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Selecting the Most Favourable Edge Detection Technique for Liquid Level Inspection in Bottles

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Abstract

In this paper few edge detection techniques viz. Optimal & Template Based are compared to inspect the over and under fill liquid level of bottle in machine vision system. The text represents the steps and approaches for the inspection of over and under filled level in the bottle which would not only be helpful for quality inspection but in précised time too using different edge detection techniques. The results of Shen-Castan's ISEF optimal edge detection algorithm were found to be much better than the traditional edge detection methods like Roberts, Prewitt, Sobel, Marr- Hilderth LoG algorithm and Canny algorithm.

Keywords: Quality control, Machine Vision, Optimal Edge detection, ISEF (Shen Castan algorithm), Canny Edge Detection, LoG.

1. Introduction

Machine or electronic perception is one of the important advanced technological field, where significant developments have been made. Machine perception attempts to mimic sensory perception of human beings. Scientists have successfully endowed computers with vision by sophisticated digital cameras and machines. Intense research is in progress all over the world on applications of machine vision based systems. Machine vision system plays a vital role in manufacturing application, quality inspection and process monitoring as well. Traditionally, quality inspection is performed by trained human inspectors. In addition to being costly, this method is highly variable and decisions are not always consistent between inspectors or from day to day. This is, however, changing with the advent of electronic imaging systems and with the rapid decline in cost of computers, peripherals and other digital devices.

Taking one application of inspection of bottle filling, the method is very fast, quiet repetitive and subjective in nature. In this type of environment, machine vision systems are ideally suited for routine inspection and quality assurance tasks. Backed by powerful state-of-the art electronic technologies, machine vision provides a mechanism in which the human thinking process is simulated artificially. In machine vision based systems many edge detection techniques proposed by many researchers are prevailing. Each technique works nicely for the particular application only. There is not a general consensus about one or couple of methods to be used for edge detection in machine vision community. Significant work in bottle defect detection and in bottle filling level inspection is done.

In the area of bottle defect detection enough literature can be found out, while in case of bottle filling level inspection cited literature is not available due to its inherently simple task of edge detection and distance measurements. But the latest developments in the field of optimal edge detection algorithms are still untouched particularly in the application of bottle filling inspection. In [1] Y. Wang et al. proposed an algorithm for bottle finishing using Hough transform methods which would detect the defected bottle from the bulk and separate it out. In [2] Y. Wang et al. proposed watershed algorithm for bottle inspection by detecting out the possible defective regions in the upper portion of the bottle called the neck of the bottle and extracting these features from the image. Further for the purpose of classification the optimal hyper plane concept based on SVM method was used. In [3] Hui-MinMa et al. proposed an automatic inspection system based on eight CCD cameras which would give a decision about good or bad bottle based on top lead of the bottle. In [4] F.Daun et al. proposed a new algorithm stating that Hough transform and edge detection is a slow process so by analyzing the histogram of the edges of the bottle. Based on those edges an analysis was done on the shape and size of the bottle. In [12] E. Grosso et. all proposed a system and algorithm of quality control for printed flasks, bottles and cans, used as containers for drugs and beverages.

Motivated by the optimal edge detection techniques like LoG, Canny edge detection and ISEF edge detection, in this paper we apply LoG, Canny & ISEF edge detection methods to inspect the filling level of the bottle and compare the performances with respect to the traditional template based edge detection techniques like Robert, Prewitt, and Sobel edge detector. In Section 2 we discuss the problem of filling water bottle. Section 3 & 4 are regarding to Template based and optimal edge detection techniques for filling level inspection using machine vision. In Section 5 we propose an algorithm for liquid level inspection. In Section 6 results are given. Section 7 concludes the paper.

2. Problem Definition

Filling bottle using machine with accuracy is subject to error from a wide variety of potential problems from flow rates to glass bottle variations. To ensure consistent fill levels 100% quality inspection is required. Inspection systems must also be capable of keeping up high speed filling / bottling machinery. Figure 1 shows a schematic of bottle filling system. Failure to properly fill bottles to the correct volumes as stated on packaging results in loss of customer loyalty, consumer fraud allegations and recalls. For instance if the milk bottles are not properly filled which are prescribed for the babies then the proper nutrition in the required amount would not reach to the baby's body which results in loss of customer loyalty as well as fraud allegations. Overfilling results in giving away products and profits. The images of overfilled and under filled bottles are shown in Figure 2.

The inspection method chosen is fast enough to keep up with high speed filling machines and provide accurate and repeatable results. An approach to the above problem is made by extracting the edges from the image captured by a 3.2 mega pixel camera and then applying a distance based novel technique, to make a decision on the above said problem of over and under filling bottle inspection.

3. Template Based Edge Detection Techniques

Edge detection is one of the most commonly used operations in image analysis [5][6]. An edge is defined by a discontinuity in gray level values and is the boundary between an object and the background [5][10]. Many edge detectors are available based on templates.

3.1 Roberts Edge detector [11]

The Robert's Cross operator performs a simple, quick to compute,2-D spatial gradient measurement on an image. The operator consists of a pair of 2×2 convolution kernels as shown in below matrix.

$$Gx = \begin{matrix} 0 & 1 \\ -1 & 0 \end{matrix} \qquad Gy = \begin{matrix} 1 & 0 \\ 0 & -1 \end{matrix}$$

These kernels are designed to respond maximally to edges running at 45° to the pixel grid, one kernel for each of the two perpendicular orientations. The kernels can be applied separately to the input image, to produce separate measurements of the gradient component in each orientation (Gx and Gy). The gradient magnitude is given by:

$$|G| = \sqrt{G_x^2 + G_y^2} \qquad (1)$$

3.2 Prewitt Edge Detector [11]

Prewitt operator is similar to the Sobel operator and is used for detecting vertical and horizontal edges in images.

$$\begin{matrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{matrix} \qquad \begin{matrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{matrix}$$

3.3 Sobel Edge Detector [9] [11]

The Sobel edge detector having the following values:

$$Sy= \begin{matrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{matrix} \qquad Sx= \begin{matrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{matrix}$$

One way to view these templates is as an approximation to the gradient at the pixel corresponding to the center of the template. Referring to Any template based edge detector, it is having specific application. The main disadvantage of these edge detectors is their dependence on the size of the object, they are having high sensitivity to noise, and are inaccurate too.

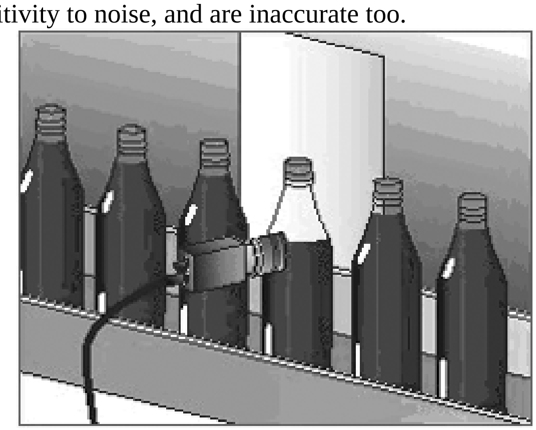

figure 1. Outline of Bottle level filling System
{Courtesy: OMRON Tech. for focused Automation [4]}

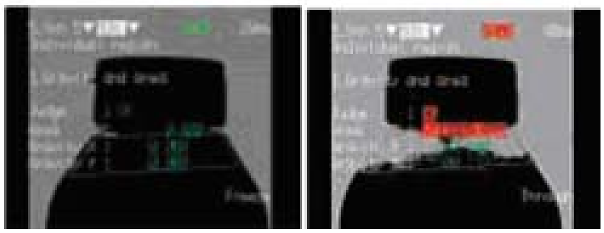

figure 2. Over and Under filled bottles
{Courtesy: OMRON Tech. for focused Automation [4]}

4. Optimal Edge Detection Techniques

Marr's theory concluded from neurophysiological experiments tell that object boundaries are the most important cues that link an intensity image with its interpretation. Marr studied the literature and explored the fact that a step edge corresponds to an abrupt change in the image function. The first derivative of the image function should have an extremum at the position corresponding to the edge in the image, and so the second derivative should be zero at same position, however it is much easier and more precise to find zero crossing position than an extremum.

4.1 LoG ALGORITHM [9]

LoG is outlined in Table 1. for which Locality is not especially good and the edges are not always thin. Still it is much better than the previous one in case of low signal to noise ratio.

Malfunctioning at corners, curves and where the gray level intensity function varies, not finding the orientation of edge because of using the Laplacian filter. Two advanced and optimized edge detectors are Canny Edge Detectors and (Shen and Castan's) Infinite Symmetric Exponential Filter (ISEF). Both are classified as Mathematical Edge Detectors.

Table 1. LoG algorithm

No.	STEPS
1	Convolve image I with a 2D Gaussian function.
2	Compute Laplacian of convolved image, call it L.
3	Edge pixels are those for which there is a zero crossing in L.

4.2 CANNY ALGORITHM [7][8]

Canny assumed a step edge subject to white Gaussian noise. The edge detector was assumed to be a convolution filter f which would smooth the noise and locate the edge. The problem is to identify the one filter that optimizes the three edge detection criteria.

Canny specified three issues that an edge detector must address. These are:

4.2.1. Error rate. The edge detector should respond only to edges, and should find all of them; no edges should be missed.

4.2.2. Localization. The distance between the edge pixels as found by the edge detector and the actual edge should be as small as possible.

4.2.3. Response. The edge detector should not identify multiple edge pixels where only a single edge exists.

The value of SNR is the output signal to noise ratio (error rate), and should be as large as possible: we need lots of signal and little noise. The localization value represents the reciprocal of the distance of the located edge from the true edge, and should also be as large as possible, which means that the distance would be a small as possible.

Canny attempts to find the filter **f** that maximizes the product SNR*localization subject to the multiple response constraint, and while the result is too complex to be solved analytically, an efficient approximation turns out to be the first derivative of a Gaussian function.

Canny algorithm (Table 2) convolves the image with the derivative of a Gaussian, the Canny implementation uses a wrap-around scheme when performing the convolution, and the areas near the boundary of the image are occupied with black pixels, although sometimes with what appears to be noise. Shen and Castan's filter gives better signal to noise ratios than Canny's filter and provides better localization.

This could be because the implementation of Canny's algorithm approximates his optimal filter by the derivative of a Gaussian, whereas Shen and Castan use the optimal filter directly, or could be due to a difference in the way the different optimality criteria are reflected in reality.

4.3 ISEF ALGORITHM [5][8]

The edge can be detected by any of template based edge detector but Shen-Castan Infinite symmetric exponential filter based edge detector is an optimal edge detector like Canny edge detector which gives optimal filtered image.

Shen and Castan agree with Canny about the general form of the edge detector: a convolution with a smoothing kernel followed by a search for edge pixels. However their analysis yields a different function to optimize namely, they suggest minimizing (in one dimension):

$$c_N^2 = \frac{4\int_0^{\infty} f^2(x)dx \cdot \int_0^{\infty} f'^2(x)dx}{f^4(0)} \quad (2)$$

That is ISEF, the function that minimizes C_N is the optimal smoothing filter for an edge detector. The optimal filter function they came up with is the infinite symmetric exponential filter (ISEF).
In one dimension the ISEF is:

$$f(x) = \frac{p}{2} e^{-p|x|} \quad (3)$$

First the whole image will be filtered by the recursive ISEF filter in X direction and in Y direction, which can be implement by using equations as written below.

Table 2. CANNY algorithm [7][8]

No.	STEPS
1	Read the image I.
2	Convolve a 1D Gaussian mask with I.
3	Create a 1D mask for the first derivative of the Gaussian in the x and y directions.
4	Convolve I with G along the rows to obtain Ix, and down the columns to obtain Iy.
5	Convolve Ix with Gx to have Ix’, and Iy with Gy to have Iy’.
6	Find the magnitude of the result at each pixel (*x, y*). $M(x,y) = \sqrt{I'_x(x,y)^2 + I'_y(x,y)^2}$

Recursion in x direction:

$$y_1[i,j] = \frac{(1-b)}{(1+b)} I[i,j] + b\, y_1[i,j-1], \quad (4)$$
$$j = 1...N, i = 1..M$$

$$y_2[i,j] = b\frac{(1-b)}{(1+b)} I[i,j] + b\, y_1[i,j+1] \quad (5)$$
$$j = N...1, i = 1..M$$
$$r[i,j] = y_1[i,j] + y_2[i,j+1] \quad (6)$$

Recursion in y direction:

$$y_1[i,j] = \frac{(1-b)}{(1+b)} I[i,j] + b\, y_1[i-1,j], \quad (7)$$
$$i = 1...M, j = 1..N$$

$$y_2[i,j] = b\frac{(1-b)}{(1+b)} I[i,j] + b\, y_1[i+1,j], \quad (8)$$
$$i = M...1, j = 1..N$$
$$y[i,j] = y_1[i,j] + y_2[i+1,j] \quad (9)$$

b=Thinning Factor ($0<b<1$)

Then the Laplacian image can be approximated by subtracting the filtered image from the original image. At the location of an edge pixel there will be zero crossing in the second derivative of the filtered image. The first derivative of the image function should have an extreme at the position corresponding to the edge in image and so the second derivative should be zero at the same position. And for thinning purpose apply non maxima suppression as it is used in Canny for false zero crossing.

The gradient at the edge pixel is either a maximum or a minimum. If the second derivative changes sign from positive to negative this is called positive zero crossing and if it changes from negative to positive it is called negative zero crossing. We will allow positive zero crossing to have positive gradient and negative zero crossing to have negative gradient, all other zero crossing we assumed to be false and are not considered to an edge. Now gradient applied image has been thinned, and ready for the thresholding.

Table 3. ISEF algorithm [5][8]

No	Steps
1	Apply ISEF Filter in X direction
2	Apply ISEF Filter in Y direction
3	Apply Binary Laplacian Technique
4	Apply Non Maxima Suppression
5	Find the Gradient
6	Apply Hysteresis Thresholding
7	Thinning

The simple thresholding can have only one cutoff but Shen-Castan suggests to use Hysteresis thresholding. Spurious response to the single edge caused by noise usually creates a streaking problem that is very common in edge detection. The output of an edge detector is usually thresholded, to decide which edges are significant and streaking means the breaking up of the edge contour caused by the operator fluctuating above and below the threshold.

Streaking can be eliminated by thresholding with Hysteresis. Individual weak responses usually correspond to noise, but if these points are connected to any of the pixels with strong responses, they are more likely to be actual edge in the image. Such connected pixels are treated as edge pixels if there response is above a low threshold. Finally thinning is applied to make edge of single pixel.

The ISEF algorithm is given in Table 3. Canny and Shen-Castan's ISEF both are optimal edge detectors. As we can know that Canny is using the Gaussian function to approximate the edge, where as the ISEF is based on exponential filter which gives better approximation as compare to Canny to find the edge even in the image that has less signal to noise ratio.

Shen & Castan's ISEF gives better signal to noise ratio and provide better localization because it uses the optimal filter directly. Shen & Castan's ISEF will create spurious responses to noisy and blurred edges. Third issue it can satisfies through tunning of parameters such as Thinning factor b, High threshold, low threshold and Thinning. Recursion always speeds up the convolution.

5. Proposed Algorithm

Image of a filled bottle is captured using a CCD camera as shown in Fig-3. The image is cropped to make it a normalized image with respect to height of the conveyor belt. For the comparative study, different Edge detection techniques like Different template based edge detectors, Canny, LoG and ISEF Edge detection techniques can be applied. The required steps for each edge detection algorithms are given in Tables 1, 2 and 3 respectively. The proposed algorithm is outlined in Table 4. We propose a simple and novel algorithm to decide the over/under filling level of bottle based on distances from the center of the region of interest (ROI). The algorithm is presented in Table 5.

Table 4. Proposed algorithm

No.	Steps
1.	Capture the image.
2.	Apply an optimal Edge detection Algorithm
3.	Find a region of interest (ROI)
4.	Apply the proposed technique of Table 5 to conclude about the over/under filling of bottle.

Table 5. Steps for finding average distance

No.	Steps
1	Decide a horizontal region of interest (Figure 4)
2	Bottom line of the cap neck end is taken as a reference. (Figure 5)
3	For each and every pixel having value 1 in box 1 (Figure 5) find a pixel having value 1 in box 2.
4	Find the vertical distance between these two pixels.
5	Do it for all the pixels having value 1, in both boxes 1 and 2. (Figure 6)
6	Take the average of all distance lines: *avgd*. (Figure 7, red line) If *avgd* > the datum distance, the bottle is over filled. If *avgd* < the datum distance the bottle is under filled.

Table 6. Distance found using Average (Template Based Edge Detection Techniques)

Avg. Distance	Roberts	Prewitt	Sobel
(in No. of pixel)	**113**	**106**	**113**
(in mm)	**39.85**	**37.38**	**39.85**

Table 7 Distance found using Average (Optimal Edge detection Techniques)

Avg. Distance	LoG	Canny	ISEF
(in No. of pixel)	**101**	**112**	**107**
(in mm)	**35.68**	**39.5**	**37.63**

figure 3. Original Image

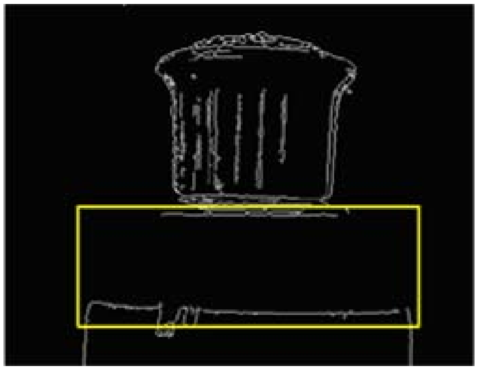

figure 4. Image with Region of Interest

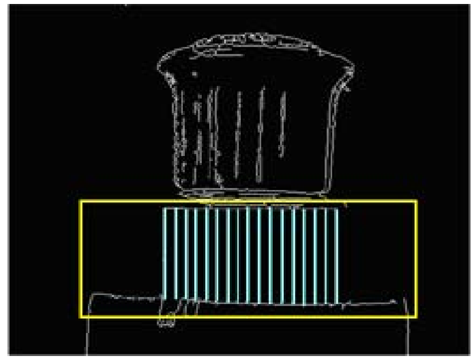

figure 6. Image with distance lines

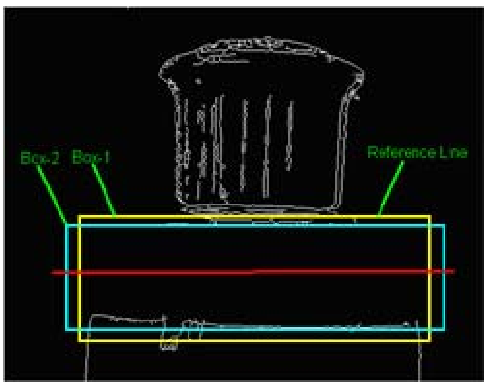

figure 5. Image with Regions in BOX 1 & BOX 2

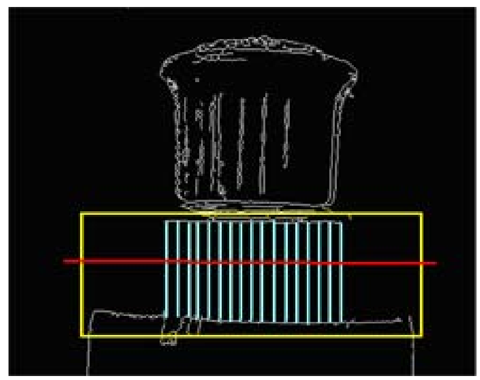

figure 7. Image with datum line differentiating the Level

6. Results

We have applied different edge detection techniques explained above, outputs for each of these methods are shown in figures 8, 9, 10, 11, 12 & 13 respectively. After applying the proposed algorithm we get the distances as given in appendix for which, the average distances are available as shown in Table 6 & Table 7. The variation of distances which we get after applying the proposed algorithm for each edge detection technique is shown in figures 14, 15, 16, 17, 18 & 19. From figures 14, 15, 16, 17, 18 & 19 we can conclude that the distance variation found using Roberts, Prewitt, Sobel, LoG & Canny is not so regulated as compared to ISEF.

7. Conclusion

In this paper we have compared performance of different edge detection techniques for a simple application of water bottle level filling inspection using machine vision system. Compared to all the edge detection techniques ISEF gives regulated edge detection and hence the decision of under and over filled of the bottles can be taken precisely. Compared to LOG, the Prewitt and Sobel operators based edge detectors give better performance. Very high variation is obtained in case of Roberts operator based edge detection.

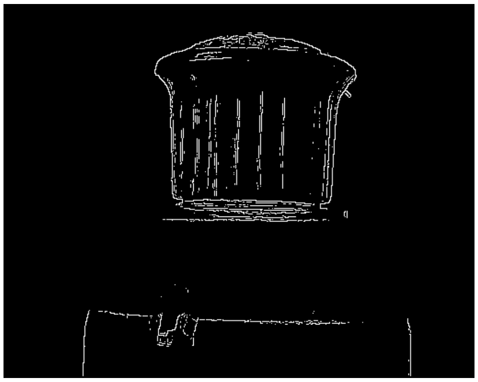

figure 8. Image after the edge detection (Roberts)

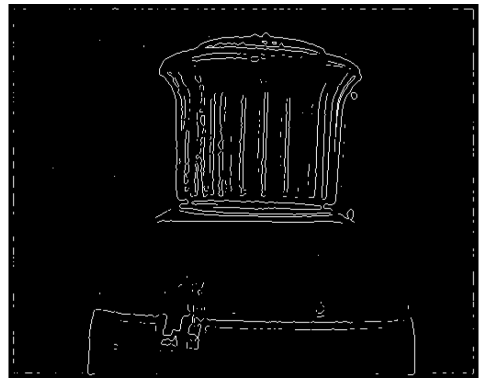

figure 11. Image after the edge detection (LoG)

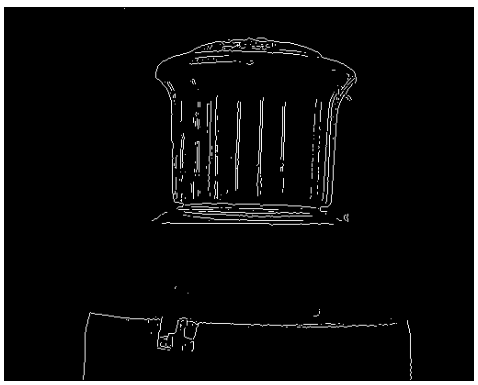

figure 9. Image after the edge detection (Prewitt)

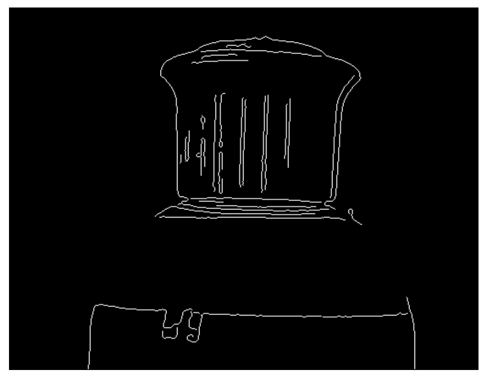

figure 12. Image after the edge detection (Canny)

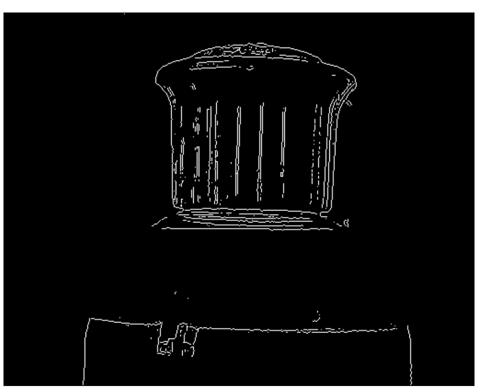

figure 10. Image after the edge detection (Sobel)

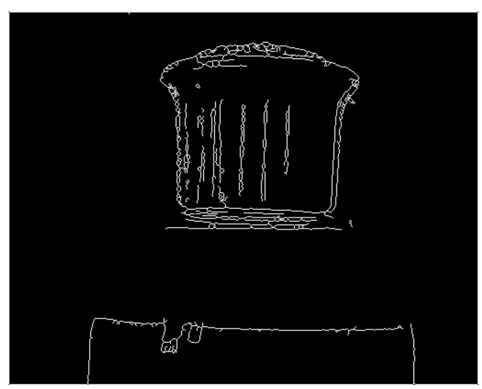

figure 13. Image after the edge detection (ISEF)(b=0.6,HT=100,LT=50,thinning=8)

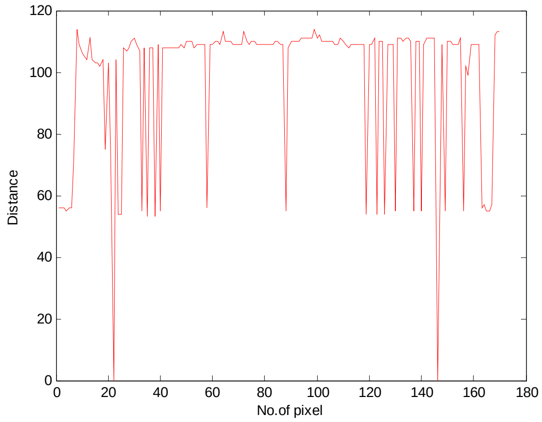

figure 14. Linear distance plot for Roberts

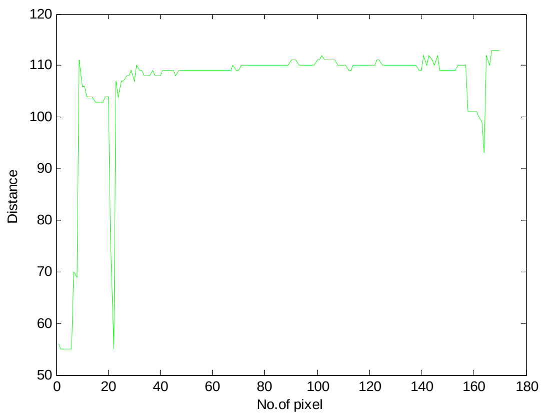

figure 15. Linear distance plot for Prewitt

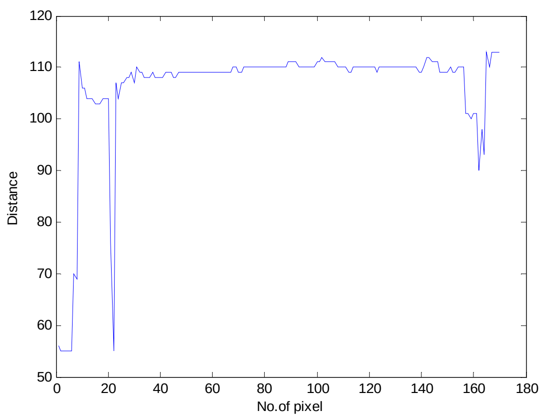

figure 16. Linear distance plot for Sobel

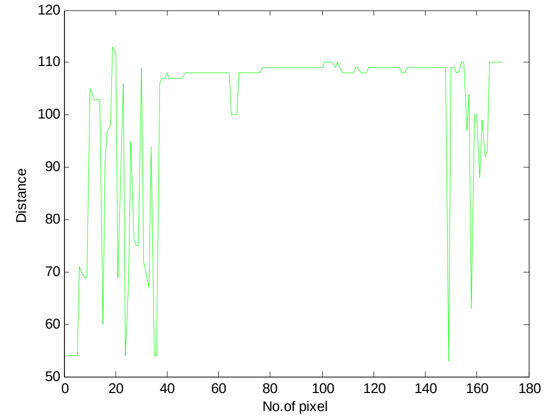

figure 17. Linear distance plot for LoG

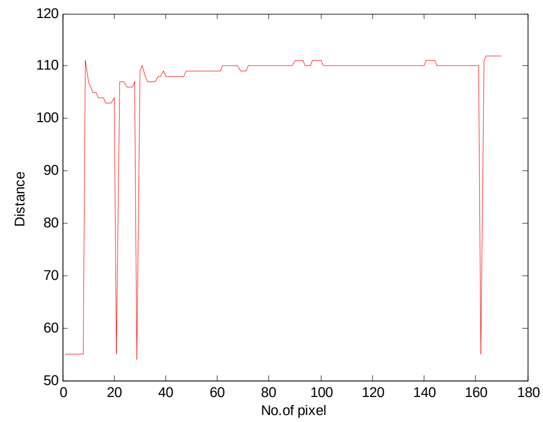

figure 18. Linear distance plot for Canny

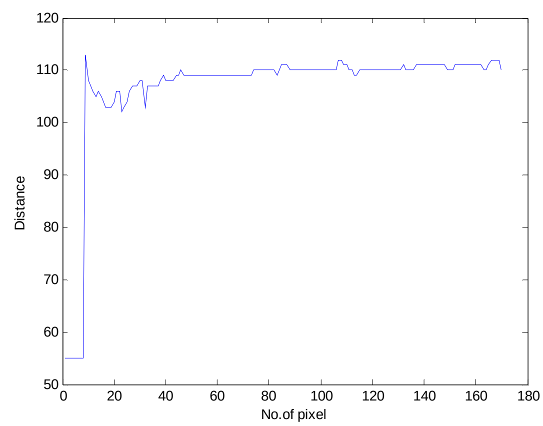

figure 19. Linear distance plot for ISEF

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Appendix

Distances Found using					
Roberts	**Prewitt**	**Sobel**	**Log**	**Canny**	**ISEF**
56	56	56	54	55	55
56	55	55	54	55	55
56	55	55	54	55	55
55	55	55	54	55	55
56	55	55	54	55	55
56	55	55	71	55	55
71	70	70	70	55	55
114	69	69	69	55	55
109	111	111	69	111	113
106	106	106	105	107	108
105	106	106	104	106	107
104	104	104	103	105	106
111	104	104	103	105	105
104	104	104	103	104	106
103	103	103	60	104	105
103	103	103	91	104	104
102	103	103	97	103	103
104	103	104	98	103	103
75	104	104	113	103	103
103	104	104	112	104	104
76	76	76	69	55	106
0	55	55	92	107	106
104	107	107	106	107	102
54	104	104	54	107	103
54	107	107	68	106	104
108	107	107	95	106	106
107	108	108	76	106	107
108	108	108	75	107	107
110	109	109	75	54	107
111	107	107	109	109	108
109	110	110	72	110	108
107	109	109	69	108	103
55	109	109	67	107	107
108	108	108	94	107	107
53	108	108	54	107	107
108	108	108	54	107	107
108	109	109	106	108	107
53	108	108	107	108	108
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