EDGE DETECTION ALGORITHM FOR MACHINE VISION SYSTEMS

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ABSTRACT: In real world machine vision problems, issues such as noise and variable scene illumination make edge and finding object difficult. Effective edge detection algorithm is required for many important areas like machine vision, automated interpretation systems and is often used as the front-end processing stage in object recognition and interpretation systems. Many research works has been done to develop effective edge detection algorithms. In this paper parameters are modified in the Robert cross edge detection method to achieve a higher level of scene illumination and noise independence. Results obtained by this method are compared with several leading edge detection methods, such as Sobel and Canny. Further this project uses the logarithmic based edge detection method for the same. Application of this algorithm can be used for Image Enhancement which is based on this edge detection concept, shows better image enhancement.

KEYWORDS: Edge Detection, Logarithmic image processing, Contrast Estimation, Standard deviation

I. INTRODUCTION

Effective edge detection algorithm is required for many important areas like machine vision, automated interpretation systems and is often used as the front-end processing stage in object recognition and interpretation systems. Many research works has been done to develop effective edge detection algorithms. This paper proposes an effective algorithm for the same with the advantage of locating the centre point of the Robert Cross method of detecting slant edges. An edge [GW02] is a set of connected pixels that lie on the boundary between two regions. A reasonable definition of edge requires the ability to measure gray-level transitions in a meaningful way and an edge detector is defined as an mathematical operator of small spatial extent that responds in some way to the discontinuities, usually classifying every image pixel as either belonging to an edge or not.

There are many ways to perform edge detection [GW02, J+12, Tru12]. However, the majority of different methods may be grouped into two categories,

- Gradient
- Laplacian

The gradient method, usually called the first derivative, detects the edges by looking for the maximum and minimum in the first derivative of the image. In the Laplacian method, the second derivative, searches for zero crossings in the second derivative of the image to find edges.

The standard operators being used for edge detection are

- Sobel operator
- Canny operator
- Robert cross operator

Each of the above said operators have a general mask which is run through the input image and the resulting edge detected output image is found.

The Sobel operator [GW02] is a discrete differentiation operator, computing an approximation of the gradient of the image intensity function. At each point in the image, the result of the Sobel operator is either the corresponding gradient vector or the norm of this vector. The Sobel operator represents a rather inaccurate approximation of the image gradient, but is still of sufficient quality to be of practical use in many applications.

The Canny operator [Can86] aims to discover the optimal edge detection algorithm. For this, it uses a technique which finds the function which optimizes a given functional. The optimal function in Canny's detector is described by the sum of four exponential terms, but can be approximated by the first derivative of a Gaussian.

The Roberts' Cross operator [GW02] is one of the earliest edge detection algorithms, which works by computing the sum of the squares of the differences between diagonally adjacent pixels. This can be accomplished by convolving the image with two, 2*2 kernels (matrices).

$$G_x = \begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$G_y = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$$

The main reason for using the Roberts Cross operator is that it is very quick to compute. Only four input pixels need to be examined to determine the value of each output pixel, and only subtractions and additions are used in the calculation.

In addition there are no parameters to be set. Roberts Cross operator responds differently to different frequencies and orientations. Its main disadvantages are that since it uses such a small kernel, it is very sensitive to noise and the centre pixel cannot be located. It also produces very weak responses to genuine edges unless they are very sharp.

II. BACKGROUND

In this section, the Logarithmic image processing model and Parameterized Logarithmic image processing model and its properties are discussed.

A. *Logarithmic Image Processing Model*

The key in the logarithmic image processing [DC93] is a homomorphic function, which exhibits a logarithmic behavior, transforming the product into a sum. The image functions are bounded between values [0, *D*]. During the image processing, the mathematical operations on real valued functions use implicitly the algebra of the real numbers i.e. on the real axis are faced with results that do not belong anymore to the interval [0, *D*]. Initial implementations of the LIP model are given by Jourlin and Pinoli [JP88].

These mathematical tools only realize their efficiency when they are put into a well defined algebraic framework, most of the time of a vectorial nature. Further the operations such as the addition "+" and multiplication "x" might not be suitable for some image processing tasks.

The direct addition of brightness of two images is not a satisfactory solution to add two images, because the result sometimes may be out of the brightness range of a digital image. Therefore, new operations were developed and a new algebraic structure defined for a particular image processing problem. The LIP model, which provides a new algebraic structure and a set of new operations for image processing, has been proved to be mathematically well defined and also physically well justified because it is consistent with Weber's law and the saturation characteristics of the human visual system.

Jourlin and Pinoli, have defined the contrast of an image using the LIP model, in their paper, "Contrast definition and contour detection for logarithmic images", and have applied the contrast definition to edge detection. They have concluded that the LIP model's framework is more accurate for the introduction of a rigorous definition of contrast in the context of human vision, or more generally of logarithmic images and sensors.

B. The PLIP (Parameterized Logarithmic Image Processing) MODEL

This model modifies well known edge detection methods for better results, with the goal of a simple and quick edge detection process. There are five fundamental requirements for an image processing framework.

It must be based on a physically and/or psychophysically relevant image formation model.

Its mathematical structures and operations must be both powerful and consistent with the physical nature of the images.

Its operations must be computationally effective.

It must be practically fruitful.

It must not damage either signal.

A LIP based Sobel operator [DC93] works in the same manner as the standard Sobel operator, with the exception that it uses LIP arithmetic. As such, this operator also has the same desirable properties, independence of overall illumination and pixel by pixel changes in illumination. This method, on further improvement, is shown to yield better results.

The parameterization of the above model is the PLIP model [PWA07] which is the Parameterized Logarithmic Image Processing model, which is a non linear framework addressing the above said issues. By using this model, instead of simply using the same values as in linear image processing, better results were obtained and hence more accurate edge detection results. Further, the Sobel operator is only applied in the horizontal and vertical orientations. By including a diagonal PLIP Sobel filer, edges which are commonly missed by the Sobel filters are detected. These methods can also be extended to any edge detection methods for better results.

The following points illustrate the advantages in going for the PLIP model:

- It maintains the pixel values inside the allowable range.
- It more accurately process images from a human visual system point of view.

This model uses the PLIP arithmetic rather than the normal arithmetic (that is, usual addition, subtraction etc). The main feature of this model is that it uses the input image as well as the gray tone function of the input image, for the computation of the functions. This model is physically consistent with real world model for image processing.

From experimental results, it was seen that the Sobel method has a tendency to miss the lowest contrast edges, while the Canny algorithm is more likely to give crooked edges and false alarm pixels. The proposed algorithm, on the other hand, is able to find all edges in all the images, scoring better than 0.9 on Pratt's Figure of Merit for every image.
The properties of the PLIP arithmetic [PWA08], namely the PLIP addition, the PLIP subtraction and PLIP multiplication are explained as follows.
Consider f, g and h to be any gray tone values of an input image, I.

PLIP addition: PLIP addition (+) can be shown to satisfy the following properties:

Associativity
(f (+) (g (+) h)) = (f (+) (g (+) h)), for all f, g, h, input image

Neutral Element
(0 (+) f) = f, for f input image

Commutative
(f (+) g) = (g (+) f), for all f, g input image.

PLIP Subtraction: PLIP subtraction (-) is shown to have the same properties of that of the PLIP addition.

PLIP Multiplication: PLIP scalar multiplication (*) between two image elements have the following properties:

Associativity:
(a (*) (b (*) f) = ((a (*) b) (*) f), where a and b are real numbers.

Unit Element
1 (*) f = f

Double Distributivity
(a (*) (f (+) g) = (a (*) f) (+) (a (*) g)
(a (+) b) (*) (f) = (a (*) f) (+) (a (*) g)

III. PROPOSED ALGORITHM

The Proposed PLIP Method described earlier can be split into the following stages:

- Gray Tone Image
- PLIP Arithmetic
- Contrast Estimation
- Edge Detection
- Image Enhancement

A. *GRAY TONE IMAGE*

In this PLIP model, images are processed as gray tone functions. The gray tone image of the input image is computed as follows:

$$g\ (i,j) = M - f\ (i,j) \qquad (1)$$

where:
f (i,j) denotes the input image,
g (i,j) denotes the gray tone function of the input image, and
M denotes the maximum value of the range.
The gray tone function is much like a photonegative.

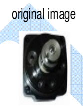

Fig. 1. Original input image

Fig. 2. Gray tone output image

B. PLIP ARITHMETIC

The PLIP arithmetic used in the model is summarized as follows

$$a\ (+)\ b = a + b - (a\ b\ /\ r\ (M)) \qquad (2)$$

$$a\ (-)\ b = k\ (M) * ((a - b)\ /\ (k\ (M) - g)) \qquad (3)$$

$$a\ (x)\ b = P^{-1}\ ((P\ (a)\ .\ P\ (b)) \qquad (4)$$

$$P\ (a) = -\ L\ (M)\ .\ \ln\ (1 - (f/\ L\ (M))) \qquad (5)$$

$$I\ (a) = L\ (M)\ .\ (1- \exp\ (-f/L\ (M)\ \wedge\ (1/2)) \qquad (6)$$

where:
(+) denotes PLIP addition,
(-) denotes PLIP subtraction,
(x) denotes PLIP multiplication,
a and b are any gray tone pixel values,
c is a constant,
M is the maximum value of the range,
r(M), L(M), and k(M) are arbitrary functions.
It has been found that the best value of these arbitrary functions is 1026.

C. CONTRAST ESTIMATION

As against other standard methods, which involve the use of mask sliding over the input image directly, in PLIP method, first the contrast between the pixels in the image is found. It is common to consider edges as region of high contrast.
The contrast estimation is done in two steps:
Define a neighborhood in the input image of any desirable size. The bigger the neighborhood the less sharper the image will be. Most commonly used size is a 3x3 or 5x5.
The next step is to find the LIP contrast between a given pixel and every other pixel in the neighborhood.
The LIP contrast between two pixels of an image is found by the following formula:

$$C=|f(x, y) \ (-) \ f(x', y')| \tag{7}$$

where f(x, y) and f(x',y') are any two pixels in the image.
This contrast estimator has many properties.

- It is not dependent on the intensity level of the illumination, and
- It is robust in small scale changing illuminations, specifically at the pixel by pixel scale.

The former can be shown through manipulation of the light intensity formulae used to derive the LIP model, and the latter cab be shown by modeling an image as the LIP summation of the objects plus the illumination.

D. EDGE DETECTION

Having found the contrast between the pixels in the neighborhood, the next step is to find the likelihood of an edge in the neighborhood. The weighted sum of these contrast measurements is taken to determine the likelihood that the pixel is an edge. This is done according to the following formula:

$$E = (1 / count(A)) \ (*) \ \Sigma \ C_{(x, y), (x', y')} \tag{8}$$

where count(A) represents the number of pixels in the neighbourhood A. Finally, the data is computed with a threshold to produce the binary output. The Sobel based LIP operator functions in the same manner as the standard Sobel kernels, with the exception that LIP arithmetic operations are used. The Sobel operator is applied for vertical orientation and horizontal orientation, and the magnitude of the two is then taken.
As will be seen in the results, however, this has a tendency to miss diagonal edges. From previous discussions, it is known that Robert Cross operator provides better result to the diagonal edges, but the exact locations of the edges are missed. Hence combining the property of Robert Cross and that of Sobel kernel, multi-directional Robert Cross kernels are obtained. This works well with horizontal, vertical and the diagonal edges.
The general matrix of Robert Cross is given as follows:

-1	0
0	1

Fig. 3. General Matrix of the Robert Cross operator

The required diagonal filter is constructed by rotating the above mask by 45 degrees and thereby converting the 2x2 block into a 3x3 block.
The matrix is as follows:

0	-1	0
0	0	0
0	1	0

Fig. 4. Matrix of the Diagonal filter

It is to be noted that all blank spaces are filled with 0s while rotating the previous matrix. It is important to note that, for both kernels, PLIP arithmetic is used. This information is collected for all four directions, and is combined in the same manner as in formula given for edge.

E. IMAGE ENHANCEMENT

The image obtained from the above algorithm can be enhanced by the Edge Detection using Image Enhancement (EDIE) algorithm [P+08]. This is mainly done for evaluating the performance of various algorithms.

IV. EXPERIMENTAL RESULTS

The algorithm was implemented in MATLAB 7.4 and the following images were used as inputs: Product 3S, Gold coin, Stone wall, Lena, Saturn, Peppers, Fire cube and House, all symmetric images. The results of the algorithm were compared with that of Sobel and Canny edge detection operators. The parameter used for evaluating the performance of the operators is the standard deviation of the output images. It can be shown that the algorithm has the least value of standard deviation and hence outperforms the leading operators for most of the images.

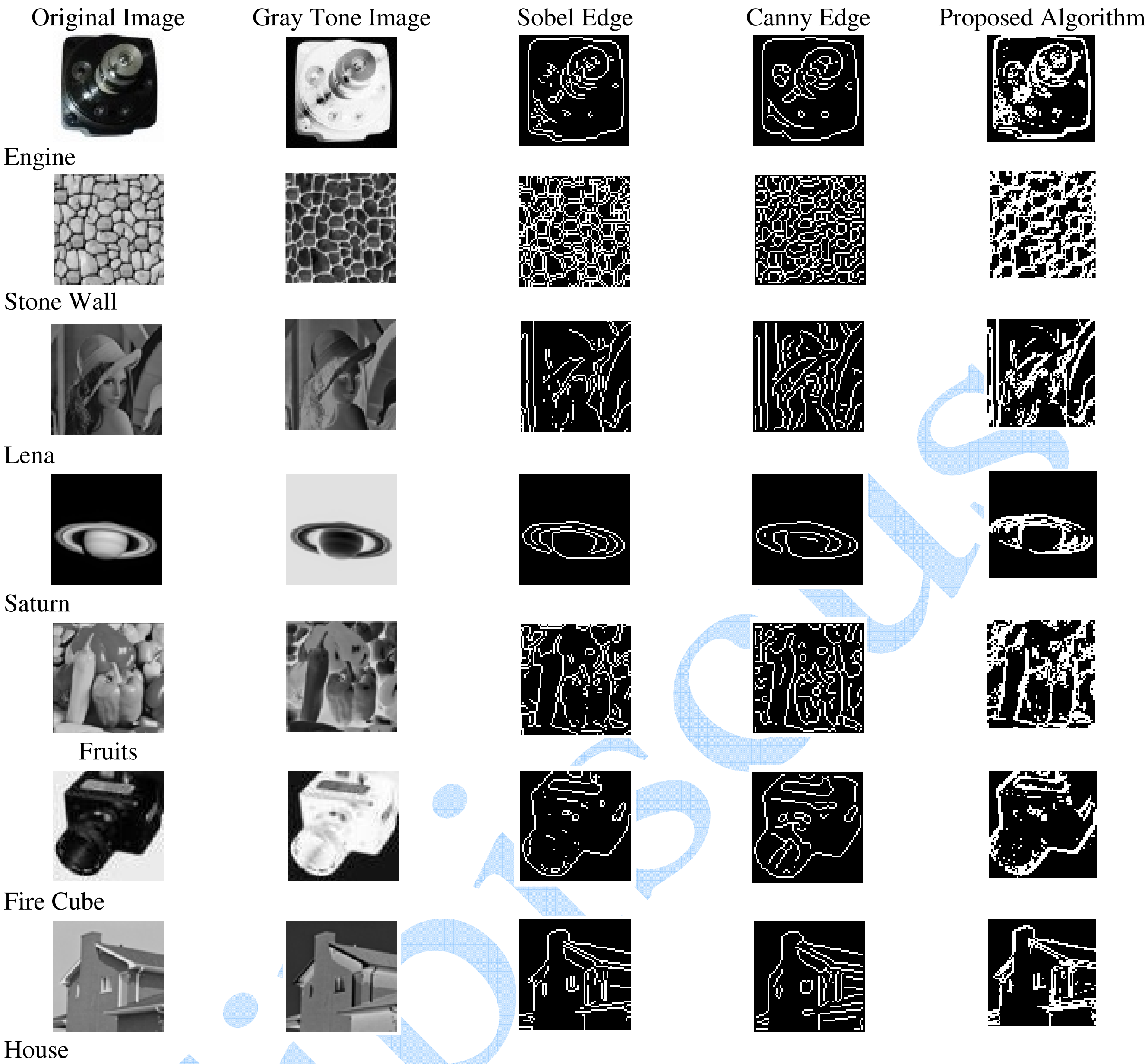

Fig. 5 Comparison of results of Sobel, Canny operators and the Proposed algorithm

A. COMPARISON OF RESULTS

The performance of the Sobel operator, Canny operator and the proposed algorithm is evaluated by comparing the standard deviations of the edge detected output image.

Table 1. Comparison of standard deviations of the Sobel operator, Canny operator and the proposed algorithm

Original Image	Sobel Operator	Canny Operator	Proposed Algorithm
Product 3s	0.1234	0.1239	0.1062
Gold coin	0.0709	0.078	0.0701
Stone wall	0.0227	0.0838	0.0638
Lena	0.1108	0.1272	0.0888
Saturn	0.0754	0.0713	0.0739
Peppers	0.0693	0.0919	0.0781
Fire cube	0.0733	0.0852	0.0726
House	0.0945	0.1105	0.0947

V.CONCLUSION

We implemented a PLIP based edge detection method. This combines the LIP contrast estimator based method with the LIP Robert Cross Method. From the table, it s shown that this method is better than the leading standard operators, Sobel and Canny, for most of the images, on the basis of measured standard deviation of the edge detected output image.
The application of this edge detection algorithm in conjunction with Edge Detection based Image Enhancement (EDIE) can further be demonstrated [ASP07]. It can be shown that, using the Parameterized LIP based Edge Detection method, we will be able to achieve better image enhancement using the EDIE algorithm.

REFERENCES

[ASP07] **S. S. Agaian, B. Silver, K. Panetta -** *Transform Coefficient Histogram Based Image Enhancement Algorithms Using Contrast Entropy*, IEEE Tran. Image Processing, 16(3), pp. 751—758, 2007.

[B+91] **J. C. Brailean, B. J. Sullivan, C. T. Chen, M. L. Giger** - *Evaluating the EM algorithm for image processing using a human visual fidelity criterion*, ICASSP-91, 1991 International Conference on Acoustics, Speech and Signal Processing, 1991.

[Can86] **J. Canny** - *A Computational Approach to Edge Detection*, IEEE Tran. Pattern Analysis and Machine Intelligence, 8(6), pp. 679—698, 1986.

[DC93] **G. Deng, W. L. Cahill** - *The Logarithmic Image Processing Model and Its Applications*, in Conf. Record 1993 Asilomar Conference on Signals, Systems, and Computers, volume 2, pp. 1047—1051, 1993.

[GW02] **R. C. Gonzalez, R. E. Woods** - *Digital Image Processing*, second edition, Prentice Hall, 2002.

[JP88] **M. Jourlin, J. C. Pinoli** - *A Model for Logarithmic Image Processing*, Journal of Microscopy, vol. 149, issue 1, pp. 21-35, 1988.

[J+12] **Jain et al** - *Edge Detection*, chapter 5, on http://www.cse.unr.edu/~bebis/CS791E/Notes/EdgeDetection.pdf, downloaded 2012.

[Pra00] **W. K. Pratt** - *Digital Image Processing*, New York: Wiley, 2000.

[PWA07] **K. A. Panetta, E. J. Wharton, S. S. Agaian** - *Parameterization of Logarithmic Image Processing Models*, IEEE Tran. Systems, Man, and Cybernetics, Part A: Systems and Humans, submitted for publication, 2007.

[PWA08] **K. A. Panetta, E. J. Wharton, S. S. Agaian** - *Logarithmic Edge Detection with Applications*, Journal of Computers, vol. 3, No. 9, pp. 11-19, 2008.

[P+08] **K. A. Panetta, E. J. Wharton, S. S. Agaian** - *Human Visual System-Based Image Enhancement and Logarithmic Contrast Measure*', EEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics, Volume 38 Issue 1, February 2008, Page 174-188.

[Tru12] **E. Trucco** - *Edge Detection*, chapter 4, on http://www.cse.unr.edu/~bebis/CS791E/Notes/EdgeDetection.pdf, downloaded 2012.