values, and fuzzy rules, decision about existing/not existing and direction of edge pixels are obtained.

III. Proposed Algorithm

In this paper, at first an input image is pre-process to accentuate or remove a band of spatial frequencies and to locate in an image where there is a sudden variation in the grey level of pixels. For each pixel in the image edge strength value is calculated with three (3) 3×3 linear spatial filters i.e. low-pass, high-pass and edge enhancement filters (Sobel) through spatial convolution process.In carrying out a 3×3 kernel convolution, nine convolution coefficients called the convolution mask are defined and labeled as seen below:

a	b	c
d	e	f
g	h	i

Every pixel in the input image is evaluated with its eight neighbors, using each of the three masks shown in Figure 1 to produce edge strength value. The equation used for the calculation of edginess values between the center pixel and the neighborhood pixels of the three (3) masks using spatial convolution process is given by:

$$\begin{aligned} O(x,y) &= aI(x-1,y-1) + bI(x-1,y) + cI(x-1,y+1) \\ &+ dI(x,y-1) + eI(x,y) + fI(x,y+1) \\ &+ gI(x+1,y-1) + hI(x+1,y) + iI(x+1,y+1) \end{aligned} \quad (1)$$

However, the result of convolution of the two Sobel kernels is combine thus, the approximate absolute gradient magnitude (edge strength) at each point is computed as:

$$O_g = |O_x| + |O_y| \quad (2)$$

The normalized edge strength is then defined as:

$$NO(x,y) = round[(O(x,y)/\max(O)) \times 100] \quad (3)$$

where $x = \{0,1,\ldots,M-1\}$ and $y = \{0,1,\ldots,N-1\}$ for an M-by-N image.

The edge strength values derived from the three (3) masks served as the inputs used in the construction of the fuzzy inference system based on which decision on pixel as belonging to an edge or not are made. Membership functions are defined for fuzzy system inputs. Many membership functions have been introduced in the literature.

In the proposed edge detection Gaussian membership functions are used. To apply these functions, each of the edge strength values of O_g, O_{Hp}, and O_{Lp} are mapped into fuzzy domain between 0 and 1, relative to the normalized gray levels between 0 and 100, using Gaussian membership functions given as

$$\mu_{mn} = G(x_{mn}) = e^{[-(x_{\max} - x_{mn})^2 / 2\sigma^2]} \quad (4)$$

where $G(x_{mn})$ is a Gaussian function, $x_{\max}$, x_{mn} are the maximum and $(m,n)th$ gray values respectively and σ is the standard deviation associated with the input variable.

$$h_{LP} = \begin{bmatrix} \frac{1}{9} & \frac{1}{9} & \frac{1}{9} \\ \frac{1}{9} & \frac{1}{9} & \frac{1}{9} \\ \frac{1}{9} & \frac{1}{9} & \frac{1}{9} \end{bmatrix}, \quad h_{HP} = \begin{bmatrix} -1 & -1 & -1 \\ -1 & 9 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

$$h_x = \begin{bmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix}, \quad h_y = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

Fig. 1: 3×3 kernels used for edge detection

Each of the mapped values are partition into three fuzzy regions Low", Medium", and High". The defined regions and membership functions are shown in Fig. 2. Fuzzy inference rules are applied to assign the three fuzzy sets characterized by membership functions μ_{Low}, μ_{Medium}, and μ_{High} to the output set. The rules, tabulated in Table 1 are defined in such a way that in the fuzzy inference system, output set E_L, E_M, and E_H correspond to pixels with low, medium and high probability value respectively. The output of the system P_{Final} representing the probability used for final pixel classification as edge or non-edge was computed using a singleton fuzzifier, Mamdani defuzzifier method given by;

$$p_{Final} = \frac{\sum_{\ell=1}^{M} \bar{y}^{\ell} \left(\prod_{i=1}^{n} \mu_{k_i^{\ell}}(\alpha_i)\right)}{\sum_{\ell=1}^{M} \left(\prod_{i=1}^{n} \mu_{k_i^{\ell}}(\alpha_i)\right)} \qquad (5)$$

where α_i are the fuzzy sets associated with the antecedent part of the fuzzy rule base, $\bar{y}^{\ell}$ is the output class center and M is the number of fuzzy rules being considered.

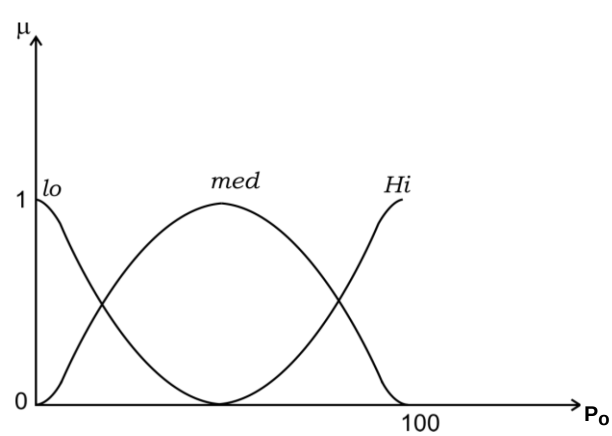

Fig. 2: Gaussian membership functions Low, Medium and High

Table 1

If $edginess_{Lp}$ is LO and $edginess_{So}$ is LO and $edginess_{Hp}$ is LO then p_{edge} is E_L

If $edginess_{Lp}$ is LO and $edginess_{So}$ is LO and $edginess_{Hp}$ is MD then p_{edge} is E_L

If $edginess_{Lp}$ is LO and $edginess_{So}$ is LO and $edginess_{Hp}$ is HI then p_{edge} is E_L

If $edginess_{Lp}$ is LO and $edginess_{So}$ is MD and $edginess_{Hp}$ is LO then p_{edge} is E_L

If $edginess_{Lp}$ is LO and $edginess_{So}$ is MD and $edginess_{Hp}$ is MD then p_{edge} is E_L

If $edginess_{Lp}$ is LO and $edginess_{So}$ is MD and $edginess_{Hp}$ is HI then p_{edge} is E_M

If $edginess_{Lp}$ is LO and $edginess_{So}$ is HI and $edginess_{Hp}$ is LO then p_{edge} is E_L

If $edginess_{Lp}$ is LO and $edginess_{So}$ is HI and $edginess_{Hp}$ is MD then p_{edge} is E_H

If $edginess_{Lp}$ is LO and $edginess_{So}$ is HI and $edginess_{Hp}$ is HI then p_{edge} is E_H

If $edginess_{Lp}$ is MD and $edginess_{So}$ is LO and $edginess_{Hp}$ is LO then p_{edge} is E_L

If $edginess_{Lp}$ is MD and $edginess_{So}$ is MD and $edginess_{Hp}$ is LO then p_{edge} is E_L

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If $edginess_{Lp}$ is HI and $edginess_{So}$ is LO and $edginess_{Hp}$ is HI then p_{edge} is E_H

If $edginess_{Lp}$ is HI and $edginess_{So}$ is MD and $edginess_{Hp}$ is HI then p_{edge} is E_H

If $edginess_{Lp}$ is HI and $edginess_{So}$ is HI and $edginess_{Hp}$ is HI then p_{edge} is E_H

IV. Experimental results

The proposed fuzzy edge detection method was simulated using MATLAB on different images, its performance are compared to that of the Sobel and Kirsch operators. Samples for a set of four test images are shown in Fig. 3(a). The edge detection based on Sobel and Kirsch operators using the image processing toolbox in MATLAB with threshold automatically estimated from image‘s binary value is illustrated in Fig. 3(b) and 3(c). The sample output of the proposed fuzzy technique is shown in Fig. 3(d). The resulting images generated by the fuzzy method seem to be much smoother with less noise and has an exhaustive set of fuzzy conditions which helps to provide an efficient edge representation for images with a very high efficiency than the conventional gradient-based methods (Sobel and Kirsch methods).

V. Conclusion

In this paper, effective fuzzy logic based edge detection has been presented. This technique uses the edge strength information derived using three (3) masks to avoid detection of spurious edges corresponding to noise, which is often the case with conventional gradient-based techniques. The three edge strength values used as fuzzy system inputs were fuzzified using Gaussian membership functions. Fuzzy if-then rules are applied to modify the membership to one of low, medium, or high classes. Finally, Mamdani defuzzifier method is applied to produce the final edge image.Through the simulation results, it is shown that the proposed algorithm is far less computationally expensive, its application on the image improve the quality of edges as much as possible compared to the Sobel and Kirsch methods.This algorithm is suitable for applications in various areas of digital image processing such as face recognition, fingerprint identification, remote sensing and medical imaging where boundaries of specific regions need to be determined for further image analysis.

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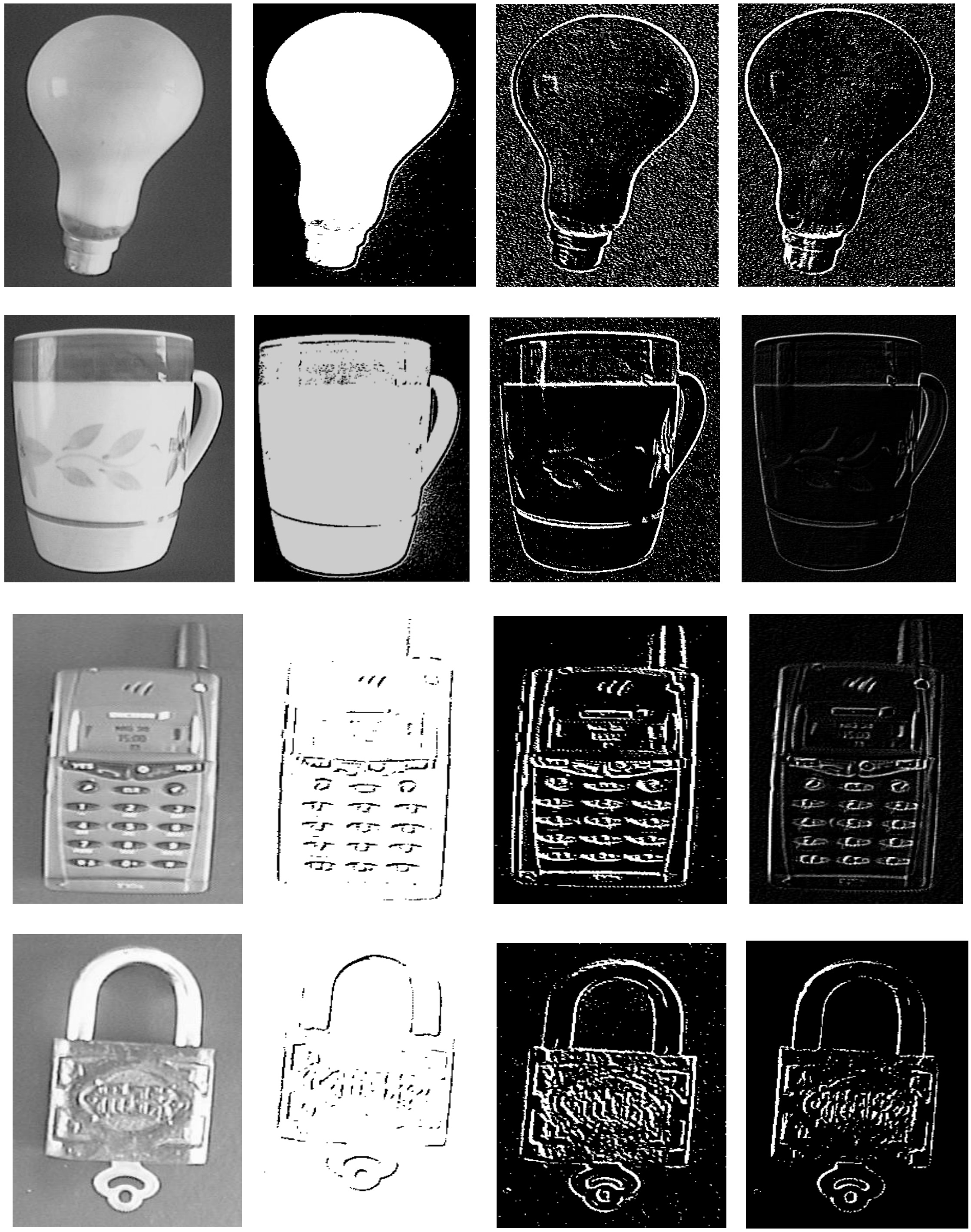

(a) (b) (c) (d)

Fig. 3 (a) Original images, (b) Sobel operator results, (c) Kirsch operator results, (d) Proposed fuzzy edge detection algorithm results

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