A 3-Pixel Fuzzy Mask for Edge Detection

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Abstract. A new group of fuzzy masks is proposed in this study to perform edge detection of images. A group of 3-pixel masks is used to detect edges in four directions. The resulting images retain more edges and show better continuity of the edges compared to the ones produced by the conventional 3 x 3 fuzzy masks. This is accomplished more efficiently using fewer fuzzy rules. Furthermore, thinning functions incorporated yielded edges with good continuity and optimal thickness.

1. Introduction

Edge detection is one of the many important areas in image processing. Edge detection enables interpretation of objects based on their outlines. Literature is abundant concerning the application of edge images in various fields such as medical diagnosis [1], detection of defects [2] and robotics navigation [3]. Edge detection of an image is based on the concept that a line can be detected to separate two regions which show significant changes in grey level values. Pioneering works by Sobel [4] and Canny [5] are well established methodologies today and has inspired many variations of edge detection methods based on them.

It is well known that changes in grey levels between regions are not abrupt but gradual. Furthermore, the changes are ambiguous and imprecise in nature. These characteristics lend themselves well to the application of fuzzy logic which is suitable to address such problems. Russo [6] pioneered the use of a fuzzy mask to classify pixels as edges and non-edges in a software implementation based on the luminance differences between the center pixel and its neighboring pixels. Tao and Thompson [7] used sixteen fuzzy rules corresponding to the various 3 x 3 pixel combinations representing the differences of grey levels of the surrounding pixels with the centre pixel. Begol and Maghooli [8] expanded the fuzzy rule base using the same fuzzy masks to perform similar tasks.

Lee, et al. [9] proposed a novel edge detection method which involved automatic fuzzy thresholding of various pixel groups. Their method demonstrated reliability in detecting doorframes along a corridor used by a mobile robot for localization despite changing illumination conditions. In this case no adjustment of parameters was necessary.

The identification of edges based on the concept of competition was introduced by Liang and Rooney [10]. This involved feeding feature vectors, which represented magnitude differences of grey level patterns, into a fuzzy network. The fuzzy network utilized Epanechikov fuzzy sets that classified...
pixels into edge, background and speckle classes. Thinning of edges were also achieved in a shorter processing time compared with Canny’s method.

An improvement [11] to fuzzy rule based edge detection methods was made by incorporating a fuzzy rule base to detect continuity in edges. Utilization of maximum entropy principles in the adjustment of the parameters of the fuzzy sets enabled detection of noisy images without the need of filtering.

The concept of generating fuzzy images from gradient magnitudes was introduced by Molina, et al. [12]. Parametric functions for the Triangular, Gaussian, Sigmoidal and Trapezoidal sets were tuned by a histogram based strategy [13] to achieve this task. This novelty was incorporated into the Canny edge detection method. Recently researches have switched to type 2 fuzzy logic [14] to improve the quality of the edges. Interval type 2 fuzzy logic [15] has shown that improvements could still be made in the edge detection of images within the fuzzy logic paradigm.

Type 2 fuzzy sets [16] were also used to determine the magnitude of fuzziness across a gradient histogram to determine the double threshold values of the Canny algorithm for edge detection. A generalized type-2 fuzzy logic [17] was implemented by using the morphological gradient values to determine the parameters of the antecedent and consequent fuzzy sets. It resulted in better detection of images compared to the interval type 2 and type 1 fuzzy logic methodologies. Interval Type 2 Fuzzy Systems coupled with morphological gradient was used by Gonzales, et al. [19] to extract edges from colour images.

Recently, a solution to the optimization of the parameters of interval type 2 fuzzy sets and type 1 fuzzy sets [20] was provided by utilizing the Cuckoo search algorithm and genetic algorithm methodologies. Results showed that the optimized parameters of the interval type 2 fuzzy antecedent sets produced edges which were closer to the ideal compared to those produced by the normally optimized interval type-2, optimized and non-optimized type 1 fuzzy antecedents and Sobel filters.

The conventional fuzzy masks technique uses a multitude of templates which detects edges in various directions but is unable to accommodate all combinations of dark and bright pixel images when convolved together in a fully 3x3 pixel setting. As a result, some edges might not fully be detected or even missed out altogether. To increase the number of templates substantially might be computationally impractical.

In this paper a new fuzzy mask is proposed and its performance in terms of edge detection is compared to one of the conventional fuzzy masks technique [8]. The edge detection is done in four directions viz. north-south, east-west, northwest-southeast and northeast-southwest using a 3-pixel template. In each direction there are six permutations or arrangements of adjacent bright and dark pixels that are used to detect edges. This ensures that no combinations of dark and bright pixels of images will be missed out in each direction when convolved with an image. These permutations are represented as a set of fuzzy rules. A separate set of rule base is added to perform the thinning of edges. Resulting images showed better continuity of the edges and also more details were retained even when thinning was carried out compared to the images yielded by the conventional fuzzy masks.

2. Methodology

Figure 1 shows the 3x3 pixel mask that is used as a fuzzy mask. Pixels i2, i5 and i8 represent the North-South directions. Pixels i4, i5 and i6 represent the East-West directions. Pixels i1, i5 and i9 represent the North-West and South-East directions. Pixels i3, i5 and i7 represent the North-East and South-West directions. Six combinations of pixel arrangements are embedded in each of these directions. This enables detection of edges in their respective directions. Each pixel is categorized into either bright or dark pixels.

Figure 2 shows all the possible combinations of the three-pixel groups for the edge detection task. Since there are three pixels in a certain direction with each pixel categorized as either a bright or dark pixel there will be eight combinations all together. Note that the all consecutive dark and bright pixel are discarded since they do not detect edges.
Group 1 pixels represent the antecedents associated with the middle intensity pixel value. Group 2 pixels represent the antecedents associated with the bright intensity pixel values. The consequents consist of bright, dark and middle intensity pixels which represent the edges. The fuzzy inferencing incorporating these rules is performed in the aforesaid four directions. The mask on the bottom right represents the fuzzy rule to remove noise or speckles in the image.

The input fuzzy sets representing the bright and dark pixels use Gaussian functions, each with a standard deviation value of 110. This value produces sufficient overlap between the two fuzzy sets. This is shown Figure 3. Figure 4 shows the fuzzy output set representing the dark, edge and bright pixels. Each has a mean grey value of 5, 135 and 250 respectively. The small standard deviation value of 5 provides the separation of pixels into their respective groups. Mamdani min-max inferencing [21] is used in this case. Defuzzification involves using the singleton method instead of the centroid method as the latter is computationally more intensive.

![Figure 1. 3x3 Mask](image)

![Figure 2. Pixel Combinations for Edge Detection and Noise Removal](image)
In edge detection, excessively thick lines are undesirable. In such situations thinning is desired while retaining most of the outlines of the objects. To achieve this task, only the maximum membership function value from the six combinations of the rule base is chosen in each respective direction. In addition to this, another 8 rules perform edge linking to minimize any loss of edges. The masks representing those rules are shown in Figure 5.

These masks link any discontinuous lines in all directions. The broken lines may have been falsely discarded in choosing the maximum membership function value in each direction during the edge detection process.

All in all, there are a total of 7 rules used for the edge detection process since the 6 rules for each direction are similar and can be written as reusable subroutines and one rule is used for denoising. As for the thinning process another 8 rules for edge linking are added. The economical use of the fuzzy rules reduces computation time while optimizing the edge detection process.
Figure 5. Masks for Edge Linking

Figure 6 shows the histograms for the number of pixels for each grey level retained after defuzzification. The histograms show an overwhelmingly concentrated number of pixels around the grey level value of 166 and 135 for the proposed method and the conventional fuzzy mask technique respectively. The importance of these values is that they are chosen as thresholding values.

Since the performance of the new fuzzy masks are compared to the conventional fuzzy masks [8], it is appropriate to show the conventional fuzzy masks representing all the fuzzy rules. They are reproduced and shown in Figure 7. In the latter case the input fuzzy sets consist of Gaussian functions representing dark and bright pixels with mean values of 0 and 255 respectively. The standard deviation values used for both input fuzzy sets were 60. The output fuzzy sets used were similar to the ones used for the new fuzzy masks. The values used were obtained by exhaustive tuning to obtain the clearest image with the least amount of noise for each case.
Figure 7. Conventional Fuzzy Masks

Figure 8 shows the representation of the 3-pixel templates in the form of IF-THEN rules with denoising in the North-South direction. Rules 1 to 6 can be repeated as reusable subroutines in the other 3 directions. The denoising rule is used only once.

If $I_2$ is Dark AND $I_5$ is Dark AND $I_8$ is Bright THEN $I_5$ is an EDGE pixel ________ Rule 1
If $I_2$ is Bright AND $I_5$ is Dark AND $I_8$ is Dark THEN $I_5$ is an EDGE pixel ________ Rule 2
If $I_2$ is Bright AND $I_5$ is Bright AND $I_8$ is Dark THEN $I_5$ is an EDGE pixel ________ Rule 3
If $I_2$ is Dark AND $I_5$ is Bright AND $I_8$ is Dark THEN $I_5$ is an EDGE pixel ________ Rule 4
If $I_2$ is Dark AND $I_5$ is Bright AND $I_8$ is Dark THEN $I_5$ is a BRIGHT pixel ________ Rule 5
If $I_2$ is Bright AND $I_5$ is Dark AND $I_8$ is Dark THEN $I_5$ is a BRIGHT pixel ________ Rule 6

If $I_1$ is Dark AND $I_2$ is Dark AND $I_3$ is Dark AND
If $I_4$ is Dark AND $I_5$ is Bright AND $I_6$ is Dark AND
If $I_7$ is Dark AND $I_8$ is Dark AND $I_9$ is Dark THEN $I_5$ is a DARK pixel ________ Rule 7

Figure 8. IF-THEN Rule Implementation

A comparison of results was also made with the images produced by the Sobel and Canny operators. All the algorithms were written using the open source software Processing version 1.5.1 which can be downloaded from https://processing.org/. The threshold grey value for the Sobel operator is 30 and upper and lower threshold values of the Canny operator were 5 and 10 respectively.

3. Results
Figures 9 and 10 show the edge detected images produced from their respective photos. One shows an outdoor image of the Kuala Lumpur tower and its surroundings and the other shows the indoor image of a mobile robot.
In the first case the edges produced by the proposed method is comparable to the one produced by the Sobel operator. Most outline details are retained, bold and continuous. However, the outlines produced by the Sobel operator is slightly thicker. This is clearly borne out by the outlines of the Kuala Lumpur tower shown in Figure 9. The edge detected image resulting from the thinning operation of the proposed method is also shown. The outlines are thinner but still retain most edges uniformly. Although the conventional fuzzy masks [8] uses more rules compared to the new fuzzy mask it is less efficient in capturing the edges. The edges produced from the proposed method is markedly sharper compared to the one obtained through the conventional fuzzy masks. The Canny operator resulted in faint edges. The bottom portion of the image showed that many details were thinned and retained but produced a somewhat scattered edge formation.

The results from the indoor mobile robot photo showed a similar outcome. The new fuzzy mask and the Sobel operator produced detailed outlines but in the latter case the edges were overly thick. The proposed method produced a clearly marked separation between the tiles and clearly shows the edges of the grout. In the case of the Sobel operation the separation of the tiles was not very clear as shown by their overly thick lines.

The edge detected images resulting from the proposed fuzzy mask with the thinning process were slightly fainter than the one produced from the conventional fuzzy masks. However, on closer inspection, the former method retained a more uniform and continuous edge. This is clearly borne out by the continuous edge of the mounted camera. The edges of the camera obtained through the conventional fuzzy mask is broken. The Canny operator in this case produced outlines that were thinned but appearing discontinuous.

To validate the improvement of the proposed method quantitatively a similarity measure analysis is carried out between the convolution of the conventional fuzzy masks and the proposed fuzzy masks with the captured image. Figure 11 shows the sample 3 x 3 image segment with its dark and bright pixel configuration. The labelling of the pixel positions is also shown.
In the proposed method a 3-pixel template is convolved with a 3 x 3 pixel image segment in the North-South direction as shown in Figure 12. This is repeated for the other three directions. In the conventional method a 3x3 pixel image is convolved with the templates shown in Figure 13. Note that this image does not resemble any of the templates in Figure 13. This is to compare the efficacy of the two methods in detecting edges.

The similarity measure is given by the equations 1 and 2.

\[
S = \sum_{x=1}^{x=k} \frac{|\text{pixel } (I_{T_x}) - |\text{pixel } (I_1)| |}{k} \quad (1)
\]

\[
H_S = \max_{j=1}^{j=m} (H_j) \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad (2)
\]

where:
- \(k\) = number of pixels
- \(m\) = total number of templates
- \(I_{T_x}\) = Template/Mask
- \(I_x\) = Image
Figure 13. Convolving the Conventional Template with an Image

The similarity measure is easily calculated. If the pixel of the image and its coincident template pixel belong to the same pixel category the difference value is zero. On the other hand, if the image pixel and template pixel belong to different pixel categories a difference value of one is produced. For instance, in the case of the conventional fuzzy mask, the similarity measure between the image and the first template is $H_1 = 1 - ((1+1+1+1+0+0+0+1+1)/9) = 3/9$.

The same treatment applies to the proposed method. In the convolution between the 3-pixel segment image with the first template in the North-South direction the similarity measure value $H_f = 1 - ((1+1+1)/3) = 0$. The segment images are convolved with all the templates to obtain their respective similarity measure values. Finally, the maximum value is chosen as the value representing the similarity measure value. Tables 1 and 2 show the complete calculated similarity values for the conventional and proposed methods.

In the conventional method the maximum similarity value is 8/9. In the proposed method the maximum similarity value is 1 in all four directions. This shows that the templates in the proposed method can more efficiently detect images in all directions. However, in some templates the similarity values are zero. In the conventional method, none of the templates yielded a zero-similarity measure value but always partially detected an edge although its similarity values could be low. The templates used in the proposed method efficiently detects all permutations of dark and bright pixels in an economical manner without the requirement to use a large number of templates as in the case of the conventional method.

4. Conclusions and Recommendations
The results obtained showed that the proposed fuzzy masks outperformed the conventional fuzzy masks in that they detected edges more sensitively by considering all pixel combinations to capture edges in four directions in a more complete manner. Furthermore, by considering only the maximum membership function value in each direction coupled with a new set of rules for edge linking and noise removal,
thinning of the edges can be carried out while retaining important edges uniformly. Compared to the conventional fuzzy masks the proposed method uses less rules and the rules for each direction can be reused by encoding them as reusable subroutines.

**Table 1. Similarity Measure for the Conventional Method**

| Similarity Measure Between Template and Image | Similarity Measure Between Template and Image |
|---------------------------------------------|---------------------------------------------|
| H₁ = 3/9                                    | H₈ = 6/9                                    |
| H₂ = 8/9                                    | H₉ = 6/9                                    |
| H₃ = 8/9                                    | H₁₀ = 7/9                                   |
| H₄ = 5/9                                    | H₁₁ = 4/9                                   |
| H₅ = 6/9                                    | H₁₂ = 1/9                                   |
| H₆ = 2/9                                    | H₁₃ = 6/9                                   |
| H₇ = 7/9                                    | H₁₄ = 2/9                                   |
| H₈ = 5/9                                    | H₁₅ = 7/9                                   |
| H₉ = 7/9                                    | H₁₆ = 5/9                                   |
| H₁₀ = 2/9                                   | H₁₇ = 7/9                                   |
| H₁₁ = 4/9                                   | H_max = 8/9                                 |

**Table 2. Similarity Measure for the Proposed Method**

| Similarity Measure Between Template and Image - North/South Direction | Similarity Measure Between Template and Image - West/East Direction |
|-----------------------------------------------------------------------|------------------------------------------------------------------|
| Hᴺ¹ = 0                                                               | H_w¹ = 0                                                        |
| Hᴺ² = 2/3                                                             | H_w² = 2/3                                                      |
| Hᴺ³ = 1/3                                                             | H_w³ = 1/3                                                      |
| Hᴺ⁴ = 1                                                               | H_w⁴ = 1                                                        |
| Hᴺ⁵ = 2/3                                                             | H_w⁵ = 2/3                                                      |
| Hᴺ⁶ = 1/3                                                             | H_w⁶ = 1/3                                                      |
| H_N max = 1                                                           | H_w max = 1                                                    |

| Similarity Measure Between Template and Image - North West /South East Direction | Similarity Measure Between Template and Image - North East /South West Direction |
|---------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| H_NW¹ = 0                                                                       | H_NE¹ = 1/3                                                                     |
| H_NW² = 2/3                                                                     | H_NE² = 1/3                                                                     |
| H_NW³ = 1/3                                                                     | H_NE³ = 2/3                                                                     |
| H_NW⁴ = 1                                                                       | H_NE⁴ = 2/3                                                                     |
| H_NW⁵ = 2/3                                                                     | H_NE⁵ = 1                                                                       |
| H_NW⁶ = 1/3                                                                     | H_NE⁶ = 0                                                                       |
| H_NW max = 1                                                                    | H_NE max = 1                                                                    |

\[ H_S = \max(H_N max, H_W max, H_NW max, H_NE max) = 1 \]
In the future type 2 fuzzy logic will be applied to improve the edge detection capabilities of the proposed method. Unlike conventional or type 1 fuzzy logic which mostly treats inputs as singleton values, type 2 fuzzy logic also takes into account uncertainties in the input measurements [14]. The yielded results indicate that the proposed method could potentially improve the detection rate of edge and surface defects of manufactured industrial products [22] currently utilizing the standard edge detection methods. For instance, the detection rate of typical glass surface defects [23] such as cracks, scratches, spots, bubbles, dirt and low contrast defective surfaces could be increased. The proposed method could also be extended to the detection of surface crack of metals [24] which is a common occurrence in manufacturing.

References

[1] Pal S K and King R A 1983 On edge detection of x-ray images using fuzzy sets IEEE Trans. on Pattern Analysis and Machine Intelligence Vol 5 No1 pp 69-77
[2] Kumar N and Kaur R 2013 Detection of defects in glass using edge detection with adaptive histogram equalization Int. Journal of Innovative Research in Computer and Communication Engineering Vol 1 pp 1321-1327
[3] Li W, Jiang X and Wang Y 1996 Road recognition and vision navigation of an autonomous vehicle by fuzzy reasoning Fuzzy Sets and Systems pp 275-280
[4] Duda R and Hart P 1973 Pattern classification and scene analysis John Wiley and Sons pp 271
[5] Canny J 1986 A computational approach to edge detection IEEE Trans. on Pattern Analysis and Machine Intelligence Vol 8 No 6 pp 679-698
[6] Russo F 1992 A user friendly research tool for image processing with fuzzy rules 1st IEEE International Conf. on Fuzzy Systems pp 561-568
[7] Tao C W and Thompson W E 1993 A fuzzy IF-THEN approach to edge detection Proc. IEEE Conf. on Fuzzy Systems pp 1356-1360
[8] Begol M and Maghooli K 2011 Improving digital image edge detections by fuzzy systems World Academy of Science, Engineering and Technology pp 76-78
[9] W Lee, D Kim and I Kweon 2003 Automatic edge detection method for the mobile robot application Proc. of the IEEE/RSJ Int. Conf. on Intelligent Robots and Systems pp 2730-2735
[10] Liang L R and Looney C G 2003 Competitive fuzzy edge detection Journal of Applied Soft Computing Vol 3 pp 123-137
[11] Liming H, Cheng H D and Ming Zhang 2007 A high performance edge detector based on fuzzy inference Information Sciences pp 4768-4784
[12] Lopez Molina C, Baets B and Bustince H 2011 Generating fuzzy edge images from gradient magnitudes Computer Vision and Image Understanding pp 1571-1580
[13] Rosin P L 2001 Unimodal thresholding Pattern Recognition pp 2082-2096
[14] Mendel J and John R I 2002 Type 2 Fuzzy sets made simple IEEE Trans. on Fuzzy Systems Vol 10 pp 117-127
[15] Melin P, Mendoza O and Castillo O 2010 An improved method for edge detection based on interval type 2 fuzzy logic Expert Systems with Application Vol 37 Issue 12 pp 8527-8535
[16] Biswas R and Sil J 2011 An improved canny edge detection algorithm based on type 2 fuzzy sets Procedia Technology pp 820-824
[17] Gonzalez C, Castro J R, Mellin P and Castillo O 2013 An edge detection method based on generalized type 2 fuzzy logic IEEE Symp. on Advances in Type 2 Fuzzy Logic Systems pp 39-44
[18] Gonzalez C I, Castro J R, Mendoza O, Rodriguez Diaz A, Melin P and Castillo O 2015 Edge detection methods based on interval type 2 fuzzy systems for colour images Fuzzy Information Processing Society (NAFIPS), pp 1-6
[19] Gonzalez C I, Mellin P, Castro J R, Castillo O, and Castillo O 2016 Optimization of interval type 2 fuzzy systems for image edge detection Applied Soft Computing pp 631-643
[20] Gonzalez C I, Castro J R, Mendoza O, Melin P and Castillo O 2016 Optimization by cuckoo search of interval type 2 fuzzy logic systems for edge detection, Recent Developments and New Directions in Soft Computing Foundations and Applications pp 141-154
[21] Mamdani E H and Assilian S 1975 An experiment in linguistic synthesis with a fuzzy logic controller Int. Journal of Man Machine Studies Vol 7 pp 1-13
[22] Chavan H L and Shinde S A 201, Defective Product Detection Using Image Processing Int. Journal of Science and Research Vol 5 Issue 6 pp 2092-2096
[23] Tiwana S S and Kaur S 2013 Study on Various Glass Defect Using Glass Edge Detection Methods, Int. Journal of Computer Science and Mobile Computing, vol.2, no.5, pp 82-85
[24] Sagar S K and Arc X J 2016 Paper Sobel Operated Edge Detection Scheme using Image Processing for Detection of Metal Cracks, Int. Journal of Comp. Technology and Applications Vol 9 Issue 37 pp 503-509