MSB based Cellular Automata for Edge Detection

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Abstract*: A vitalcrucial pre-processing phase in image processing, computer vision and machine learning applications is Edge Detection which detects boundaries of foreground and background objects in an image. Discrimination between significant edges and not so important spurious edges highly affects the accuracy of edge detection process. This paper introduces an approach for extraction of significant edges present in images based on cellular automata. Cellular automata is a finite state machine where every cell has a state. Existing edge detection methods are complex to implement so they have large processing time. These methods tend to produce non-satisfactory results for noisy images which have cluttered background. Some methods are so trivial that they miss part of true edges and some methods are so complex that they tend to give spurious edges which are not required. The advantage of using cellular computing approach is to enhance edge detection process by reducing complexity and processing time. Parallel processing makes this method fast and computationally imple. MATLAB results of proposed method performed on images from Mendeley Dataset are compared with results obtained from existing edge detection techniques by evaluation of MSE and PSNR values Results indicate promising performance of the proposed algorithm. Visually compared, the proposed method produces better results to identify edges more clearly and is intelligent enough to discard spurious edges even for cluttered and complex images.

Index Terms*: Cellular automata, Edge detection, *Finite state machine, Linear rules, Parallel processing.

I. INTRODUCTION

Edge extraction is a procedure to detect contour of objects by finding the discontinuities or change in brightness within an image. Several digital image processing and computer vision applications preserve important structural features of an image through crucial step of edge detection. There are several mathematical methods for edge detection [1]-[3]. These techniques mainly compute gradient of image in both the axis and uses some smoothing filters. Two broad categories of edge detection techniques are Gradient based and Laplacian based. In gradient based method, it computes edge strength by finding gradient magnitude and gradient direction. In Laplacian method, edges are traced by locating zero crossings in the second derivative of the image. The possibility of false edge detection and missing true edges can significantly affect the result of object recognition, pattern recognition and feature extraction processes. Due to these limitations of kernel-based methods like sobel, prewitt, canny etc., several soft computing methods also evolved.

Cellular Automata finds its wide applications in the area of Image processing and computer vision [14]. Theory of self-reproducing Automata (CA) was initiated by J. Von Neumann and Stan Ulam [4]-[5] in 1950's. Stephen Wolfram extended the concept of automata by developing CA Theory [6]-[8]. Digital image is represented by a matrix of intensities for a grayscale image and a collection of three matrices for each color channel in color image. Two dimensional Cellular Automata [10] can be implemented on an image with an ease. Various possible applications of CA in image processing ranges from edge detection algorithms, translation of images, rotation through an angle, scaling operations like thinning and zooming, finding contour and edges for image segmentation and other NP-complete problems, such as graph coloring or satisfiability, designing a controlled random number generator with smaller aliasing rate than a linear counter based on shift register and XOR gates and pattern generation [12].

II. CONCEPT OF CELLULAR AUTOMATA

A. Structure of Cellular Automata

Cellular Automata (CA) is a mathematical model having multiple cells and several rules to construct self-organizing behaviour. One dimensional CA is represented as a vector of cells and two-dimensional CA [10] is an array where each cell is influenced by its neighboring cells. There is a finite range of possible states of a cell which is updated simultaneously depending upon previous states of its neighboring cells. Cellular Automata can be represented as

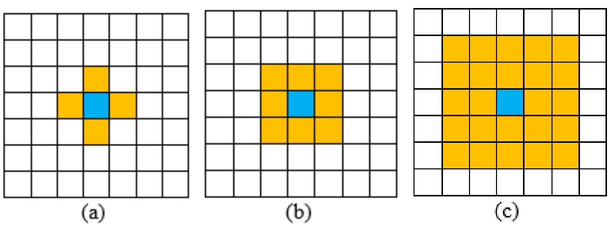

Fig 1: (a) Von-neumann neighborhood (b) Moore neighborhood (c) Extended Moore neighborhood

There are two basic neighborhood structures in Cellular Automata, namely, von-neumann neighborhood and Moore neighborhood.as shown in Fig 1.

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Von-neumann neighborhood has four neighbors surrounding a cell and in Moore neighborhood, there are eight neighbors. The radius of neighborhood is 1. In extended Moore neighborhood, radius is increased to 2 having 24 neighbors and one center cell [15].

Four boundary conditions in cellular automata are:

Null boundary condition.

0	8 bits	0

Fixed boundary condition.

0/1	8 bits	0/1

Periodic boundary condition.

LSB	8 bits	MSB

Adiabatic boundary condition.

MSB	8 bits	LSB

Reflexive boundary condition.

2nd MSB	8 bits	2nd LSB

B. Rule formation

Elementary CA has two states, 0 and 1, for every cell. For a combination of three neighbors there can be 8(=23) possible combinations i.e. 000,001,…,111. There are total of 28 rules, each rule is represented by an 8-bit binary number denoted as Rule 0, Rule 1 and so on till Rule 255. For a two state nine neighborhood CA, there exist 2^{2^9} possible rules. Among these, 29 rules are linear and can be determined by fig. 2. Remaining $2^{2^9} - 29(= 502)$ are non-linear rules [16],[17].

64	128	256
32	1	2
16	8	4

Fig 2: 2-Dimensional CA rule convention

Cellular automata have several advantages over other methods of computation. Simplicity of implementation makes it appropriate for solving complex problem in less computational time complexity. CA is comparatively faster than other methods [13].

III. RELATED WORK

A tremendous work is done for edge detection in an image. Sobel, prewitt and robert are some techniques based on gradient value. Generally, threshold value is decided empirically which might result in loss of edge details. An adaptive edge detection method was introduced by Li Er-sen et al. [26] based on analysing conventional canny operator in which both the thresholds were calculated self-adaptively making the algorithm consume more computational time.

According to literature so far, CA roots itself for more than two decades in image processing [19].

In [16], Choudhury et al. employed eight basic rules for 2-Dimensional Cellular Automata (Rule 2, 4, 8, 16, 32, 64, 128 and 256) to an image for its translation in all directions. Various rules were applied to obtain various operations on images like scaling and thinning horizontally as well as vertically, zooming of symmetric images. Qadir et al. [20] extended the concept of translation of the image by using twenty-five neighborhoods instead of nine neighborhoods. This method for translation was used in gaming applications. In [21], khan proposed that hybrid CA is the possible solution for rotation of images through an arbitrary angle. According to him, 2-D CA rules are applied which rotates an image about x and y axis by an angle π.

Determination of rule set is a crucial step in CA. Specifying and selecting rules manually is a slow and laborious process, also it may not scale well to larger problems. The Fuzzy Cellular Automata (FCA) is employed with fuzzy logic, having fuzzy states of a cell and fuzzy functions for transition rules. FCA is a special class of CA which is applied to design the pattern classifier [22]. Wang Hong et al. [23] suggested a new method for segmentation of an image based on fuzzy cellular automata. In [24], More and Patel used the property of Cellular Learning Automata to enhance the edges detected by fuzzy logic. In [15], Nayak, Sahu and Mohammed compared the performance of existing edge detection techniques with their proposed method based on extended neighborhood CA and null boundary conditions.

IV. PROPOSED ALGORITHM

In the proposed algorithm, all input images are grayscale. This method highlights the contribution made to overall appearance of an image by significant bits. Considering the fact, that each pixel is represented by 8 bits. Higher-order bits i.e. first four most significant bits of binary representation of intensity depict maximum image information.

Each cell represents an image pixel with certain intensity or pixel value. According to Moore neighborhood, four linear rules are identified which can efficiently result in identification of boundary of a region. These composite rules are as given below and are calculated with some basic rules and XOR function. These rules are computed as follow:

$Rule\ 29 = Rule16 \oplus Rule8 \oplus Rule4 \oplus Rule1$

$Rule\ 113 = Rule64 \oplus Rule32 \oplus Rule16 \oplus Rule1$

$Rule\ 263 = Rule256 \oplus Rule4 \oplus Rule2 \oplus Rule1$

$Rule\ 449 = Rule256 \oplus Rule128 \oplus Rule64 \oplus Rule1$

Integration of these rules result in edges present in the image.

$Rule29 \,||\, Rule113 \,||\, Rule263 \,||\, Rule449$

The image is first divided into its bit planes which is called bit plane slicing, then these transition rules are applied to every binary bit plane in parallel. The resultant successor matrix bit planes are merged into gray image followed by binarization of image done according to Otsu's threshold technique.

Finally, morphological operations are performed to enhance the results by removing noise and obtain true edges in the given input image.

The cell state in the next generation is found dependent upon the previous state of its neighboring cells and all cells are updated synchronously resulting in unit time complexity. Every cell can have two states, 0 or 1. In a 1x3 neighborhood structure, state of d pixel is updated by considering previous states of pixel a, b and c. Fig. 3 illustrates the method to apply identified composite rules by taking different set of 1x3 neighbors to update value of pixel d. These four rules can be represented as four borders which result in edge detection when applied by sliding a window of 3x3 pixels over an image of size mxn.

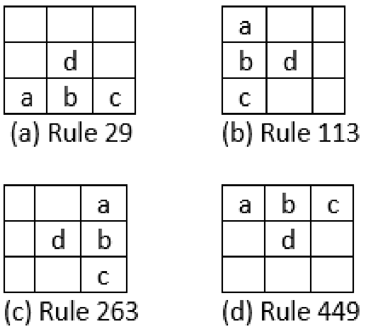


Fig 3: Conceptual representation for identification of four rules.

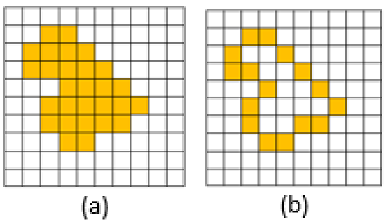


Fig 4: Illustration (a) region in an image (b) Contour identified by applying these four rules.

V. EXPERIMENTAL RESULTS

A comparison of proposed method is carried out against the commonly deployed kernel-based methods. These techniques experience the problems of imprecise edge detection such as missing true edges or producing extra edges due to noise etc. Also, selection of optimal threshold value in these techniques influences accuracy of edge extraction.

The results of Mendeley Dataset [25] as shown in Fig. 6-8, are compared with existing edge detection methods and indicate promising performance of the proposed algorithm by evaluating Mean square error (MSE) and Peak signal to noise ratio (PSNR) values as given by Table 1. MSE and PSNR are mainly used to compare quality of reconstructed image with its ground truth image. High MSE and less PSNR values of a resultant image indicates that operator used for edge detection has high performance capabilities.

Table 1: Experimental results for test images

Original image		Proposed method	Canny	Sobel	Prewitt
Image 1	MSE	0.8810	0.9172	0.9741	0.9745
	PSNR	0.5500	0.3754	0.1138	0.1122
Image 2	MSE	0.9156	0.9201	0.9720	0.9718
	PSNR	0.3831	0.3616	0.1232	0.1242
Image 3	MSE	0.8855	0.9258	0.9740	0.9741
	PSNR	0.5283	0.3346	0.1146	0.1142
Image 4	MSE	0.8738	0.9046	0.9586	0.9585
	PSNR	0.5858	0.4355	0.1837	0.1840
Image 5	MSE	0.8825	0.9313	0.9671	0.9670
	PSNR	0.5427	0.3092	0.1453	0.1459

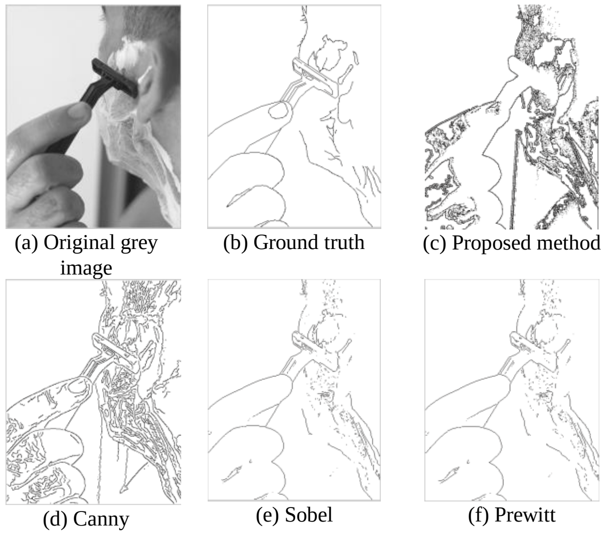


Fig 6: Results of test image1

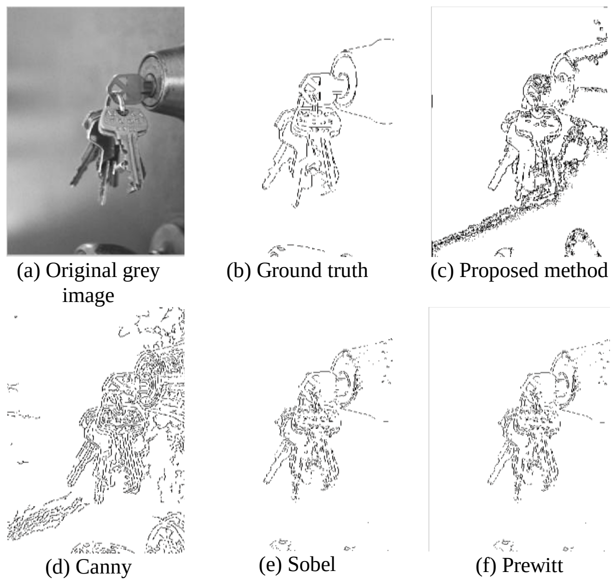
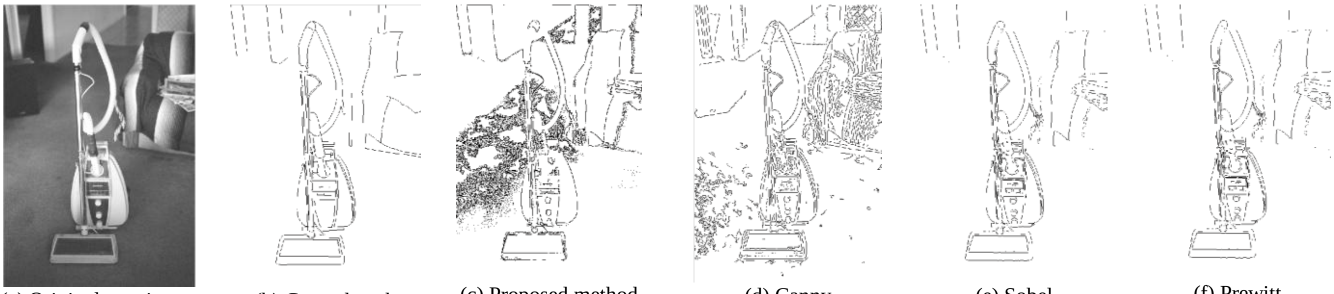


Fig 7: Results of test image2



(a) Original grey image (b) Ground truth (c) Proposed method (d) Canny (e) Sobel (f) Prewitt

Figure 8: Results of test image3

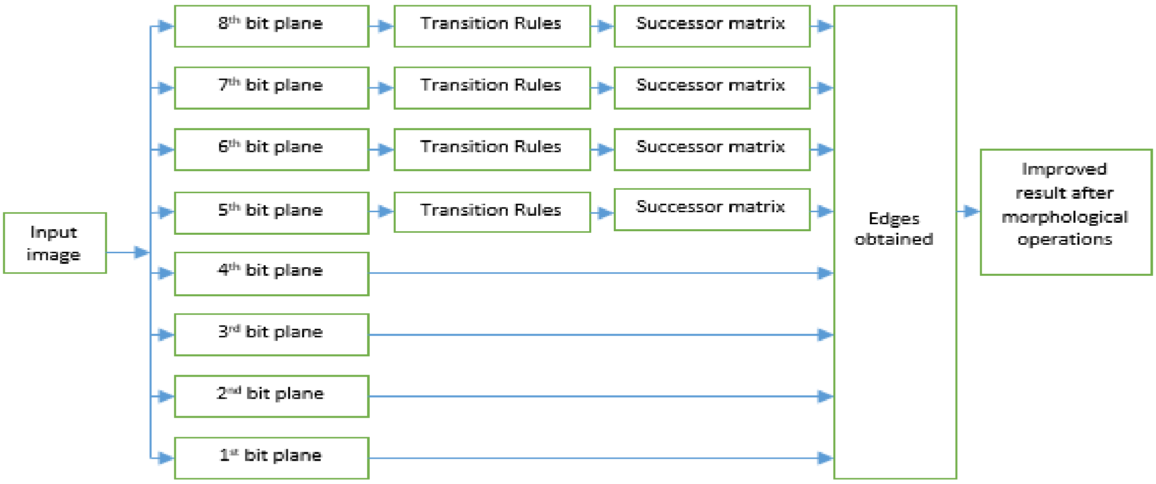


Figure 5: Flowchart of proposed method

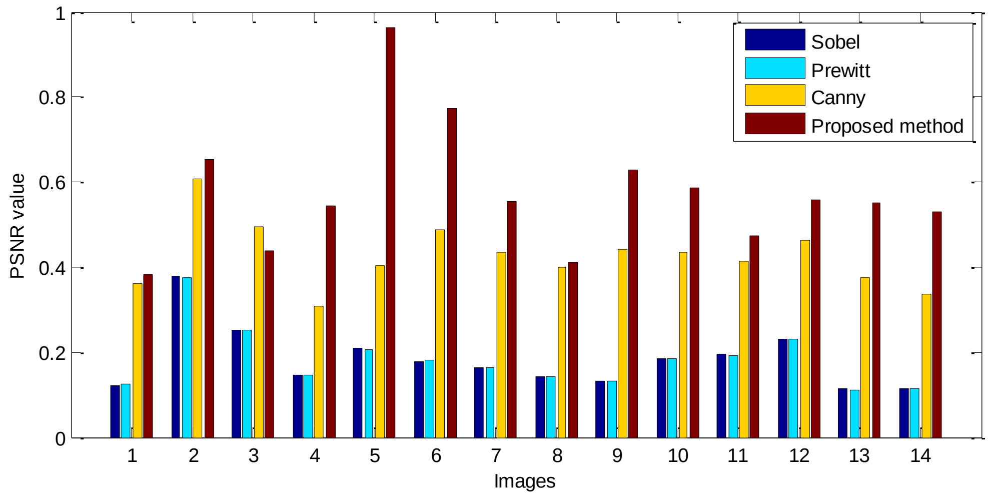


Figure 9: Bar chart of PSNR values of results of different edge detectors and proposed method.

VI. CONCLUSION

Evaluation of test images show that proposed method exhibit better performance even for noisy and cluttered images. Visually, finite state machine based method produced promising results of edge detection when compared with canny, sobel and prewitt edge detectors. Canny consist of several spurious edges whereas sobel and prewitt lack some of the strong edges.

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