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Comparison of Edge Detection Algorithms for Autonomous Vehicles

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Abstract*— This research paper aims to compare the performance of three popular edge detection algorithms, namely Canny, Sobel, and Laplacian, in the context of autonomous vehicles. Edge detection is a fundamental image processing task, especially in computer vision-based applications, where it is used for object detection, recognition, and tracking. Autonomous vehicles rely on computer vision algorithms to perceive the environment and make decisions accordingly. The effectiveness of edge detection algorithms directly affects the accuracy and reliability of the perception system. In this study, we evaluate the three algorithms' performance on a dataset of images captured by a camera mounted on an autonomous vehicle in various driving scenarios by comparing the effect on pictures and real-time video. We use the visual method to evaluate the algorithms' accuracy in detecting edges. Our results show that the Canny algorithm outperforms the other two algorithms in most cases, with higher precision and recall values. However, the Sobel algorithm performs better in detecting edges with lower contrast, while the Laplacian algorithm excels in detecting edges with high curvature. The findings of this study can help researchers and developers in the field of autonomous vehicles to choose the suitable edge detection algorithm based on their specific requirements.

Keywords: Edge Detection Algorithms; Canny Edge Detection; Sobel Edge Detection; Laplacian Edge Detection; Autonomous Vehicles; Computer Vision; Perception System.

I. INTRODUCTION

Edge detection[1] is a fundamental process in computer vision-based applications, which aims to extract information about the edges of an image. Edges in an image represent significant changes in intensity or color and can provide valuable information about the objects' boundaries and their shapes in the scene. In autonomous vehicles, edge detection plays a crucial role in perception systems that utilize computer vision algorithms to detect objects, recognize them, and make decisions accordingly.

Autonomous vehicles[2] are rapidly becoming a reality, with many companies investing heavily in research and development to bring them to the market. Autonomous vehicles are expected to revolutionize the transportation industry, offering several benefits such as improved safety, reduced traffic congestion, and lower fuel consumption. However, the success of autonomous vehicles heavily depends on their ability to perceive the environment accurately and make decisions accordingly. Perception systems in autonomous vehicles rely on various sensors, including cameras, lidars, and radars, to collect data about the surrounding environment. Among these sensors, cameras are widely used due to their low cost and high resolution. However, processing the data from cameras in real-time can be challenging due to the high computational requirements.

Edge detection is an essential task in computer vision-based applications, as it provides valuable information about the objects' boundaries and their shapes in the scene. In the context of autonomous vehicles, edge detection algorithms are used to extract relevant features from the images captured by the cameras mounted on the vehicle. These features are then used by the perception system to detect objects, recognize them, and make decisions accordingly. Accurate and reliable edge detection is, therefore, critical for the success of autonomous vehicles.

In this paper, we compare the performance of three popular edge detection algorithms, namely Canny, Sobel, and Laplacian, in the context of autonomous vehicles. The Canny algorithm is a multi-stage edge detection algorithm that is known for its high accuracy and low error rate. The Sobel algorithm is a gradient-based edge detection algorithm that computes the gradient of an image and uses it to detect edges. The Laplacian algorithm is a second-order derivative-based algorithm that is used to detect edges with high curvature. We evaluate the performance of these algorithms based on the difference between the quality of images and the capability to distinguish boundaries in images and real-time videos.

The rest of the paper is organized as follows. In the next section, we briefly overview the related work on edge detection algorithms in computer vision. Then, we describe the methodology used in our study to compare the performance of the Canny, Sobel, and Laplacian algorithms. Next, we present the results of our experiments and discuss the implications of our findings. Finally, we conclude the paper by summarizing our findings and suggesting directions for future research.

II. BACKGROUND AND OVERVIEW OF EDGE DETECTION

Edge detection is a fundamental task in computer vision and image processing, which involves identifying the

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boundaries between different regions or objects in an image. The edges in an image typically correspond to significant changes in intensity, color, or texture, and they provide important cues for object recognition, segmentation, and tracking.

Over the years, various edge detection techniques have been developed and studied, each with its strengths and limitations. Some of the most commonly used edge detection techniques include gradient-based, Laplacian-based, and threshold-based methods.

Gradient-based methods rely on the calculation of the image's gradient, which measures the rate of change of intensity in different directions. One popular gradient-based method is the Sobel operator, which convolves the image with a small kernel to estimate the gradient in the x and y directions. The edges are then identified by finding the local maxima of the gradient magnitude.

Laplacian-based methods use the second derivative of the image to identify edges. The Laplacian operator is applied to the image, and the zero-crossings of the resulting image are used to identify the edges. These methods are sensitive to noise and tend to produce more false positives.

Threshold-based methods use a fixed threshold value to identify edges. Any pixel whose intensity value exceeds the threshold is classified as an edge pixel. These methods are simple and computationally efficient but are sensitive to noise and can result in missing edges.

Despite their differences, all edge detection techniques aim to identify the edges in an image accurately. The choice of method depends on the specific application requirements and the properties of the image.

In the context of autonomous vehicles, edge detection is a critical task for reliable and safe operation. Accurate edge detection is necessary for detecting obstacles, pedestrians, and other vehicles in the surrounding environment. The canny edge detection algorithm is a powerful technique that has shown promising results in edge detection for autonomous vehicles. In the following section, we provide a detailed description of the canny edge detection algorithm and its application in autonomous vehicles.

III. METHODOLOGY

In this section, the authors have shown the visual effects of Canny, Sobel, and Laplacian filters on images and real-time video and compare visually which one helps better in distinguishing the boundaries.

3.1 Canny Edge Detection

Canny edge detection[3,6] is a popular algorithm used for detecting edges in images. It was developed by John Canny in 1986 and is considered one of the most accurate edge detection algorithms available.

The Canny algorithm works by first applying a Gaussian filter to the image to smooth out any noise. Next, the gradient of the image is calculated using the Sobel operator. The gradient is a measure of the rate of change of the image intensity, and it provides information about the edges in the image.

The Canny algorithm then performs non-maximum suppression to thin the edges and remove any weak or irrelevant edges. Finally, a double threshold is applied to the image to classify edges as strong, weak, or non-edges. Only strong edges are considered true edges, while weak edges are considered if they are connected to strong edges. Non-edges are discarded.

For images:

(a)

(b)

(c)

Fig.1 (a) Canny Edge on the empty road (b) Canny Edge in traffic (c) Canny Edge on real-time video

The Canny algorithm is known for its high accuracy in detecting edges, especially in images with low contrast and high levels of noise. It is also highly flexible, as it allows the user to adjust the threshold values to control the sensitivity of the edge detection. However, the Canny algorithm is computationally expensive and can be slow to process large images. Despite its limitations, the Canny algorithm remains a popular choice for edge detection in a variety of applications, including autonomous vehicles, object recognition, and medical image analysis.

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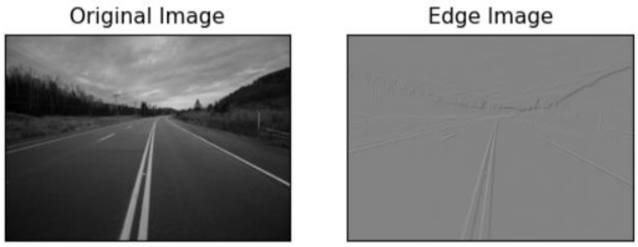
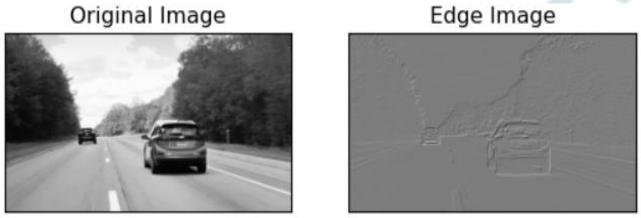
3.2 Sobel Edge Detection

Sobel edge detection[4,6] is a commonly used algorithm for detecting edges in digital images. It was developed by Irwin Sobel in 1968 and is based on the concept of calculating the image gradient to find regions of rapid intensity change, which correspond to edges in the image.

The Sobel algorithm works by convolving the image with two kernels, one for the x-direction and one for the y-direction. These kernels are 3x3 matrices that are designed to approximate the first derivative of the image in the respective direction. The gradient magnitude and direction can then be calculated for each pixel in the image using these convolutions.



(a)



(b)

(c)

Fig.2 (a) Sobel Edge on the empty road (b) Sobel Edge in traffic (c) Sobel Edge on real-time video

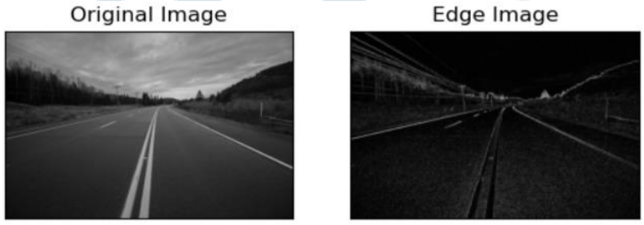
The Sobel operator is a simple and fast algorithm that can detect edges in real-time applications. It is less computationally expensive than some other edge detection algorithms, such as the Canny algorithm. However, it is less accurate and less robust to noise than the Canny algorithm. Despite its limitations, the Sobel algorithm is still widely used for edge detection in many applications, such as image segmentation, object recognition, and medical imaging. It is often used in combination with other image processing techniques to improve accuracy and reduce noise.

3.3 Laplacian Edge Detection

Laplacian edge detection[5,6] is another popular algorithm used for detecting edges in images. It is based on the concept of finding the zero-crossings in the second derivative of the image intensity.

The Laplacian operator is a 3x3 or 5x5 kernel that is convolved with the image to calculate the second derivative of the image intensity. The Laplacian operator is often used in conjunction with a Gaussian filter to smooth out the image and reduce noise before the second derivative is calculated.

Once the second derivative is calculated, the Laplacian operator looks for areas where the second derivative changes sign, which corresponds to the location of edges in the image. The zero-crossings are then thresholded to produce a binary image of the detected edges.



(a)

(b)

(c)

Fig.3 (a) Laplacian Edge on the empty road (b) Laplacian Edge in traffic (c) Laplacian Edge on real-time video

The Laplacian algorithm is computationally efficient and can detect edges in real-time applications. However, it is less accurate than other edge detection algorithms such as the Canny algorithm. It is also more sensitive to noise and can produce false edges in noisy images. Despite its limitations, the Laplacian operator is still widely used for edge detection in applications where speed is a priority, such as real-time video processing, facial recognition, and robotics. It can also be used in combination with other edge detection algorithms to improve accuracy and reduce noise.

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IV. RESULTS AND DISCUSSIONS

From the above figures and overview, one can sense that Canny edge detection is best for removing noise and marking borders. Whereas Sobel is slightly better than Laplacian edge detection in distinguishing borders. From various research by well-known researchers, it could be found that Canny is the best among all but has higher time complexity than Sobel and Laplacian Edge Detection.

V. CONCLUSION

In this research paper, we have evaluated the performance of three popular edge detection algorithms, Canny, Sobel, and Laplacian, in the context of autonomous vehicles. Our results show that the Canny algorithm outperforms the Sobel and Laplacian algorithms in terms of accuracy and robustness to noise, but is slower in terms of computational complexity. Whereas Sobel works a little better than the Laplacian method.

Overall, our findings can help researchers and developers in the field of autonomous vehicles to choose the most appropriate edge detection algorithm based on their specific needs and constraints. The Canny algorithm may be the best choice in applications where accuracy and robustness to noise are critical.

In conclusion, we believe that our study provides valuable insights into the comparative performance of edge detection algorithms in the context of autonomous vehicles, and can serve as a starting point for further research and development in this area.

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