SINGLE IDEAL-SCALE EDGE DETECTION USING NOISE WITHIN IMAGES

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Abstract – Researchers spend time and money developing techniques to solve some common problems associated with the rapidly developing field of image processing. These problems include poor edge detection in low contrast images, speed of recognition and high computational cost. Scale space analysis is an efficient solution to the edge detection of objects. However, this approach is time consuming and computationally expensive. These expenses can be marginally reduced if a single ideal (optimal) scale is found in scale space analysis and then edge detection is performed using only that single ideal scale. This paper reports on a new approach to detecting 3-dimensional objects in their 2-dimensional projections using noise within the images. The novel idea is based on selecting one ideal scale for the entire image at which edge detection can be applied. The selection of an ideal scale is based on the hypothesis that "an ideal edge detection scale depends on the noise within an image". This paper aims at presenting the above hypothesis mathematically and throughout some experiments made on simple 3-dimensional objects.

I. INTRODUCTION

Noise sensitivity and scale dependency can be problematic in image recognition [1]. Previous works suggested the use of an optimal scale in multiscale edge detection [2][3]. In our novel approach, both noise and scale dependency will be utilised to yield a single ideal scale, which will be used by the AEDS; Automatic Edge Detection Scheme [4], to provide ideal edge detection. The AEDS is based on combining scale space analysis, edge detection and neural networks. AEDS delivers very quick edge detection of three-dimensional objects, as well as two-dimensional objects, through the automatic selection of a single ideal scale for applying the scale space edge detection. The computational cost is minimised through using a fast edge detection operator combined with the power of a successfully trained neural network that recognises only one ideal scale (referred to as the ideal sigma σ_{Ideal} in this paper), out of the multiscales possible in scale space.

The hypothesis that is presented within this paper suggests that the ideal scale is dependent upon the amount of noise present within the image and that the mapping from the image to the ideal scale is non-linear. The work presented within this paper provides experimental evidence and an in-depth understanding of the mapping hypothesis.

II. IDEAL-SCALE NOISE-DEPENDENCY

In order to provide the experimental evidence on the methodology of using noise within images to determine an ideal detection scale, a mathematical foundation is required. For the purpose of understanding the mapping hypothesis, assume the existence of two images (of size 512x512 pixels), *image* I_A and *image* I_B. Both images represent the same three-dimensional object, but they are taken, using a frame grabber, at different times and under different conditions. The different conditions will result in the existence of different amounts of random noise in both images, although they both represent the same three-dimensional object. The grey level value of a pixel P_A in image I_A at spatial co-ordinates (x_n, y_n) should be equal to the grey level value of pixel P_B in image I_B at the same spatial co-ordinates, as shown by equation (1).

$$P_A(x_n,y_n) = P_B(x_n,y_n) \qquad (1)$$

where $n = 0, 1, 2, 3, \ldots, 511$

The amount of noise N_A present in image I_A at spatial co-ordinates (x_n, y_n) is not equal to the amount of noise N_B in image I_B at the same spatial co-ordinates, as shown by equation (2).

$$N_A(x_n,y_n) \neq N_B(x_n,y_n) \qquad (2)$$

Thus, the grey level values of the image at spatial co-ordinates (x_n, y_n) can be represented for both Images I_A and I_B as shown by equation (3) and equation (4).

$$I_A(x_n,y_n) = P_A(x_n,y_n) + N_A(x_n,y_n) \qquad (3)$$
$$I_B(x_n,y_n) = P_B(x_n,y_n) + N_B(x_n,y_n) \qquad (4)$$

where the value of equation (3) is not equal to the value of equation (4).

Therefore, the total grey level value of an image at any spatial co-ordinate $I(x,y)$ is dependent on the amount of noise $N(x,y)$ present at that co-ordinate, as in equation (5).

$$I(x,y) \propto N(x,y) \qquad (5)$$

The convolution between the Laplacian of a Gaussian [5] (equation (6)) and an image I is represented in equation (7).

$$\nabla^2 G(x,y,\sigma) = A\left(2 - \frac{x^2+y^2}{\sigma^2}\right)\exp\left(-\frac{x^2+y^2}{2\sigma^2}\right) \qquad (6)$$

$$F_\sigma = \nabla^2\left(G(\sigma) * I\right) \qquad (7)$$

By convoluting the image with the LoG operator, smoothing will take place before edges are located [6]. The larger the value of the standard deviation of the Gaussian function σ, the heavier the smoothing and the larger the reduction of edges due to noise *N*. This can be expressed in equation (8).

$$\sigma \propto \frac{1}{N} \qquad (8)$$

The standard deviation of the Gaussian (σ) plays a vital rule in the automatic edge detection scheme (AEDS). A compromise has to be made in order to eliminate the noise present within the image and, at the same time, preserve all the edges of the objects within the image. The determination of such an ideal scale, what we call the *Ideal Sigma* (σ_{IDEAL}), depends on the choice of the result of the convolution between the image and the LoG function. This convolution results in many images; each convoluted at a different scale depending on the value of the scale (σ) [7].

Equation (5) shows the dependency of an image on the amount of noise present within it. Whereas, equation (8) presents the relationship between the noise and the scale (σ) at which the image is convoluted. The choice of the ideal scale, at the *Ideal Sigma* (σ_{IDEAL}), depends on the convoluted image, which in turn depends on the amount of noise present within it. Therefore, the relationship between the *Ideal Sigma* (σ_{IDEAL}) and the amount of noise present within the image prior to convolution can be expressed as in equation (9).

$$\sigma_{IDEAL} = F(N) \qquad (9)$$

This relationship between the *Ideal Scale* and the noise represents a non-linear function that is very difficult to define precisely. The amount of noise present within an image is variable and, normally, of a random nature. The scale at which the image is processed is also variable and once applied it has an impact on the amount of the noise. Thus, the AEDS [4]

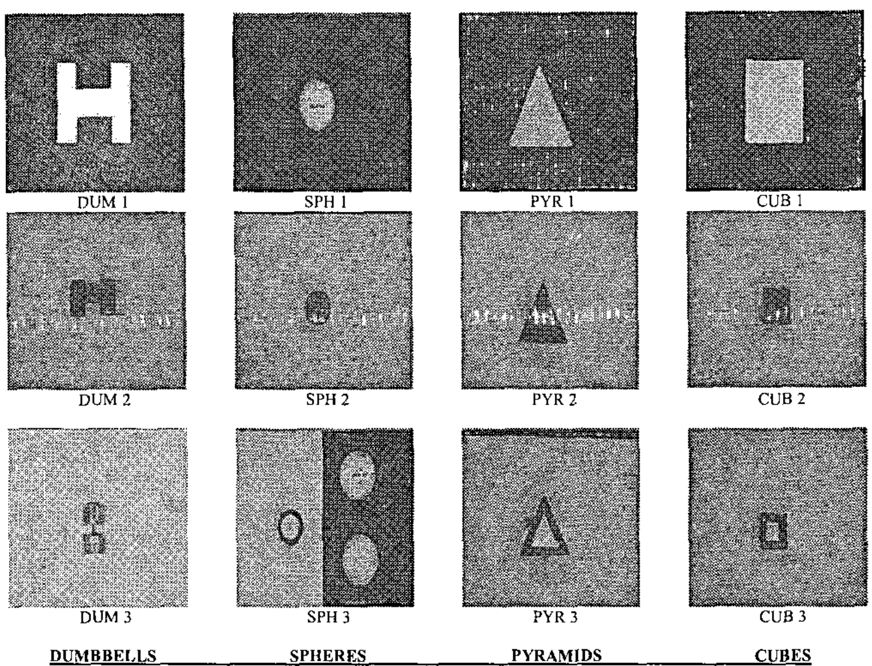

Fig.1. Twelve 2-D images of the four 3-D objects

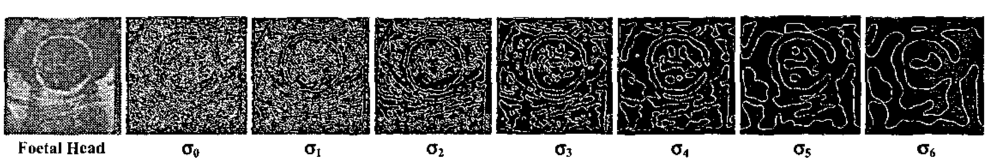

Fig.2. Scale space events occurring on foetal head at various scales

utilises a neural network model to map the two vectors, throughout repeated presentations of images with different noise levels and mapping those patterns to their corresponding ideal scales. The presentation of various images and their corresponding ideal scales σ_{Ideal} will teach the neural network this relationship that is impossible to solve using conventional techniques.

The basis of the methodology is that the alteration in the amount of noise present within the image causes a change in the choice of the ideal scale σ_{Ideal} and thus the ideal edge detection of the image.

III. 3-DIMENSIONAL OBJECTS EDGE DETECTION

For the purpose of demonstrating the change in the ideal scale in relation to the amount of noise within the image, twelve images, representing four simple three-dimensional objects (dumbbells, spheres, pyramids and cubes [8]) are used and can be seen in Figure 1.

These images were distorted by the deliberate addition of random noise of a determined range. This range is defined as random values between [0 - 100]. The range was chosen as it provides sufficient amounts of noise to monitor the scale space events occurring on the objects within the images, while maintaining the objects from total distortion and deformation. An example of edge deformation throughout various scale space events can be seen in Figure 2, where the analysed object within the ultrasound scan image is a foetal head [9]. Seven scales (σ_0 - σ_6) are used in the scale space edge detection presented within this paper. The number of scales is limited to seven since scale space events, occurring on the objects at scales higher than seven, lead to a heavy deformation of the objects [10]. In addition, processing the images at higher scales, would marginally increase the computational cost which defies an objective of the work presented within this paper.

Having selected the ideal scales and thus the ideal edge detection for each of the distorted twelve images according to the ideal detection criteria [11], the values of the ideal scales σ_{Ideal} are then compared to those for the same 12 images prior to the introduction of noise. All values of σ_{Ideal} are shown in Table I.

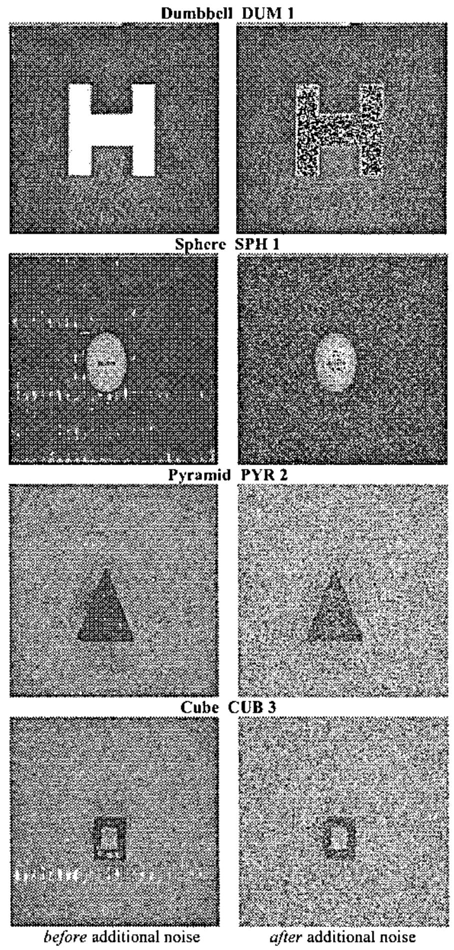

Fig.3. Images of dumbbell (DUM1), sphere (SPH1), pyramid (PYR2) and cube (CUB3) before and after adding random noise

IV. RESULTS

Four out of the twelve images are presented here to demonstrate the work carried out to provide the evidence for our methodology. These are: dumbbell (DUM 1), sphere (SPH 1), pyramid (PYR 2) and cube (CUB 3). Figure 3 shows the four images before and after the introduction of noise within a range of [0 – 100].

Figure 4 shows the scale space edge detection of dumbbell (DUM 1), sphere (SPH 1), pyramid (PYR 2) and cube (CUB 3) before and after additional noise. Three edge detection results are presented for each image:

- Firstly, the ideal edge detection and the ideal scale σ_{Ideal} for each of the four images before adding the noise.
- Secondly, the edge detection of the noisy images at the scales which are considered ideal in the case before the addition of noise.
- Finally, the new different ideal edge detection of the noisy images as a result of additional noise.

V. CONCLUSIONS

The work that has been presented in this paper introduces a novel approach to image processing, while addressing setbacks such as the time and computational expense due to multiscale edge detection. The hypothesis, on which, this work was based, was shown to be mathematically feasible. Here, the noise within an image can be used to determine the ideal scale (σ_{Ideal}) in scale space analysis, at which, the outline of the object of interest within the image is at its clearest for

TABLE I
VALUES OF σ_{Ideal} FOR THE 12 IMAGES BEFORE AND AFTER THE ADDITIONAL NOISE

IMAGE	DUM 1	DUM 2	DUM 3	SPH 1	SPH 2	SPH 3	PYR 1	PYR 2	PYR 3	CUB 1	CUB 2	CUB 3
(σ_{Ideal}) Before Noise	σ_4	σ_5	σ_5	σ_3	σ_5	σ_4	σ_5	σ_5	σ_2	σ_6	σ_5	σ_3
(σ_{Ideal}) After Noise	σ_6	σ_6	Higher than σ_6	σ_5	σ_6	σ_5	σ_6	Higher than σ_6	Higher than σ_6	Higher than σ_6	σ_6	σ_5

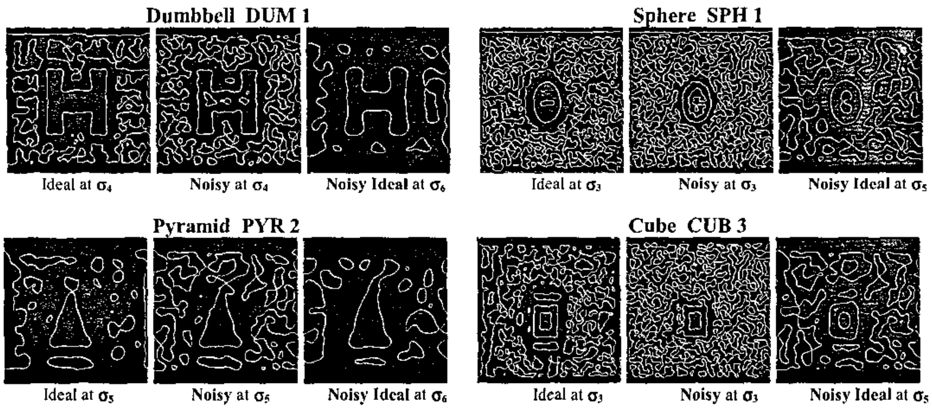

Fig.4. Edge detection of dumbbell (DUM 1), sphere (SPH 1), pyramid (PYR 2) and cube (CUB 3) before and after additional noise

subsequent detection. This analysis is based on the hypothesis that the ideal scale (σ_{Ideal}) is a non-linear function of noise. In this non-linear function the changes in the amount of noise within the image affect the choice of the ideal scale.

The addition of noise to the images has altered the choice of the ideal edge detection; thus altering the ideal scale σ_{Ideal}. This immediate alteration of the values of σ_{Ideal} due to the introduction of the added noise provides the experimental evidence concerning the basis of our methodology. Future work and development will be carried out on implementing single ideal-scale edge detection for face recognition.

VI. REFERENCES

[1] T. LINDEBERG, "Detecting Salient Blob-Like Image Structures and Their Scales with a Scale-Space Primal Sketch: A Method for Focus-of-Attention", *Inter. National Journal of Computer Vision*, Vol. 11, No. 3, 1993, pp. 283-318.

[2] T. LINDEBERG, "Edge Detection and Ridge Detection with Automatic Scale Selection", *IEEE Computer Soc. Conf. on Computer Vision and Pattern Recognition*, Ch. 137, 1996, pp. 465-470.

[3] D. GEIGER and T. POGGIO, "An Optimal Scale for Edge-Detection", *10th Inter. Joint Conf. on Artificial Intell. IJCAI 87*, 1987, Vol. 1-2, Ch. 242, pp. 745-748.

[4] A. KHASHMAN and K.M. CURTIS, "A Novel Image Recognition Technique For 3-Dimensional Objects", *Proceedings of the 13th IEEE International Conference on Digital Signal Processing (DSP'97), Greece, July 1997.*

[5] G.E. SOTAK and K.L. BOYER, "The Laplacian-of-Gaussian Kernel: A Formal Analysis and Design Procedure for Fast, Accurate Convolution and Full-Frame Output", *Comp. Vision, Graphics and Image Processing*, Vol. 48, No. 2, 1989, pp. 147-189.

[6] J.S. CHEN, A. HUERTAS and G. MEDIONI, "Fast Convolution with Laplacian-of-Gaussian Masks", *IEEE Trans. on Pat. Anal. and Mach. Intell.*, Vol. 9, No. 4, 1987, pp. 584-590.

[7] A. KHASHMAN and K.M. CURTIS, "Scale Space Analysis Applied to 3-Dimensional Object Recognition", *E-LETTER on Digital Signal Processing*, Georgia Institute of Technology, Atlanta, USA, Issue No. 24, June 1995.

[8] A. KHASHMAN and K.M. CURTIS, "Neural Networks Arbitration For Automatic Edge Detection of 3-Dimensional Objects", *Proc. The third IEEE International Conference on Electronics, Circuits and Systems (ICECS'96)*, Greece, 1996, pp. 9-52.

[9] A. KHASHMAN, "Neural system for monitoring Non-Linear Foetal measurements", Proceedings of the IEEE Nordic Signal Processing Symposium (NORSIG'2000), Kolmarden, Sweden, June 2000.

[10] A. KHASHMAN, "Automatic Detection of Military Targets Utilizing Neural Networks and Scale Space Analysis", *NATO RTO MEETING PROCEEDINGS, Issue No. 49, ISBN 92-837-1061-4,* Printed by St. Joseph Ottawa/Hull,Canada, Page 25, April 2001.

[11] A. KHASHMAN and K.M. CURTIS, "Scale Space Analysis and Neural Arbitration for 3-Dimensional Edge Detection", Proceedings of the IEE 5th International Conference on Image Processing and its Applications, Edinburgh, UK, July 1995.