Proceedings of the 2009 IEEE International Conference on Systems, Man, and Cybernetics
San Antonio, TX, USA - October 2009

An Improved Canny Edge Detection Application for Asphalt Concrete

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Abstract **— In this paper we introduce an improved Canny edge detection algorithm and an edge preservation filtering procedure for Asphalt Concrete (AC) applications. Datasets of AC images were randomly selected to test this algorithm. Computer simulations show that the improved algorithm can make up for the disadvantages of Canny algorithm, detect edges of AC images effectively, and is a less time-consuming process. Particularly, it has been shown that the presented algorithm can not only eliminate noises effectively but also protect unclear edges.**

Keywords**—Asphalt concrete, Canny operator, edge detection, gradient vector, image fusion , image segmentation**

I. INTRODUCTION

Image edge detection is an effective image processing tool that provides essential image edge information and characteristics. This information is used in wide areas such as image segmentation, image categorization, image registration, image visualization, and pattern recognition. These applications may vary in their outputs but they all share the common need of precise edge information in order to carry out the needed tasks successfully. An edge detector can be defined as a mathematical operator that responds to the spatial change and discontinuities in a gray-level (luminance) of a pixel set in an image [1][7].

Asphalt Concrete (AC) mixtures are uniquely complex heterogeneous materials composed of air voids, mastics, and aggregates. Mastics consist of binder and fines. The overall performance of AC is highly dependent of the proportions of these materials as well as the distribution and characterization of their physical properties [4] [5]. The development of high resolution X-ray computed tomography (CT) has shown a considerable promise to efficiently characterize the AC microstructure. X-ray CT imaging technique generates 2D and 3D high resolution images with the capability of capturing the details of microstructures. Several studies have demonstrated the potential application of such imaging technique to characterize different properties of AC mixtures. Recently, it is used effectively to quantify air void distributions, aggregate orientation, segregation, and surface textures [5].

These studies started to incorporate methods of digital asphalt concrete image processing as well as other manual/subjective techniques for processing AC images in a format suited to numerical simulations. Image processing techniques include image contrast enhancement, image noise removal, thresholding, edge detection and image segmentation. Typically, the gray level threshold that separates aggregates from mastics, referred to as thresholding, is selected subjectively. Additional pixel modifications are required to adjust the relative promotions of aggregates and mastic to reflect the actual volumetric of the AC [4].

The application of image processing algorithms to AC mixtures involves three main stages. The first stage involves image pre-processing for contrast enhancement and noise removal. Noise removal can be achieved using various methods of image digital filtering techniques. The common filter used for AC is the median filter with different window sizes ranging from 3 x 3 to 9 x 9. The second stage is concerned with the main thresholding routine where the enhanced image in stage one and the volumetric information for the AC are fed into this stage. It consists of two components, namely volumetric-driven thresholding and 3D representation/sectioning. The third stage further enhances particle separation through edge detection and image segmentation [4]. The common edge detection algorithm is Canny edge detection algorithm.

Moreover, edge information can be used to feed-in various applications seeking the shapes, size, or edge locations of particular objects. In all edge detection algorithms, the main objective is to locate the edge (intensity transitions) from the scene neither with prior information nor with human interpretation. Some popular algorithms include Sobel, Roberts, Prewitt, Laplace, LOG, and Canny Algorithm [2].

These edge detection operators share almost the same concept which is to find the singularities and locate them accurately. The gradient intensity changes rapidly in the edge and the maximal intensity change along a particular orientation produces a peak or a zero-crossing. Hence, the first derivative and the second derivative of the gradient of every pixel in an image are used to find edges in the image [1]-[3].

Canny method has proven to be superior over many of the available edge detection algorithms and thus was chosen mostly for real time implementation and testing. Canny edge detection algorithm was introduced in 1986 [2]. It is considered as the modern "standard" in the sense that the validity of all other algorithms is often checked against it [3]. In Canny algorithm, the Gaussian function is used to smooth the image prior to edge detection. The filtering or smoothing operation

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actually services two purposes. The first one is the reduction of the effect of noise prior to the detection of pixel intensity changes. The second purpose is setting the resolution or scale at which intensity changes are to be detected [3]. These factors contribute effectively towards a precise edge detection method, overcoming the problem of detecting false edges resulted from noise sitting on some pixels.

Canny algorithm has the defect of being vulnerable to noise disturbances, so there are certain limitations to its application. Also, the traditional Canny operator will adopt the 2 x 2 difference template to calculate the gradient amplitude, or the second order differential operator [-1 0 1] and $[-1\ 0\ 1]^T$. This method has a precise edge positioning but quite sensitive to noise and may detect false edges, as well as missing some details of real edges in an image [1]. This issue is of a great importance in noisy images where many false edges resulting from noise are detected. Moreover, Canny algorithm compares the adjacent pixels on the gradient direction to determine if the current pixel has local maximum, which results in inaccuracy of edge detection and influences a connected edge points [1]. Furthermore, the Canny edge detector cannot also detect branching edges [8]. By closely analyzing the gradient magnitudes and directions of the missed edges, it is observed that although gradient magnitudes at the missing edges are larger than those of pixels adjacent to them, such maxima are not in the gradient direction. Since gradient maxima in an image form ridges, and since at the ridge points the slopes are either zero or very small, the directions of the slopes cannot be accurately determined [8]. Considering the hysteresis threshold values, one might need to manually set threshold values to detect certain edges that were smoothed by Gaussian smoothing filter [9]. In addition, because of the noisy nature of Asphalt Concrete data and characteristic of Asphalt Concrete depth-image, traditional Canny algorithm doesn't perform well in these cases. On the one hand, it can't eliminate some noises and will generate many false edges; hence, it will lose some edges with less gray level changing. It is difficult to design a general edge detection algorithm which performs well in many contexts and captures the requirements of subsequent processing stages. Consequently, over the history of digital image processing, a variety of edge detectors have been devised which differ in their mathematical and algorithmic properties [10].

In this paper, an improved Canny edge detection algorithm has been developed and applied to AC test images. The paper is organized as follows. The proposed edge detection algorithm is described in Section III. The edge preserving filtering algorithm is described in Section IV. Experimental results are presented and discussed in Section VI. Finally, other applications and conclusions are drawn in Section VII and VIII respectively.

II. BACKGROUND

In this section, the necessary mathematical background is presented. This includes an overview of the original Canny operator..

Canny operator consists of the main processes shown in Figure (1). The first order Gaussian function is defined as:

$$G(x, y, \sigma) = \frac{1}{2\pi\sigma^2} e^{(\frac{-x^2 + y^2}{2\sigma^2})} \quad (1)$$

The Gaussian smoothing function smoothes out the image to have a noise-free image prior to applying the derivative function. The derivative function is approximated using a 3 x 3 kernel that is applied on the horizontal and vertical direction of an image. These approximated kernels are shown as *G(x)* and *G(y)* to operate in a horizontal and a vertical manner respectively.

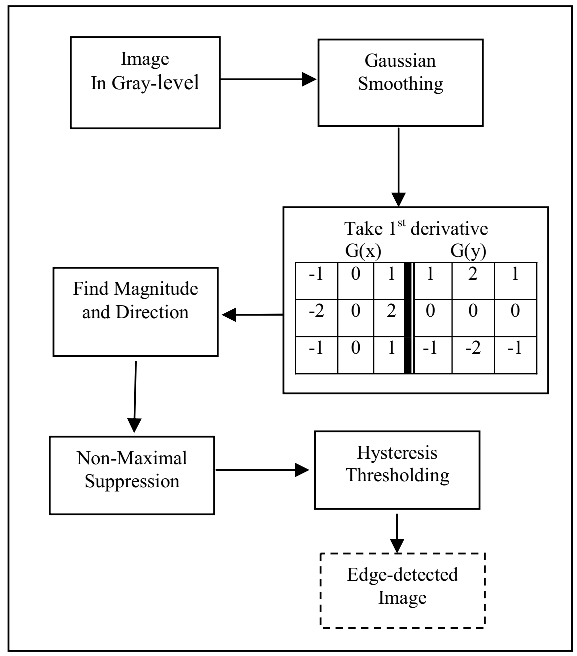


Figure (1). Canny edge detection process

By convolving the previous kernels of *G(x)* and *G(y)* with the Image, the gradient vector $\nabla G = \begin{bmatrix} \partial G / \partial x \\ \partial G / \partial y \end{bmatrix}$ (2)

results. The magnitude and the direction of each pixel of the image can be calculated using:

$$\text{Magnitude} = \sqrt{(\partial G / \partial x)^2 + (\partial G / \partial y)^2} \quad (3)$$

$$\text{Direction: } \Theta = \arctan\left(\frac{\partial G / \partial y}{\partial G / \partial x}\right) \quad (4)$$

III. IMPROVED CANNY EDGE DETECTION

Conventional Canny algorithm works as follows:

A. Smooth an image with Gaussian filter.
B. Calculate gradient magnitude and gradient direction.

C. "Non - maximal suppression" to ensure the desired edge with one single pixel width.
D. Determine two threshold values, and then select possible edge points and trace edges.

A. Replacement of Gaussian smoothing kernel

The first part is to replace the Gaussian smoothing kernel with one of the following kernels for enhancing the image edges in both directions.

$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & \alpha & -1 \\ -1 & -1 & -1 \end{bmatrix}, \begin{bmatrix} 0 & 0 & -1 & 0 & 0 \\ 0 & -1 & -2 & -1 & 0 \\ -1 & -2 & \alpha & -2 & -1 \\ 0 & -1 & -2 & -1 & 0 \\ 0 & 0 & -1 & 0 & 0 \end{bmatrix}$$

where α = 2, 4, or 8. Extensive simulations results showed that α = 2 has the best performance.

B. Modification of the gradient magnitude of Canny operator

It was shown previously that the gradient operator of the horizontal and vertical directions can be computed as $\partial G / \partial x$ and $\partial G / \partial y$ respectively. The presented algorithm joins together gradient magnitude and direction:

$$\text{Magnitude } (x,y,\theta) = \text{Max } (\cos\theta \frac{\partial G}{\partial x}, \sin\theta \frac{\partial G}{\partial y}) \qquad (6)$$

C. Modification of gradient kernel

The Canny method gradient magnitude and direction are calculated by pixels within a 2-by-2 neighborhood is sensitive to noise and may detect false edges. One solution is to calculate the gradient magnitude and direction by using pixels within an M-by-N neighborhood. In [6], a generalized set of kernels for derivative approximation was introduced. It can be used effectively for edge detection, line detection, and consequently for feature extraction. Kernel sizes could be of 5x11, 3x9 or 5x7.

$$G(x) = \begin{bmatrix} 1 & \sqrt{2} & 2 & 0 & -2 & -\sqrt{2} & -1 \\ \sqrt{2} & 2 & 2\sqrt{2} & 0 & -2\sqrt{2} & -2 & -\sqrt{2} \\ 2 & 2\sqrt{2} & 4 & 0 & -4 & -2\sqrt{2} & -2 \\ \sqrt{2} & 2 & 2\sqrt{2} & 0 & -2\sqrt{2} & -2 & -\sqrt{2} \\ 1 & \sqrt{2} & 2 & 0 & -2 & -\sqrt{2} & -1 \end{bmatrix}, G(y) = \begin{bmatrix} 1 & \sqrt{2} & 2 & \sqrt{2} & 1 \\ \sqrt{2} & 2 & 2\sqrt{2} & 2 & \sqrt{2} \\ 2 & 2\sqrt{2} & 4 & 2\sqrt{2} & 2 \\ 0 & 0 & 0 & 0 & 0 \\ -2 & -2\sqrt{2} & -4 & -2\sqrt{2} & -2 \\ -\sqrt{2} & -2 & -2\sqrt{2} & -2 & -\sqrt{2} \\ -1 & -\sqrt{2} & -2 & -\sqrt{2} & -1 \end{bmatrix} \qquad (7)$$

D. Fusion of edge images

Conventional Canny algorithm uses a method of non-maximum suppression (NMS) to process the smoothed image and make sure each edge is of one-pixel width. In this method, a fusion of two edge detection techniques is proposed. The first edge-detected image contains the modified kernel set in (7). The second edge-detected image contains the same kernel set mentioned previously in addition to using the modified graident magnitude in (6). The fusion of the two edges would gurantee the existence of all edges that one image may miss over the other one. Figure (2), shows the proposed fusion concept.

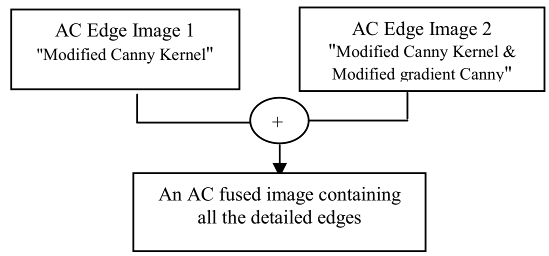


Figure (2). A block diagram showing the fusion of two edges

IV. EDGE PRESERVATION

In this part, an edge preservation filtering technique is introduced. The idea behind such a concept is to avoid blurring edges during the filtering of the images, and hence, avoiding missing some important branch edges that separate AC different components. The resulted fused image in part D is used in this task.

First, the pixel coordinates that correspond to edge locations in the fused image are saved to be avoided when filtering the original image. Once filtering takes place, it jumps these coordinates that correspond to edges, and then continue to swap all over the remaining of the image. However, one might investigate the possibility of the existence of some impulse noise laying on these avoided edges. Therefore, a switching filter is proposed to operate on these unwanted noise impulses on edges. It could be a median filter with different window size or a weighted median filter that operate on edges only. Figure (3) shows the block diagram of such algorithm.

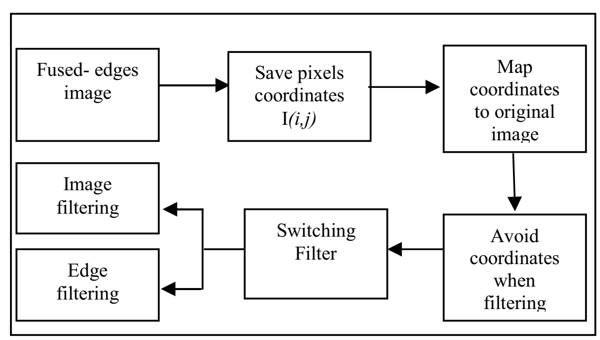


Figure (3). Edge preserving algorithm

V. SIMULATION RESULTS AND COMPARISON

In this section, various test images are edge-detected using the original Canny method, and compared with those deploying the new proposed edge detection algorithm. MATLAB environment is used to simulate the execution of both algorithms. In figure (4) and figure (5), samples of AC test images are presented. The algorithm output succeeded to show other branch edges that were not detected using the original Canny algorithm.

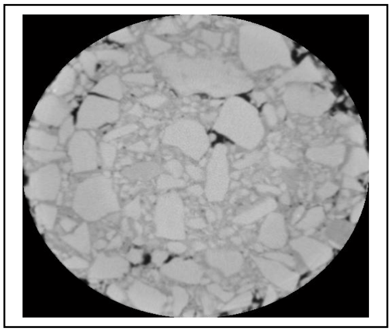


Figure (4)a Original AC image "512x512"

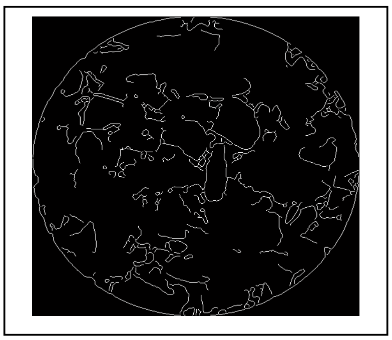


Figure (4)b Canny Edge detection output

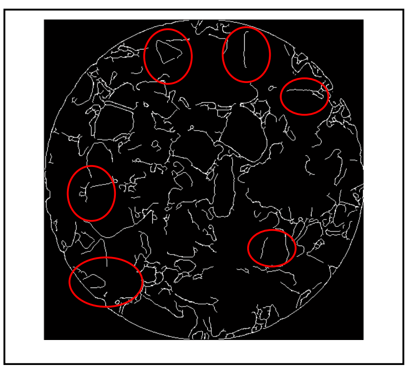


Figure (4)c Algorithm output showing more branch edges

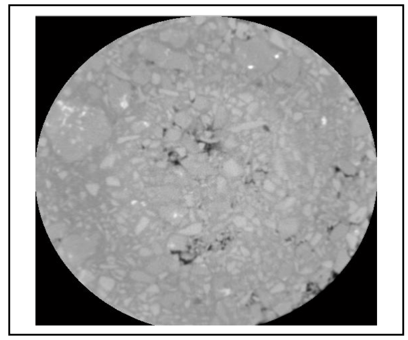


Figure (5)a Original AC image "512x512"

Figure (5)b Canny Edge detection output

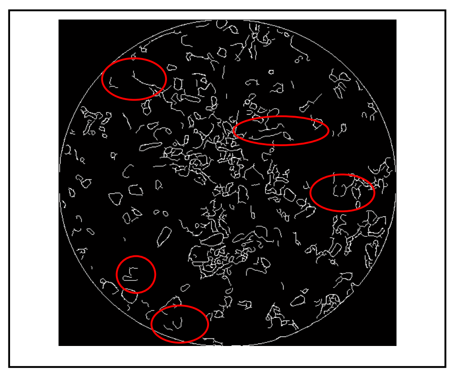


Figure (5)c Algorithm output showing more branch edges

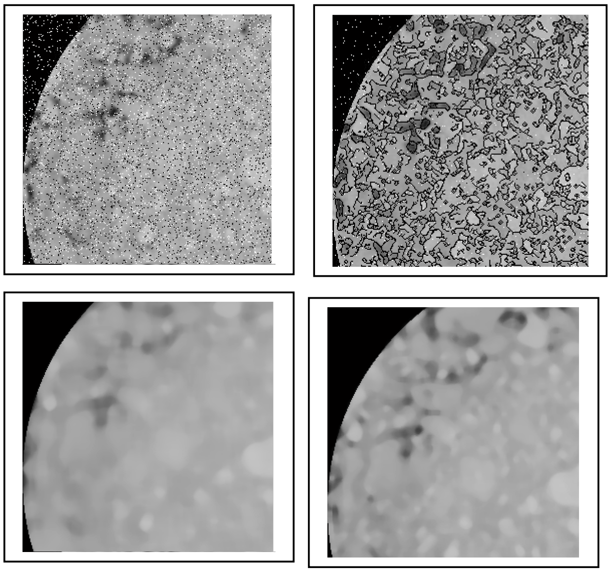
The developed canny edge detection algorithm was tested on 25 AC images where the detection of small branch edges is observed and compared with the original Canny. The simulation results of seven images are tabulated in the next table where the higher number of stars represents more edges.

Image	1	2	3	4	5	6	7
Original Canny	***	***	**	**	***	**	**
Algorithm output	*****	*****	***	**	****	****	**

Table (1). Comparison of Canny and algorithm output .

Considering noise filtering using median filter, the algorithm fusion output produces superior results when applying median filters with a larger window size, e.g. 7x7,9x9 or larger to remove heavy noise. The effect of a larger window size would result in blurred edges that the algorithm overcomes in filtering the added salt and pepper noise in figure (6).

a) Original noisy image b) Edge-detected image



c) Filtered image using 7x7 median d) Edge-preserved filtered image using 7x7 median

Figure (6): edge preservation

VI. OTHER APPLICATIONS

Other applications may consider applying the proposed improved Canny edge detection algorithm to track road cracks. Edge detection in such images needs to be modified to be image- dependent as road cracks vary in scale. An example of the applied algorithm on a sample road crack image is shown in figure (7).

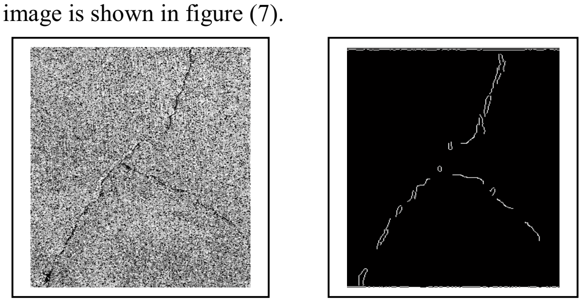
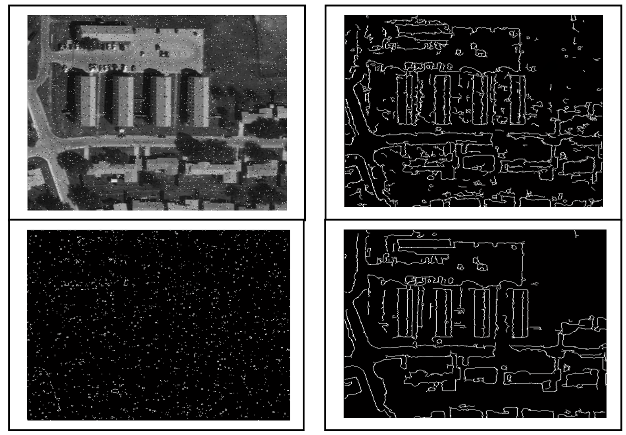


Figure (7). An original image of a road crack followed by the algorithm output of the imrpoved canny edge detection

The applications of developed algorithms are not limited to AC only as they extend that to be universally applied to other images of interest especially when impulsive noise exists. Figure (8) shows how the developed algorithm manages to detect real edges of interest and avoid detecting false noisy edges.

a)Original noisy image *b) Canny output*



c) Sobel output d) Algorithm output

Figure (8) algorithm output avoids detecting impulsive noise

VII. CONCLUSION

In this paper, an improved Canny edge detection and an edge preservation algorithms were introduced. The concept of fusion of two edge-detected images using the improved modified Canny algorithm is applied to highlight the branch edges that could not be obtained using the original Canny algorithm. Some other applications that also can benefit from the developed algorithms were highlighted.

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