient methods can be used to extract important features from images and present data in a more convenient and

informative form [16].

Contour segmentation: Edge detection methods are also used in contour segmentation tasks where you want to highlight the contours of objects in an image. Methods such as contour detection and hierarchical segmentation, classification modeling for segmentation, and contour selection using grouping are used to accurately define object contours [3-10-9].

Image Quality Assessment: Edge detection techniques also find application in image quality assessment tasks. For example, the Feature Similarity Index (FSIM) and gradient-based image quality score use edge detection to compare the original image with its reconstructed or compressed version, which makes it possible to estimate the degree of preservation of image edges and details [14-15].

Object detection: Edge detection methods are widely used in object detection tasks such as pedestrian detection and boundary detection of objects [18-17]. These methods allow objects to be identified and highlighted based on their contours, which is of great importance in safety systems, autonomous cars and other applications that require accurate detection of objects.

Conclusion

The conclusion can reflect the main results and conclusions drawn from the methods and operators of edge detection in images considered. First, edge detection is an important task in the field of image processing and computer vision. Edges contain important information about the boundaries of objects and structures in an image, and their accurate detection is of great importance for a variety of applications, including object segmentation, classification, and detection. Second, the edge detection methods and operators discussed present different approaches to solving this problem. Each has its own advantages and limitations, and the choice of a particular method depends on the required accuracy, speed of operation and the features of the input data. A third observation is that a combination of several edge detection techniques can lead to improved outcomes. For instance, using multi-scale combinatorial grouping allows you to combine edge information at different levels of detail and improve detection accuracy. In addition, it is worth noting that there is great potential for applying deep learning in the field of edge detection. Neural networks demonstrate high efficiency in solving complex image processing problems and can be used to improve edge detection accuracy.

In conclusion, edge detection in images is an actively developing field of research. The methods and operators discussed in this paper represent only part of the existing

approaches. In the future, research can be aimed at developing new methods, combining different approaches, as well as improving the performance and accuracy of edge detection.

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