The measurement of circles with subpixel accuracy

大綱

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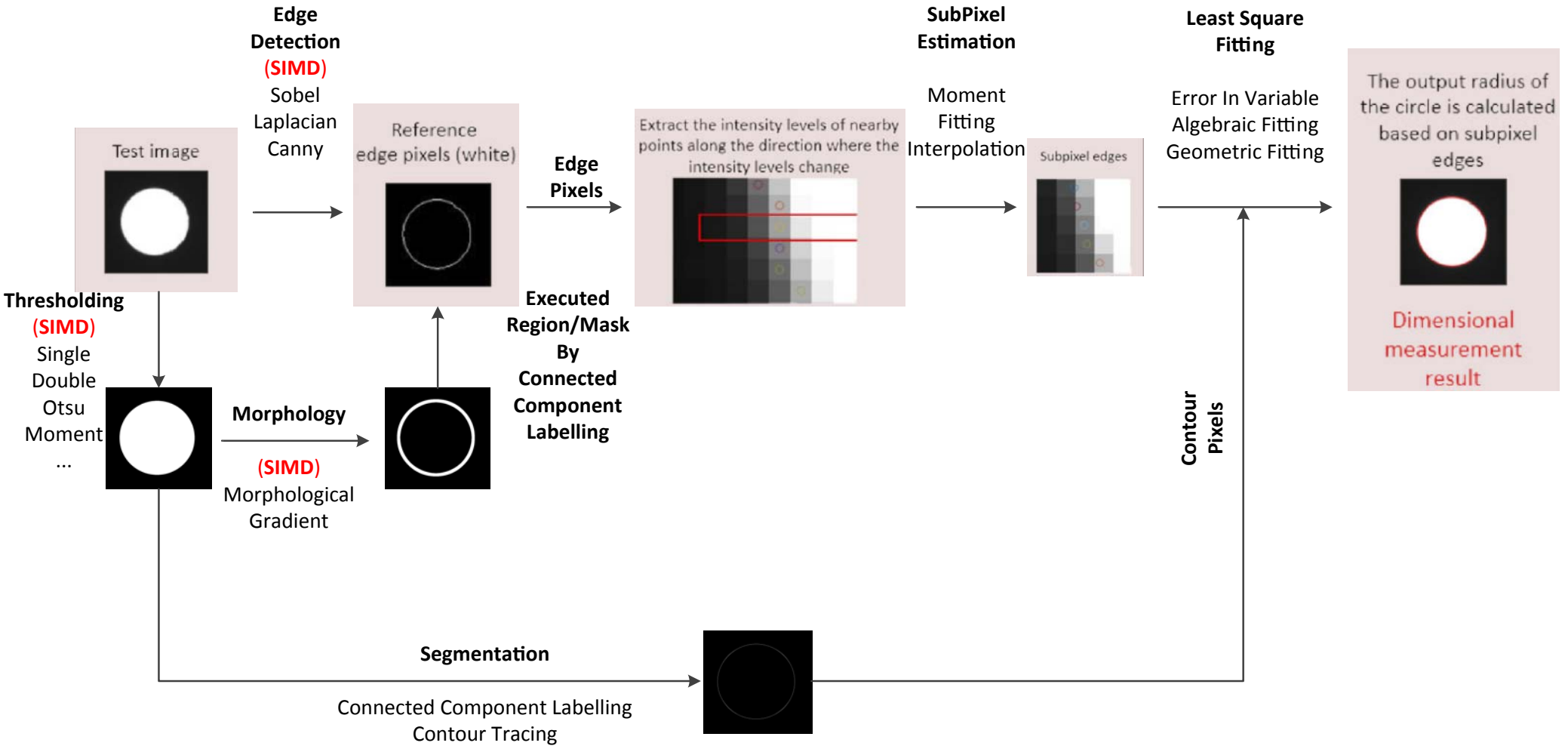
  - ✓ 次像素方法 (Cognex Patent)
  - ✓ 圓擬合方法 (Kasa Fitting)

圓量測流程說明


Test image
Edge Detection (SIMD) Sobel Laplacian Canny
Reference edge pixels (white)
Edge Pixels
Extract the intensity levels of nearby points along the direction where the intensity levels change
SubPixel Estimation
Moment Fitting Interpolation
Subpixel edges
Least Square Fitting
Error In Variable Algebraic Fitting Geometric Fitting
The output radius of the circle is calculated based on subpixel edges
Dimensional measurement result
Thresholding (SIMD) Single Double Otsu Moment ...
Morphology
(SIMD) Morphological Gradient
Executed Region/Mask By Connected Component Labelling
Contour Pixels
Segmentation
Connected Component Labelling Contour Tracing

處理步驟討論

- 邊緣模型：

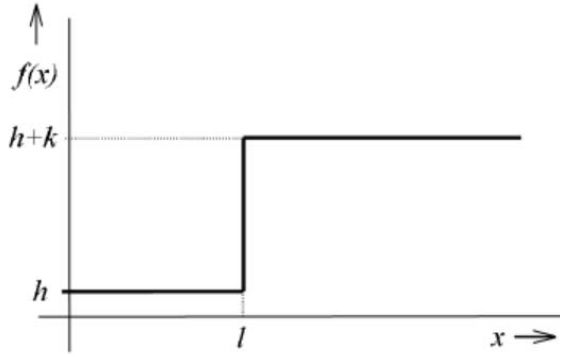


Fig. 1. Step edge.

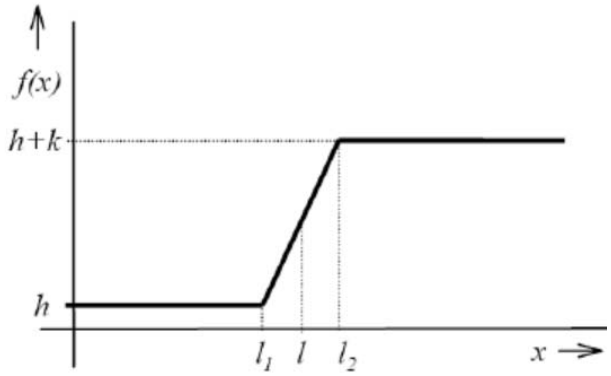


Fig. 2. Ramp edge.

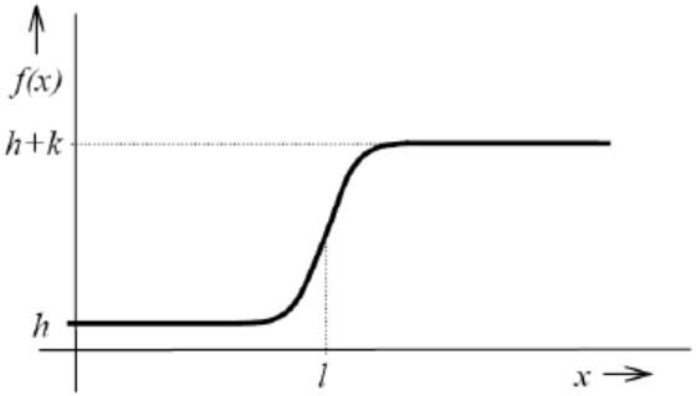
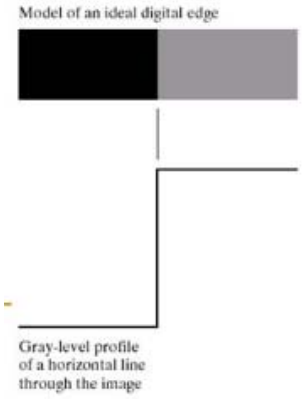
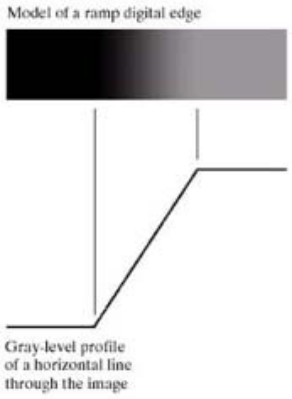
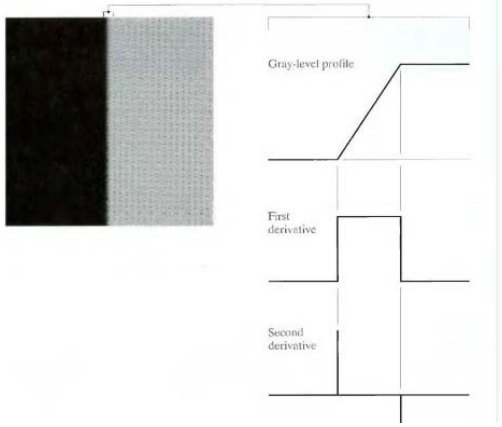
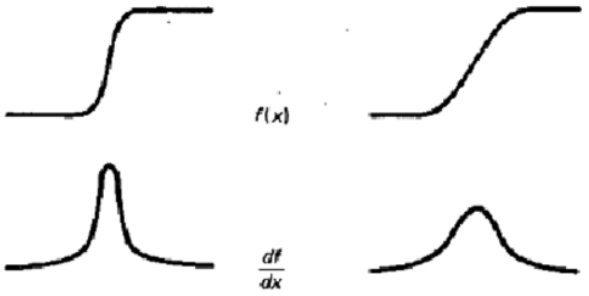


Fig. 3. Blurred edge.









處理步驟討論

- 邊緣模型：

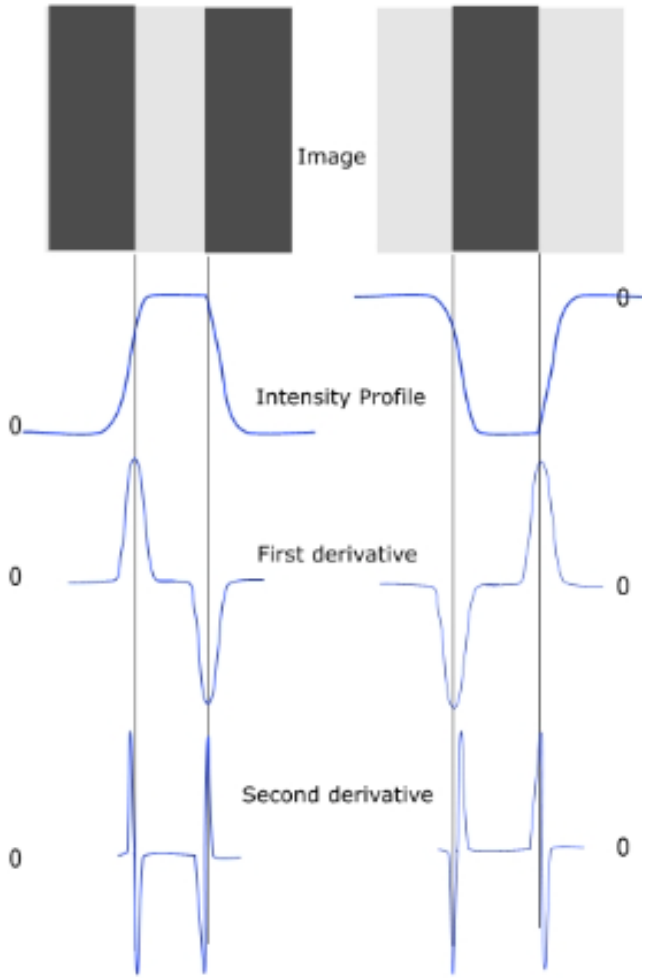
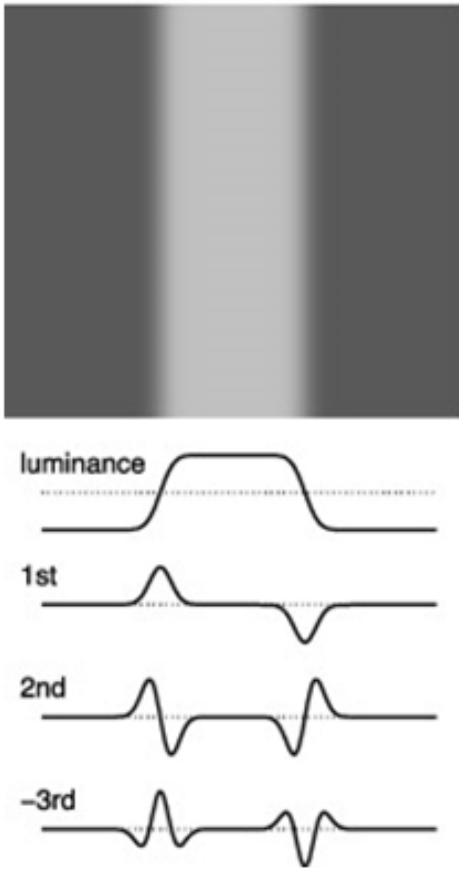


Image
Intensity Profile
First derivative
Second derivative
0
0
0
0
0
0


luminance
1st
2nd
–3rd

處理步驟討論

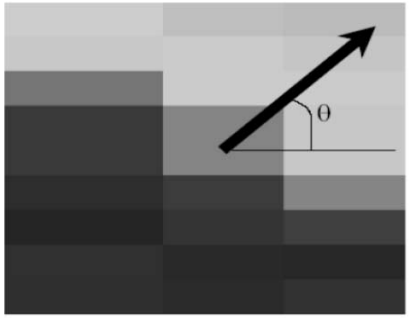
- 梯度向量與方向 (Sobel operator)：

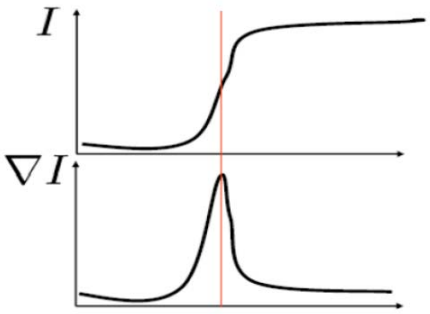
-1	0	1
-2	0	2
-1	0	1

x-component

1	2	1
0	0	0
-1	-2	-1

y-component



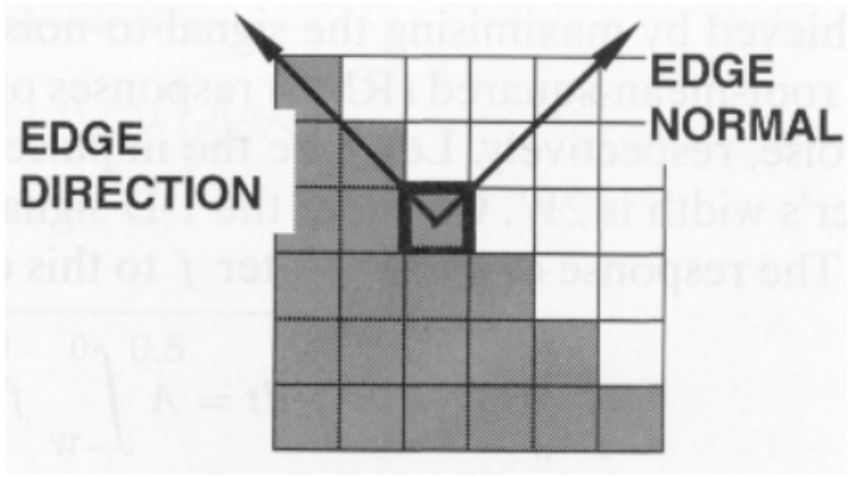


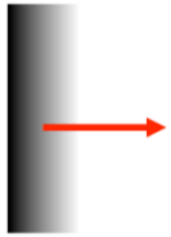
Edge pixels are at local maxima of gradient magnitude
Gradient direction is always perpendicular to edge direction

Gradient Vector: $\nabla I = [\frac{\partial I}{\partial x}, \frac{\partial I}{\partial y}]^T$

Magnitude: $|\nabla I| = \sqrt{(\frac{\partial I}{\partial x})^2 + (\frac{\partial I}{\partial y})^2}$

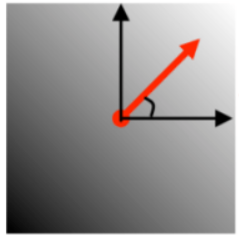
Orientation: $\theta = atan2(\frac{\partial I}{\partial y}, \frac{\partial I}{\partial x})$





Gradient in x

Gradient in y



Gradient in
both x and y

處理步驟討論

- 次像素方法 (Cognex Patent)

x

-1	0	1
-2	0	2
-1	0	1

121

y

1	2	1
0	0	0
-1	-2	-1

122

FIG. 1B

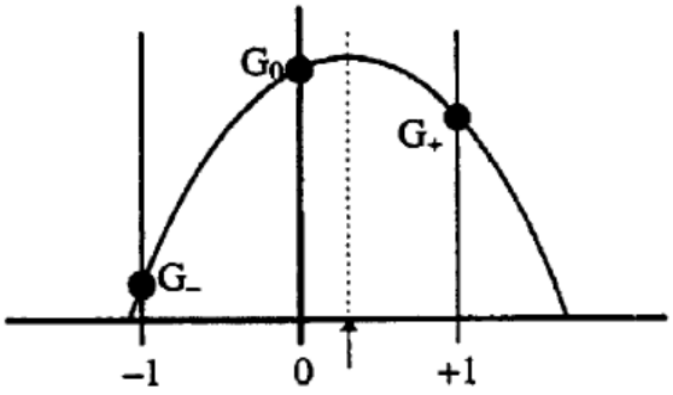


FIG. 4A

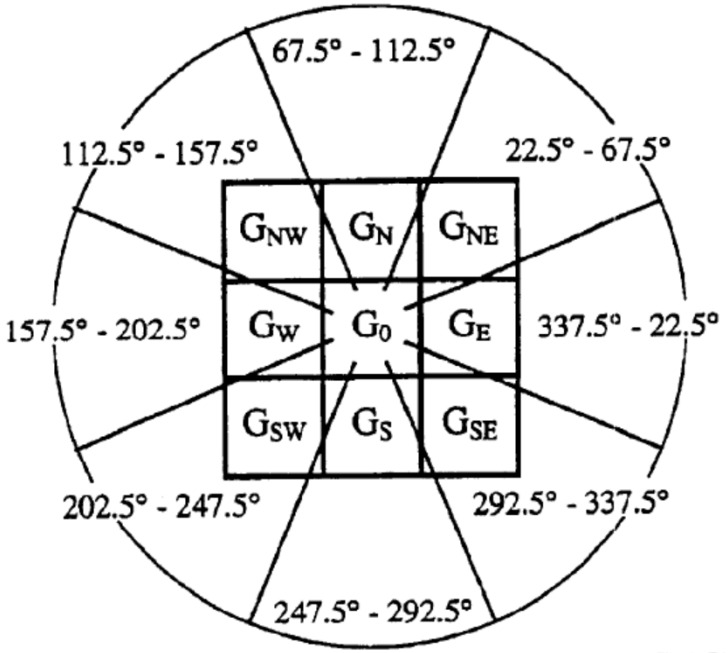


FIG. 3A

處理步驟討論

- 次像素方法 (Cognex Patent)

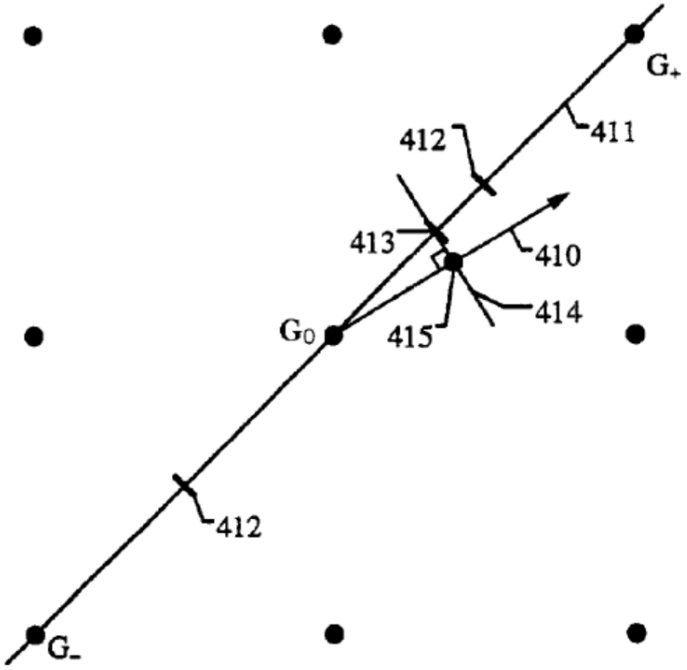


FIG. 4C

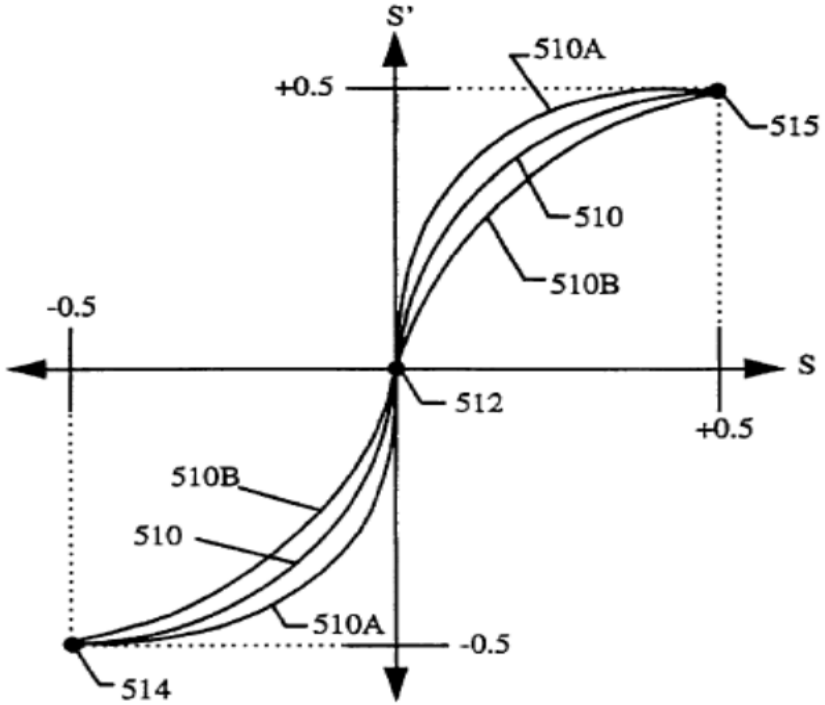


FIG. 5

處理步驟討論

- 最小平方擬合 (Kasa Fitting)

$$\sum_{i=1}^{N}(R_i - R)^2 = \min \quad \Rightarrow \quad u = \sum_{i=1}^{N}[(x_i - A)^2 + (y_i - B)^2 - R^2]^2 = \min$$

$$C = R^2 - A^2 - B^2$$

$$D = \begin{pmatrix} 2\Sigma x_i & 2\Sigma y_i & N \\ 2\Sigma x_i^2 & 2\Sigma x_i y_i & \Sigma x_i \\ 2\Sigma x_i y_i & 2\Sigma y_i^2 & \Sigma y_i \end{pmatrix}$$

$$E = \begin{pmatrix} \Sigma(x_i^2 + y_i^2) \\ \Sigma(x_i^3 + x_i y_i^2) \\ \Sigma(x_i^2 y_i + y_i^3) \end{pmatrix} \quad \Rightarrow \quad Q = D^{-1}E.$$

$$Q = \begin{pmatrix} A \\ B \\ C \end{pmatrix}$$