Practical Study for the Properties of Hueckel Edge Detection Operator

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Abstract. The first practical study for the Hueckel edge detection operator was presented in this research, where it is tested on standard step edge set images. A number of criteria were adopted to evaluate its practical performance, which is the accuracy in detecting the edges direction, the error in the edges location (dislocation), edges width, the calculated edge goodness criterion and the consumed execution time. These criteria were studied with the edge direction and the used disk radius of the Hueckel edge detection operator. Important notes were recorded for the performance of this operator depending on the direction of the edge and/or with the radius of the used disk. There is a variation in the performance of the operator in terms of precision in detecting of the edges direction and position. A discussion was presented for the all criteria adopted in the research.

1. Introduction
Edge detection is an important field in the image processing science as a pre- or post-processing step since the edges play a major part in the recognizing the objects in the human vision. Many edge detectors are proposed in the literature that vary in its concept or complexity, but in general, they are classified into two groups [1]. The gradient edge detectors and the fitting edge detector, the first group is widely used in the image processing analysis, since it is easy to implement and they don’t consume a lot of the computer resources. But they suffer from major fault, which is their sensitivity to the presence of noise, where their ability to detect the edge degrades dramatically [2]. The other group (fitting edge detection), they are designed to override the sensitivity to the presence of the noise, but their algorithms are complex and consume a lot of the computer resources comparing to the gradient edge detector group, therefore, they are used rarely in the image processing fields [3].

Hueckel edge detector is one of the famous detectors in the fitting edge detector group, its algorithm published by Hueckel, but he didn’t reveal its full derivation [4 and 5]. Few researchers mentioned Hueckel edge detector in their literature and very fewer how tries to analysis it, therefore, Hueckel edge detector suffers from the lake in analysis especially in the practical studies in spite of some researchers try to analyze it theoretically [6 and 7], but it still needs more analysis.

This study tries to put some insight on the Hueckel edge detector performance in the practical approach that didn’t study by other researchers.

2. Research Methodology
The restrictions and conditions that adopted by Hueckel in his papers [3 and 4] are adopted in this research besides other restriction, which are:

- In ‘figure 1’, eight standard step edge images set created that represent the edges in the directions 0°, 30°, 45°, 60°, 90°, 120°, 135° and 150° to be used in this study.
Figure 1. Standard step edge of the images set for the edge directions $0^\circ$, $30^\circ$, $45^\circ$, $60^\circ$, $90^\circ$, $120^\circ$, $135^\circ$, and $150^\circ$ respectively.

- The value 0.9 for the edge goodness is considered as a threshold value for detecting edges.
- To nullify the rounding error of the periphery of the disk, the area of the sliding window outside the disk is considered to be equal to the void area inside the disk, where the following empirically equation is used (disk radius = $0.53305 \times$ slide window size).
- All possible edge directions are considered in the Hueckel algorithm (the one-degree angular difference is used).
- The range (2-9) pixel is used for the sliding window size in the Hueckel edge detection algorithm with a single pixel difference between two successive sliding windows, which represent the range.

The perfect edge for these images is calculated using a logical condition to locate it since the test set images are binary. ‘Figure 2’ shows the perfect calculated edges.

Figure 2. Standard images edges calculated using logical condition for the edge directions $0^\circ$, $30^\circ$, $45^\circ$, $60^\circ$, $90^\circ$, $120^\circ$, $135^\circ$, and $150^\circ$ respectively.

These edges are used as a reference to qualify the edges that founded by using Hueckel edge detection algorithm.

3. Results and Discussion

The set the standard step edge images are used in the Hueckel edge detection and the following edge parameters are calculated:

3.1. Edge Detectability

Applying Hueckel edge detection algorithm on the standard set images of the step edge image for different disk size can be summarized using figure 3, where the number of the detected points that classified by the Hueckel algorithm as edge points, from it we can notice the following:

i) Hueckel edge detection can be used to detect edges starting from the disk radius $R=1.5992$, and its efficiency increases with disk radius.

ii) The number of the detected edge point has a forward relationship with the disk size and the number keep increasing with the disk radius tell it to give the edges an exaggerated shape.

iii) The length of the detected edge is shortening with the disk radius by comparing with the edge length that detected using logical conditions. This is expected since no extended in the image dimension are applied in this research, therefore, a number of the image rows and columns will neglect in order to operate Hueckel algorithm.

To overtake the exaggerated shape of the detected edge, a customized simple $(2 \times 2)$ element erosion morphological thinning operator is applied to remove the excessive points. The customization in the erosion thinning operator is made to maintain the straightness of the thinned edge (without branching in the edge ends), ‘figure 4’ illustrates the edges before and after the thinning process, which will have adopted in the rest of this research.
Figure 3. Number of the edge points: (a) the direct results after applying Hueckel algorithm, (b) after erosion edge thinning, (c) the real number of edge points detected using logical conditions.

Figure 4. Hueckel edge detection algorithm results: a) for angle 0, slide window size 6, b) its standard simple element erosion thinning, c) the customized simple element erosion thinning, d) for angle 150, slide window size 8, e) its standard simple element erosion thinning, c) the customized simple element erosion thinning.

After thinning process, the number of the edge points stabilized regarding the number of the detected edge points or the disk radius, except for the reduction in the detected edge length that mentioned in (iii).

3.2. Edge Direction Accuracy
The edge direction for the edges images set was calculated for different disk size. Hueckel algorithm for some edge direction gives a range of number that related to that edge direction instead of giving a unique edge direction, therefore, the mean and the standard deviation (STD) of edge direction for points that belong to the founded edge are calculated, see ‘figure 5’.
In ‘figure 5’, the following notices can be devised:

i) For the angles 0°, 45°, 90°, and 135°, Hueckel algorithm success to determine the edge direction without error (zero STD) while for the other their edge directions there is a small deviation from the correct value and that due to rounding error.

ii) For the angle 90°, it was more difficult for the Hueckel algorithm to detect it, it needed 2.1322 as disk radius to be able to detect the edge in that direction.

iii) The calculated edge direction accuracy increase with the disk radius.

3.3. **Edge Dislocation**

The Dislocation (the distance from the real edge location) for the detected edge is calculated from the exact edge (the logical edge), as is illustrated in ‘figure 6’.

In ‘figure 6’ we can notice the following:

i) For the edge direction of 135° the calculated edge location coincides with the exact edge location (no dislocation).

ii) The dislocation value for the edge direction other than 135° was ranging from 1-3 pixels, most of the error came from the thinning process.

iii) There is no variation (SD) in the edge dislocation values for the direction 0°, 45°, 90°, and 135° in the most cases, while for other edge direction it was very small value comparing to the dislocation mean.

3.4. **Edge Goodness Value**

To evaluate the Hueckel edge detection algorithm, the maximum, minimum, mean and variation in the value of the edge goodness criterion are calculated to analyze it.
'Figure 7', give a representation of the edge goodness behaviour with edge direction and disk radius, and the following points can be noticed:

i) The edge goodness criterion is inefficient with the small disk radius (i.e. less than 2.1322) because the maximum value for the edge goodness criterion is less than 0.9.

ii) Starting from disk radius 2.1322 the edge goodness criterion record high values even when its mean value becomes low (for the radii 2.6653, 3.1984 and 4.7976), but it has high variation values (STD) for the other radius.

![Figure 7](image)

**Figure 7.** The edge goodness recorded values with edge radius and edge direction: (a) minimum value, (b) maximum value, mean value, variation (STD).

3.5. Execution Time

The execution time of applying Hueckel edge detection algorithm with different disk radius and different edge directions are calculated, see figure 8.

'Figure 8', give a representation of the execution time behaviour with edge direction and disk radius, and the following notices can be devised:

i) The execution time differs depending on the edge direction, in which, the edge direction for 0°, 30° and 135° recorded the lowest execution time. On the contrary with the edge direction 45° and 60°, which it recorded the highest execution time due to the interpolation process that Hueckel edge detection algorithm performs in order to detect it.

ii) In general, the execution time increases with the disk radius, which is not obvious in the execution time results due to the small dimensions of the sample set images, as it recorded by Abduljabar [3].
4. Conclusions

Hueckel edge detection algorithm gives strongly connected edge with high immunity to noise, from the obtained results, the following conclusions can be derived:

1. The minimum valid disk radius that can be used in the Hueckel edge detection algorithm which makes it fully operate is starting from 2.3122 pixels.

2. The detected edge of the high disk radius suffers from exaggerating edge width that can be eliminated by using a customized simple (2x2) element erosion thinning process.

3. The detected edge direction accuracy increases with the disk radius.

4. The best value that can be used good edge direction with acceptable edge occurred when the disk radius is 1.5992 and 2.1322 (i.e. slid window size is 3 and 4 pixels) which represent the half radius values that recommended by Hueckel.

5. The recorded dislocation in the detected edge location is mainly due to the thinning process.

References

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Figure 8. Recorded execution time for the Hueckel edge detection algorithm