Need for
More and More

ENERGY

Need for
More and More

ENERGY

Need for
More and More

ENERGY

Need for
More and More

ENERGY

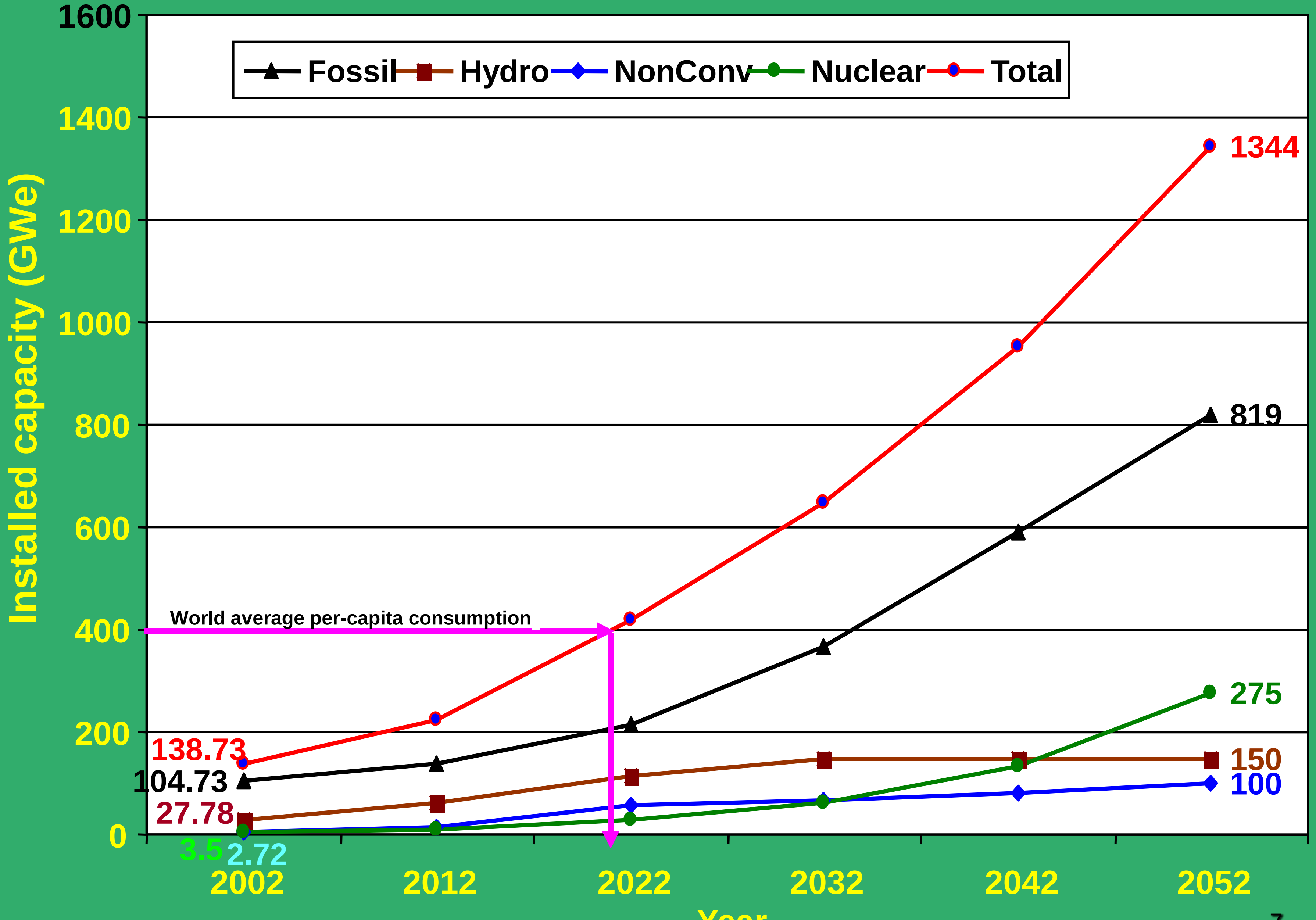
Need for
More and More

ENERGY

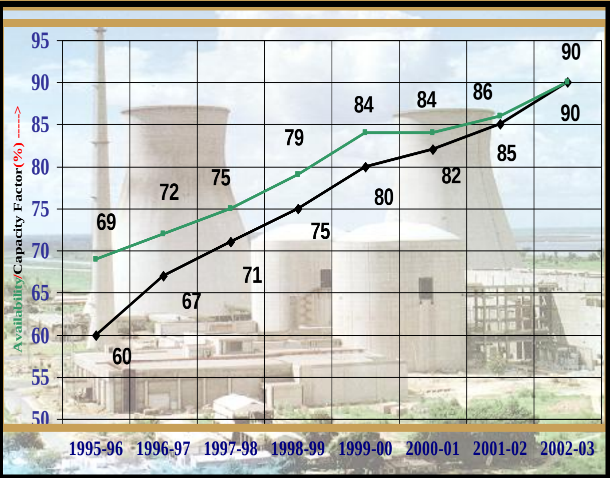
Need for More and More

ENERGY

Projected Installed Power Capacity



Three Stage Nuclear Power Program



Stage – I
PHWRs
Uranium Based Reactors

- 12- Operating
- 6 - Under construction
- Scaling to 700 MWe

LWRs

- 2 BWRs Operating
- 2 Russian Reactors under construction

- **POWER POTENTIAL ≅ 12,000 MWe**

Stage – II
Fast Breeder Reactors

Uranium → Plutonium

- 40 MWth FBTR - Technology Demo (1985)
- 500 MWe PFBR- Under Construction
- Technology development for closing the fuel cycle

POWER POTENTIAL ≅ 540,000 MWe

Stage - III
Thorium Based Reactors

Thorium → Uranium

- 30 kWth KAMINI- Operating
- 300 MWe AHWR- Under Development

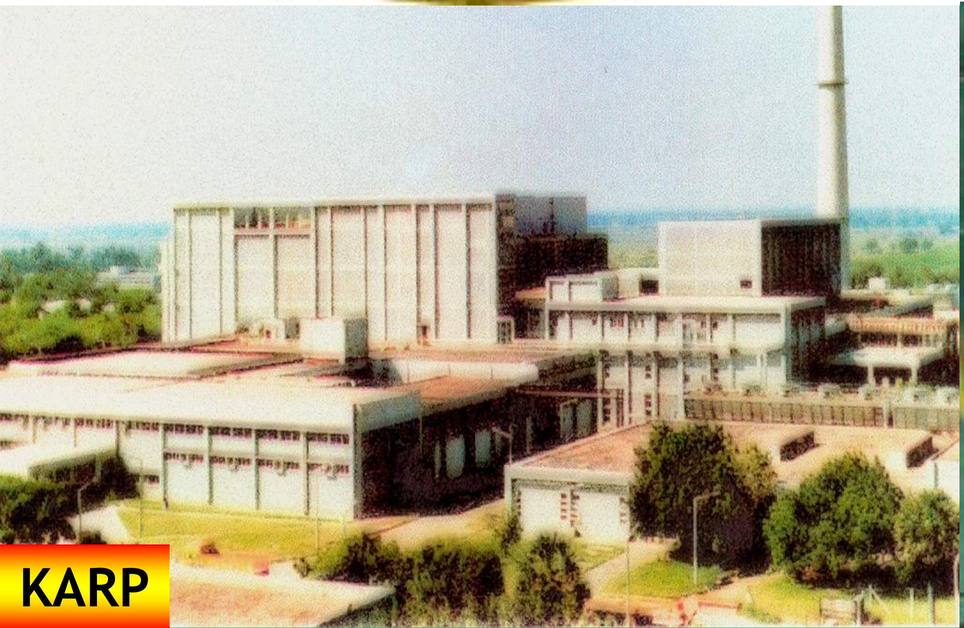
POWER POTENTIAL ≅

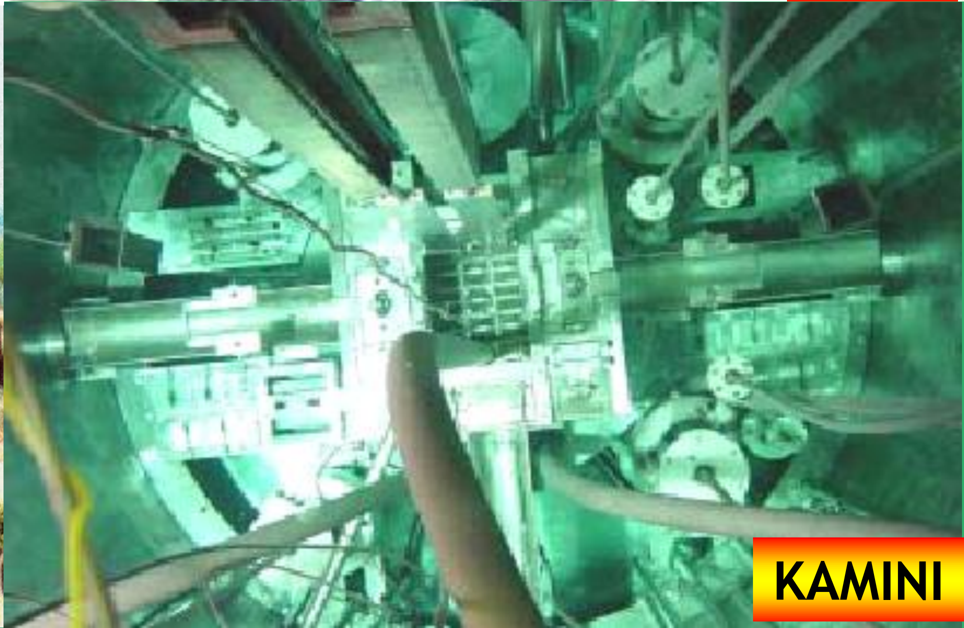
VERY LARGE

Nuclear Programme at Kalpakkam – A Glance


MAPS


FBTR


KARP

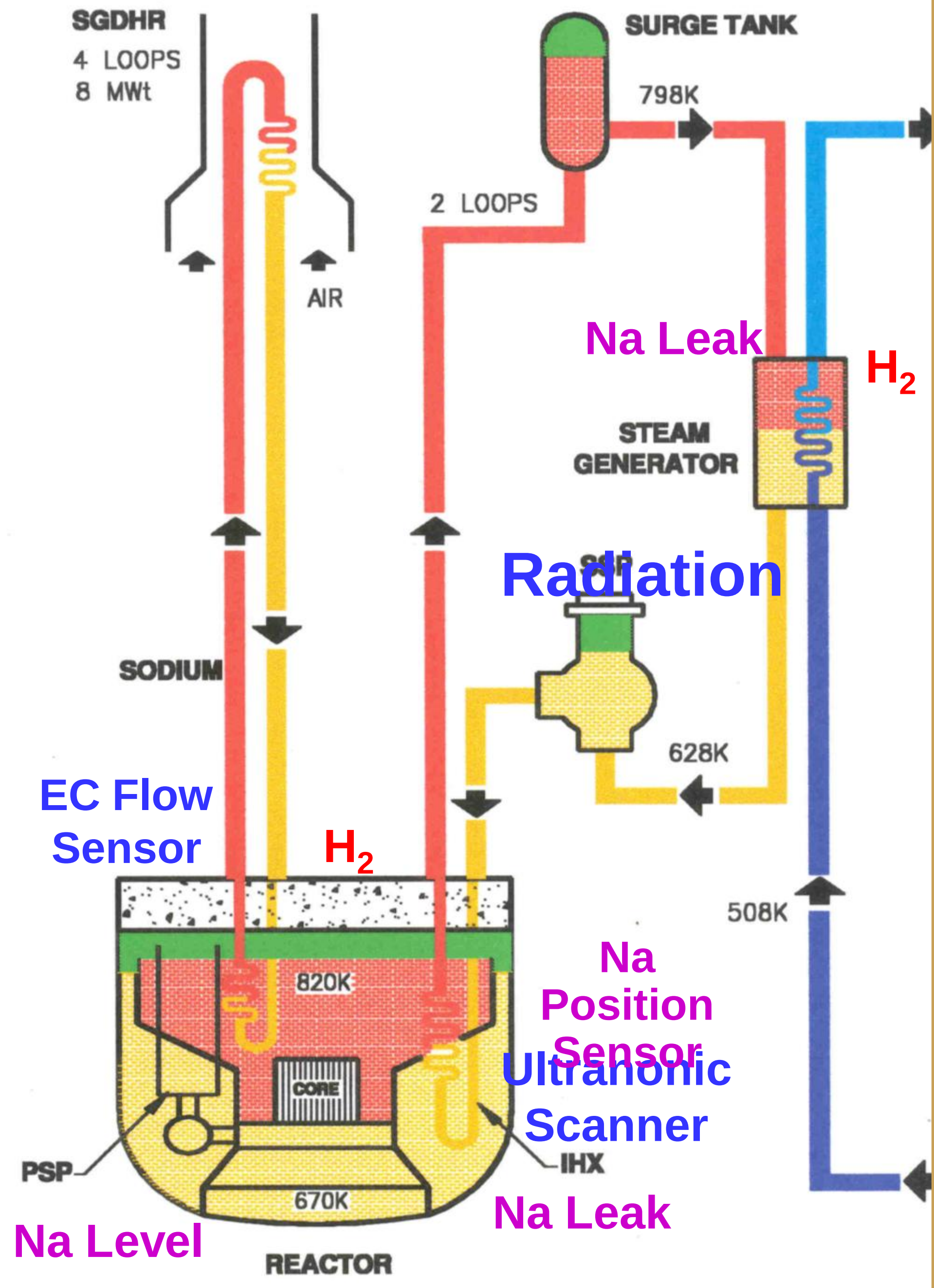

KAMINI

500 MWe FBR in Progress

QUALITY
SAFETY
RELIABILITY
LONGIVITY

OF
CRITICAL INSTALLATIONS

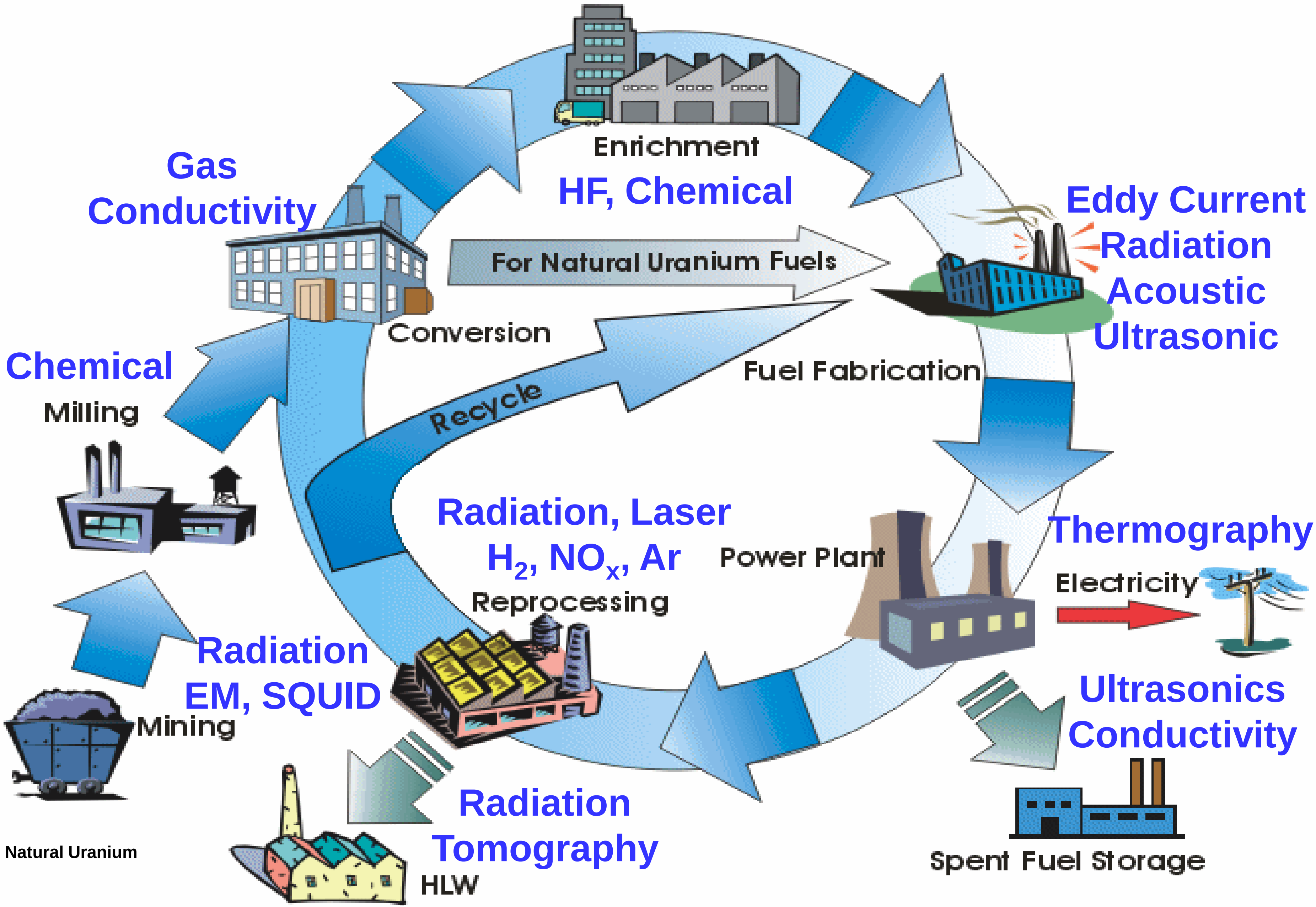
Sensors in Reactors



Pressure
Temperature
Stress
Strain
Chemical
Radiation

and so on….

Sensors in Nuclear Fuel Cycle



Sensor Science and Technology

at

Indira Gandhi Centre for Atomic Research

Kalpakkam – India

A Voyage of Creativity
Driven by Necessity

- **Quality Control Tests → Data**
- **Need for detailed analysis**
- **Signal Analysis**
- **Image Analysis**

Boundary based Classification

C. Babu Rao and B. Sasi
IGCAR, Kalpakkam

OUTLINE

- Introduction
- Chain code
- Incremental circle transform (ICT)
  - Implementation
  - Object recognition
- Classification of Eddy Current Impedance Signals
- Application ICT for the calculation of Fractal dimension

OUTLINE

- **Introduction**
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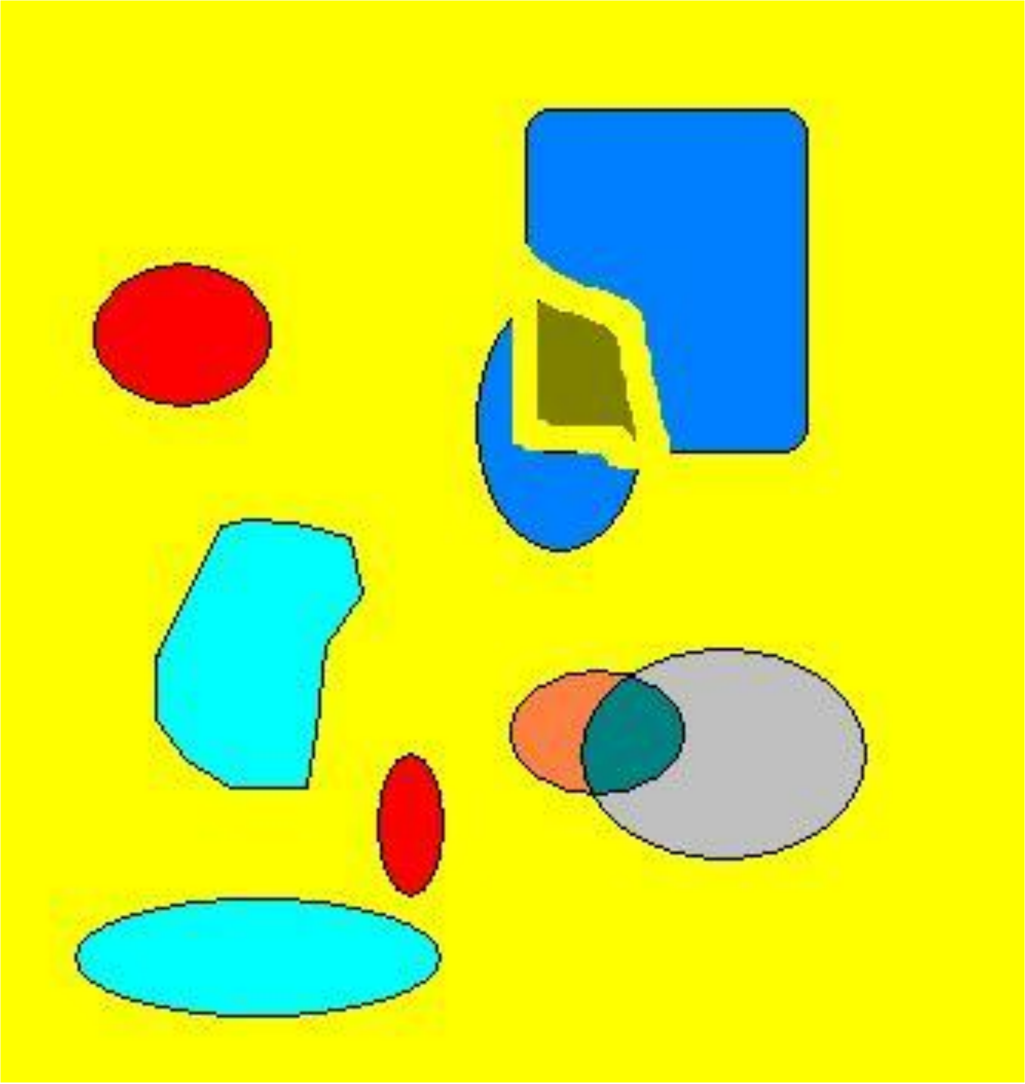
INTRODUCTION

- Recognition of object
  - Important in computer Vision and pattern recognition ,regardless of the orientation.
  - Computer vision used in manufacturing industries for performing an assembly task with great consistency and repeatability than human workers
- Several properties can be used for the recognition and categorization
  - Shape , texture, color

Importance Of Boundary Representation



Importance Of Boundary Representation

Importance of proper representation of boundaries

- Shape analysis
- Shape synthesis

Shape analysis

- Detection of irregular feature
- Recognition of irregular feature

Shape synthesis

- Image stimulation application such as video games cartoon movies, environmental modeling
- Medical diagnosis
- Computer aided design of parts and assembly

Boundary Representation

➢2-D pose of the object by Central moments and principal axis (Hu (1962)

oLimitation: whole image to be examined to find central moments of an object

➢Plots the tangential orientation Ψ as a function of the boundary distance s Barrow et.al(1971)

oLimitation: sensitive to noise

➢ Fourier descriptors conveying shape information by coefficients Persoon(1977)

o Limitation: time consuming

➢Hotelling transform represent the direction of maximum variance of the objectGonzalez and Wintz(1977)

o.Limitation: time consuming

➢Decomposing the boundary of the object by group of con-curves to classify the object Perkins(1978)

Limitation: time consuming for finding the con-curves

Boundary Representation

- 2-D pose of the object by Central moments and principal axis (Hu (1962)

o Limitation: whole image to be examined to find central moments of an object

- Plots the tangential orientation Ψ as a function of the boundary distance s Barrow et.al(1971)

o Limitation: sensitive to noise

- **Fourier descriptors → Shape → Fourier coefficients**

o Limitation: time consuming

- Hotelling transform represent the direction of maximum variance of the object Gonzalez and Wintz(1977)

o. Limitation: time consuming

- Decomposing the boundary of the object by group of con-curves to classify the object Perkins(1978)

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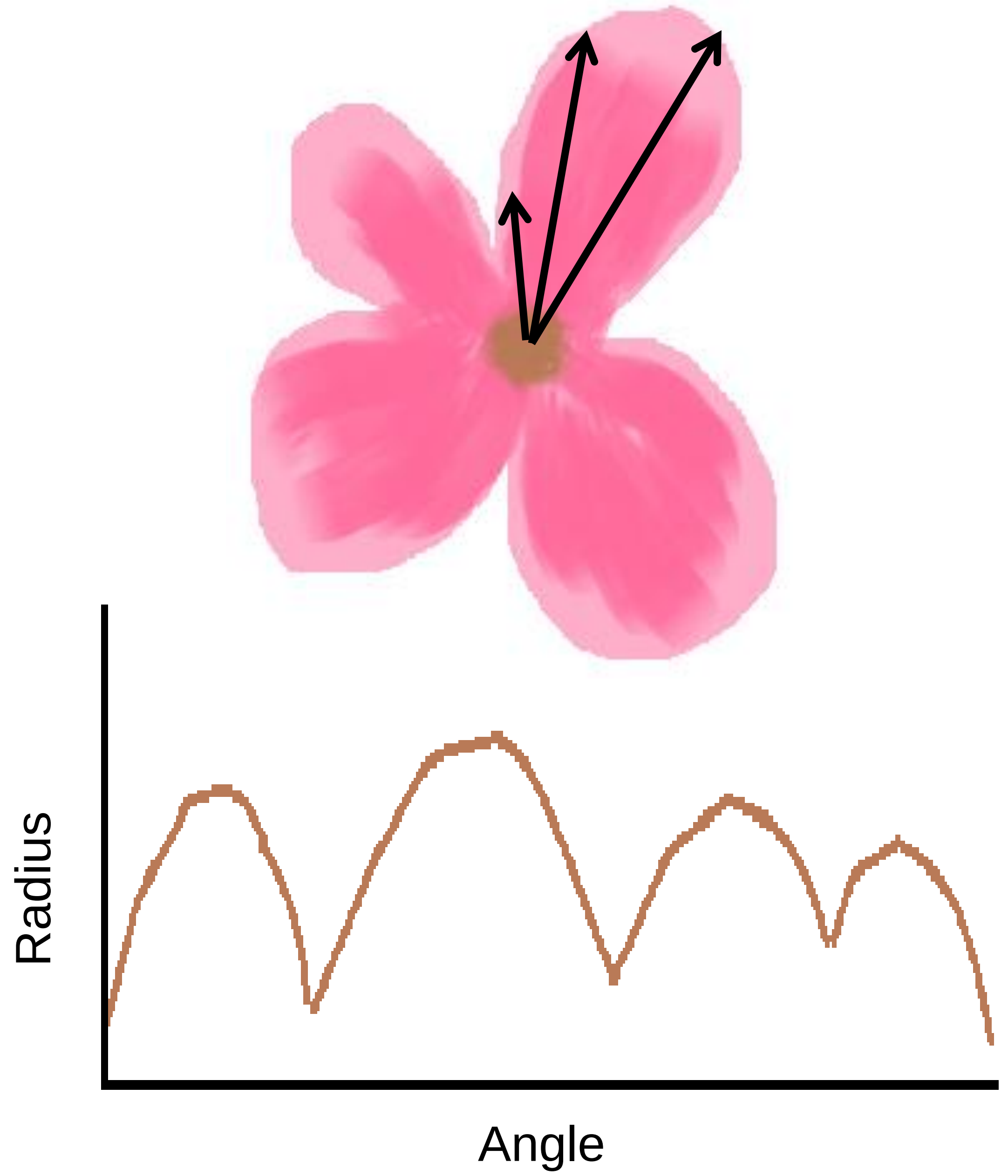
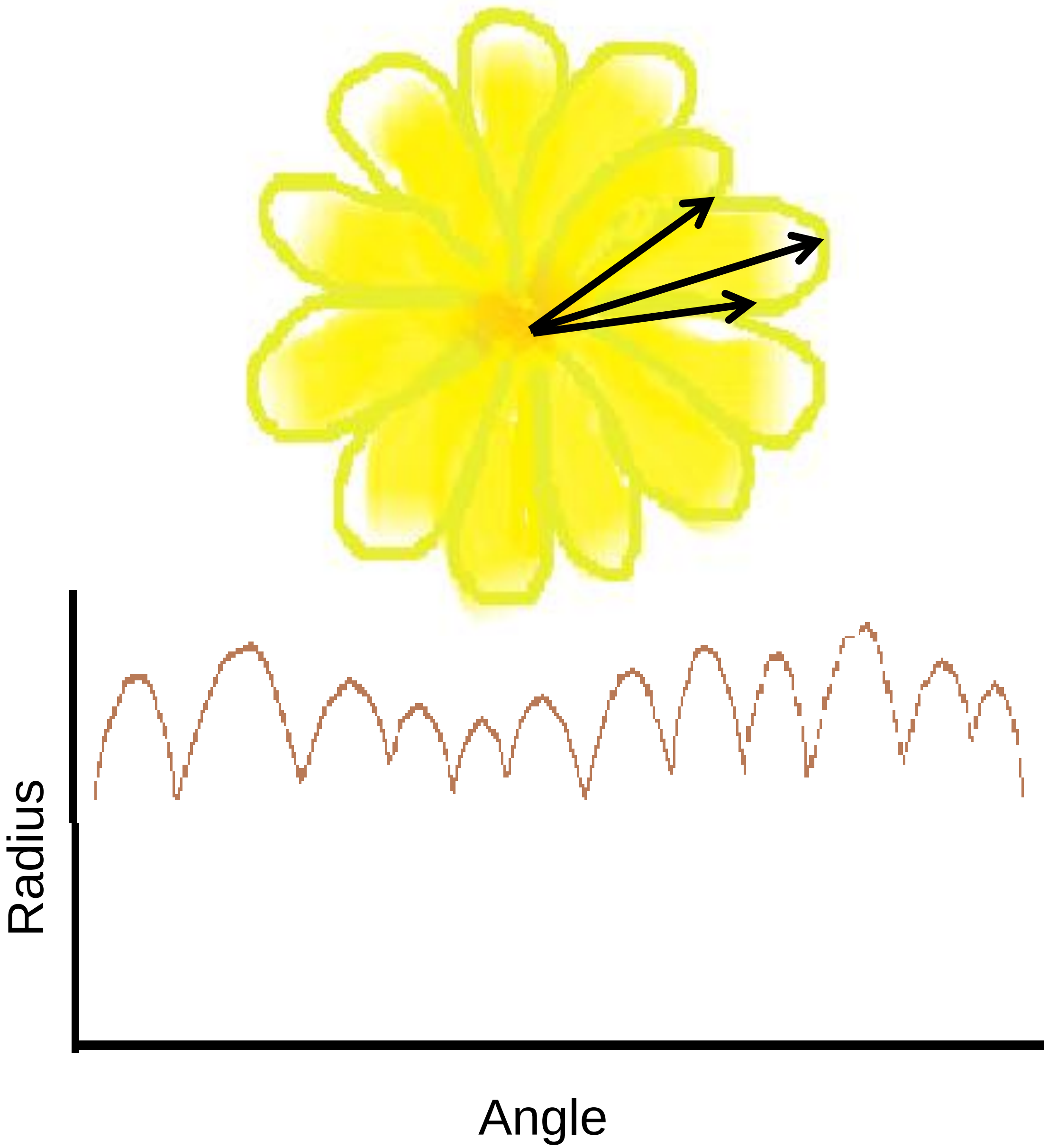

Radius
Angle


Radius
Angle

OUTLINE

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- **Chain code**
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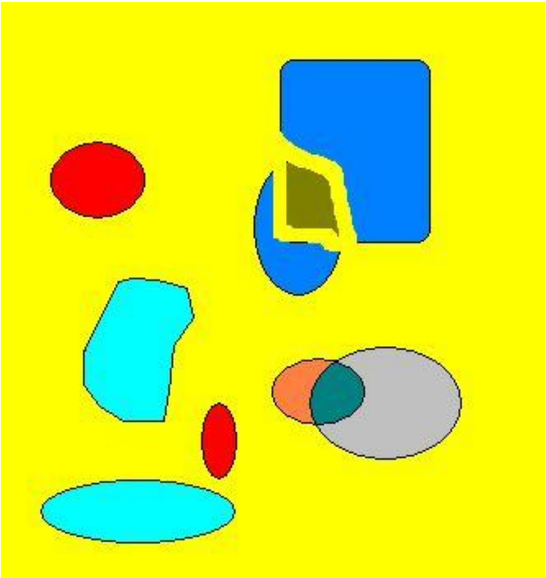
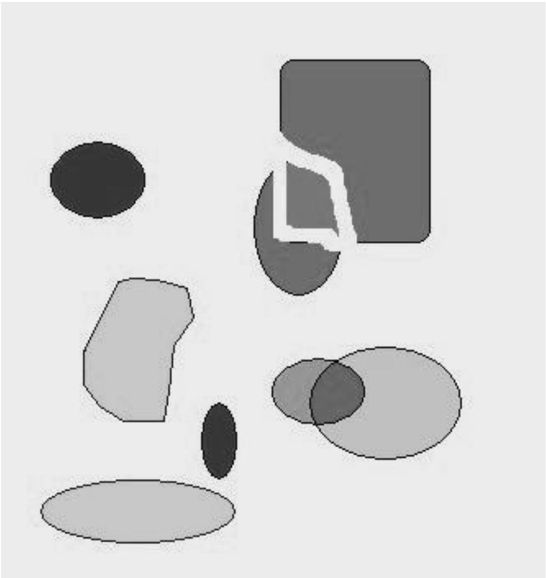
READING THE IMAGE

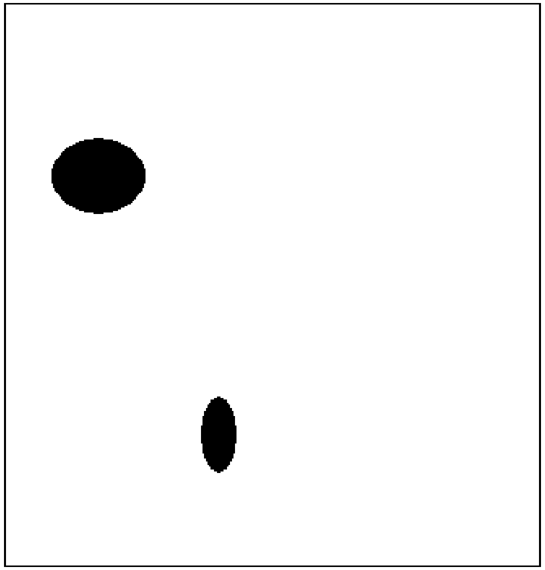
Original image



Grayscale image



Binary image



CHAIN CODE

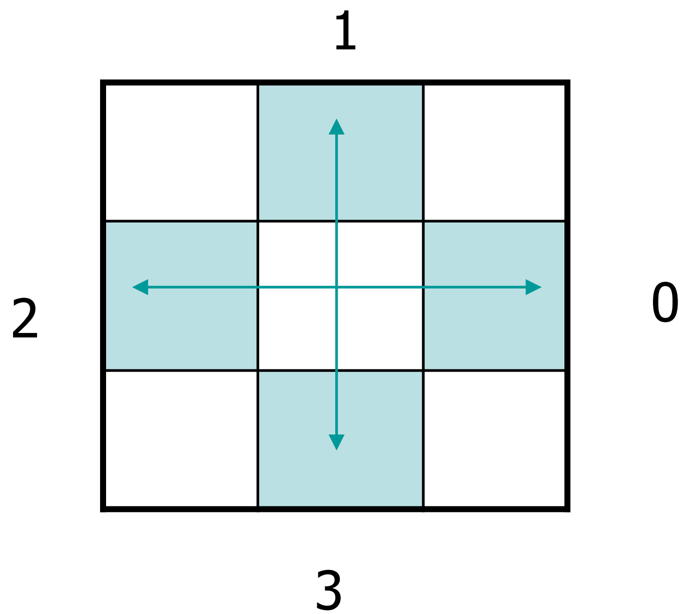
It gives the direction vectors between successive boundary pixels.

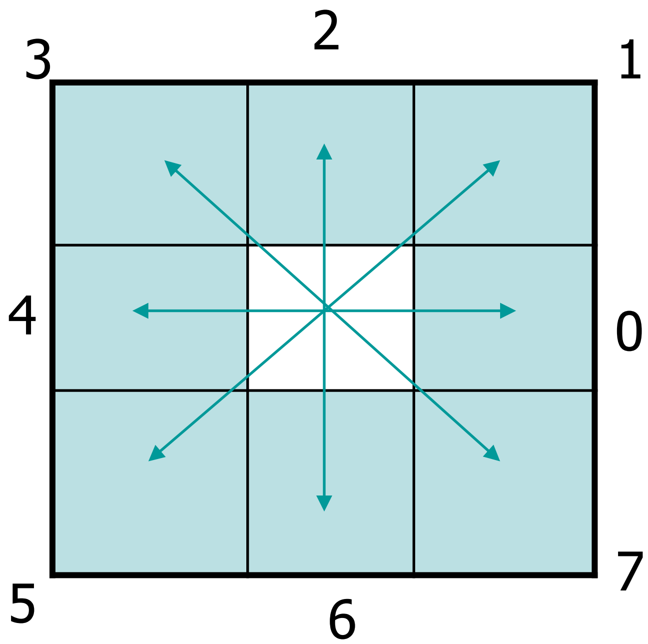
4 CONNECTIVITY

- It shares edges

8 CONNECTIVITY

- It either shares an edges or vertex





ALGORITHM FOR CHAIN CODE

- Finding the starting pixel
- Find the nearest edge pixel by Scanning the 8 neighbor pixel
- Coding its orientation
- Continue until the starting pixel is found

1	1	1	1	1	1
1	1	0	0	0	1
1	1	0	0	0	1
1	0	0	0	0	1
1	1	1	1	1	1

ALGORITHM FOR CHAIN CODE

- Finding the starting pixel
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1	1	1	1	1	1
1	1	0	0	0	1
1	1	0	0	0	1
1	0	0	0	0	1
1	1	1	1	1	1

6

ALGORITHM FOR CHAIN CODE

- Finding the starting pixel
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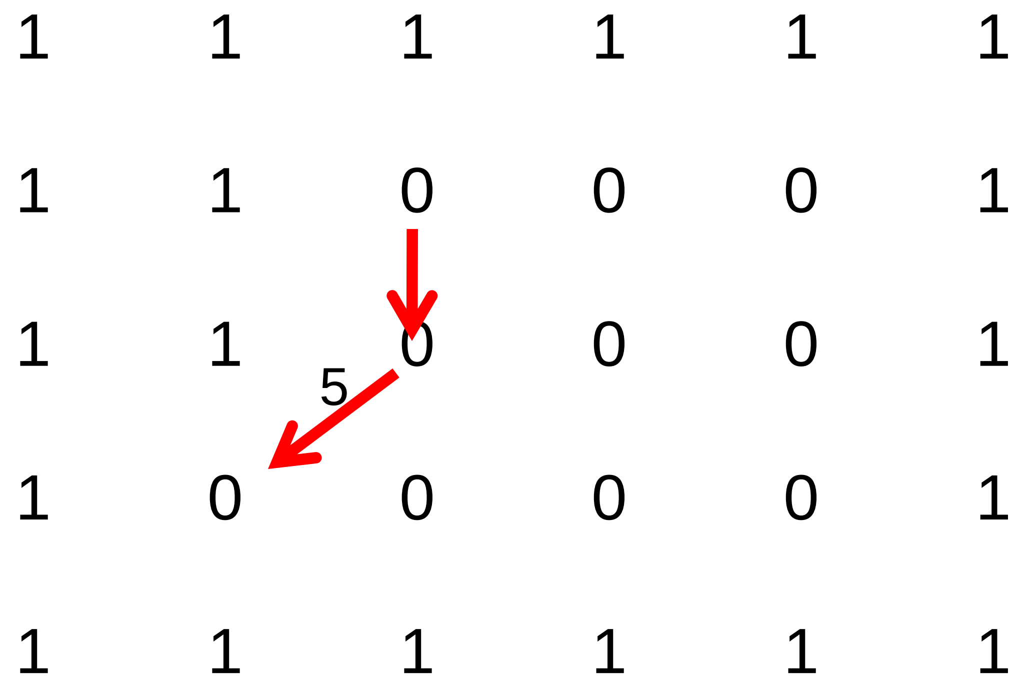

ALGORITHM FOR CHAIN CODE

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1	1	1	1	1	1
1	1	0	0	0	1
1	1	0	0	0	1
1	0	0	0	0	1
1	1	1	1	1	1

0

ALGORITHM FOR CHAIN CODE

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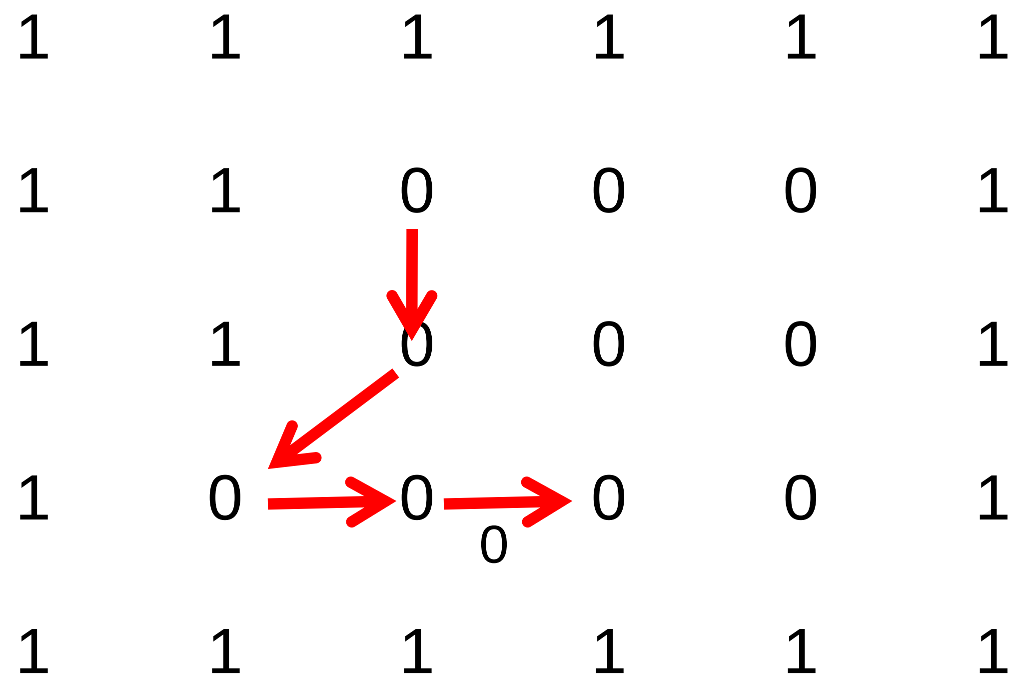

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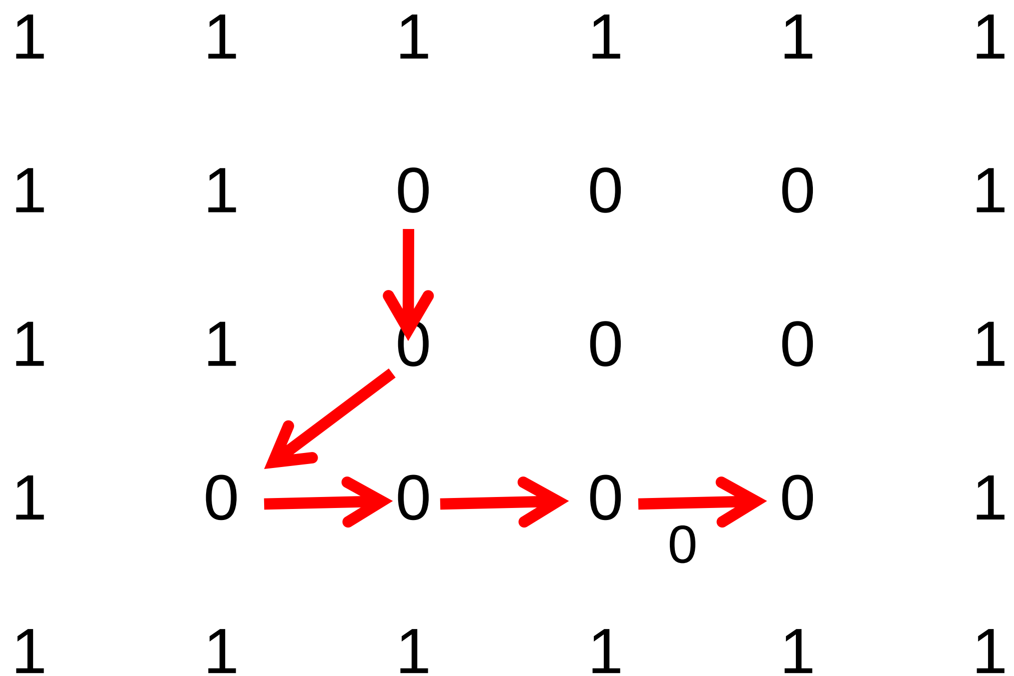

ALGORITHM FOR CHAIN CODE

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ALGORITHM FOR CHAIN CODE

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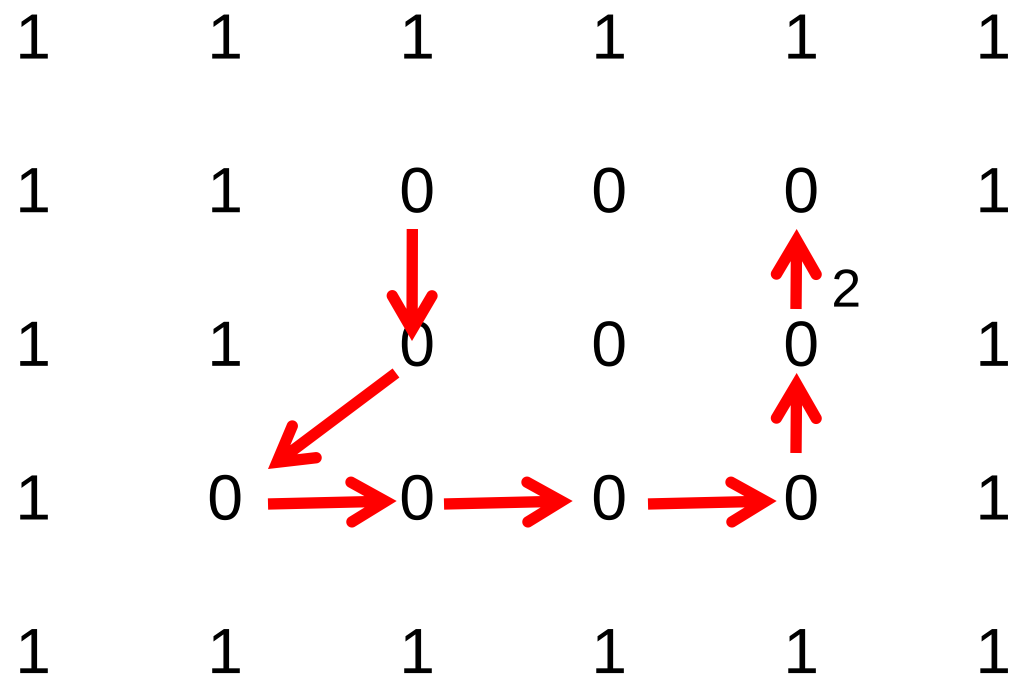

ALGORITHM FOR CHAIN CODE

- Finding the starting pixel
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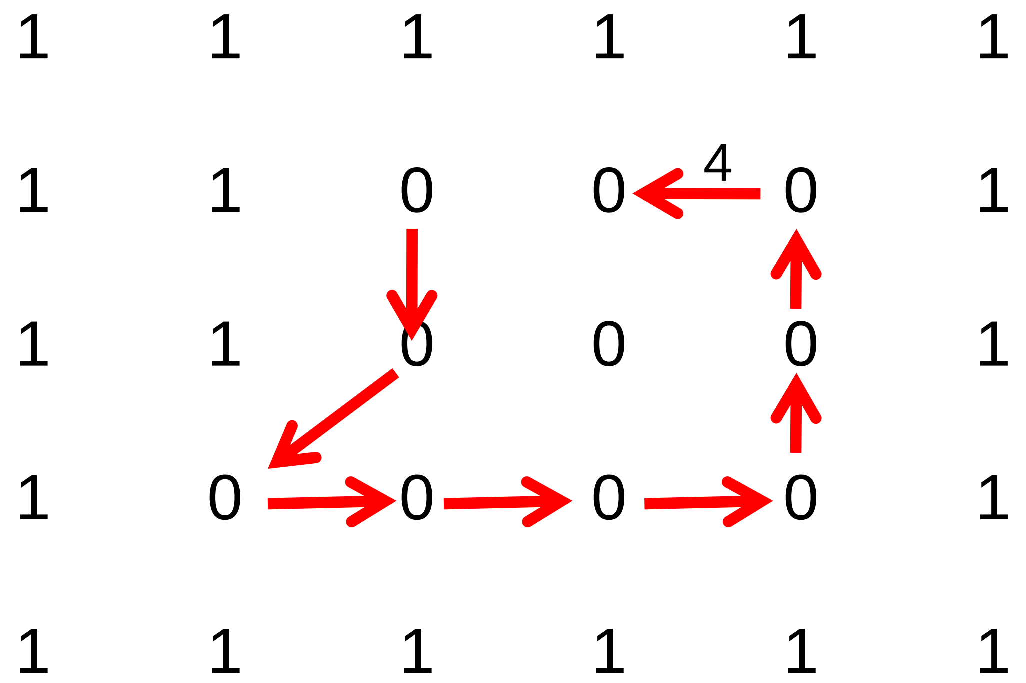

ALGORITHM FOR CHAIN CODE

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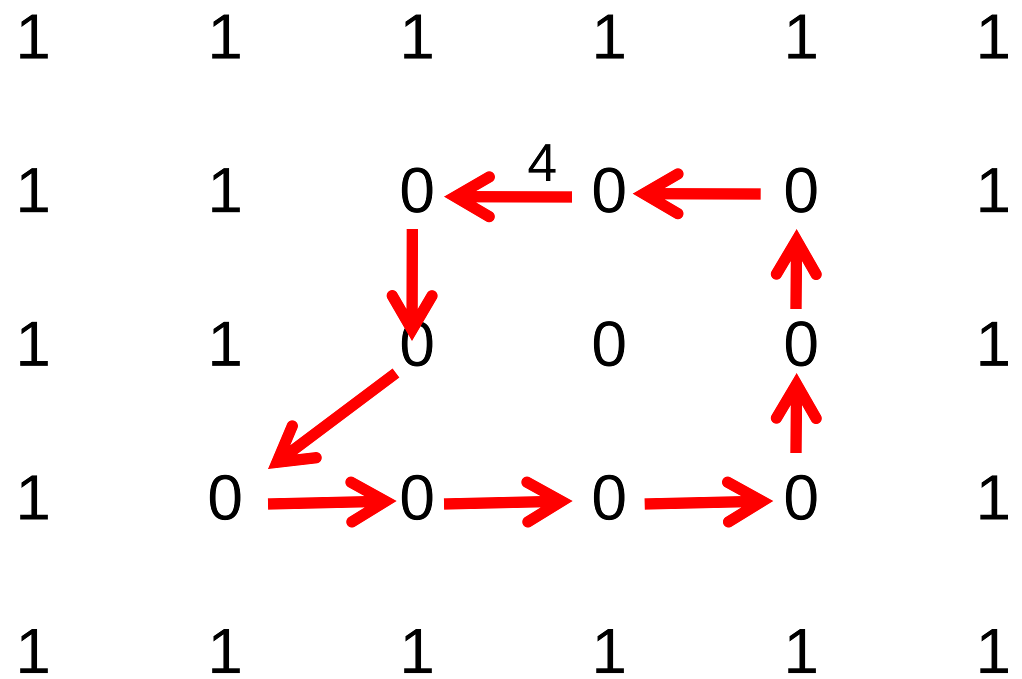

ALGORITHM FOR CHAIN CODE

- Finding the starting pixel
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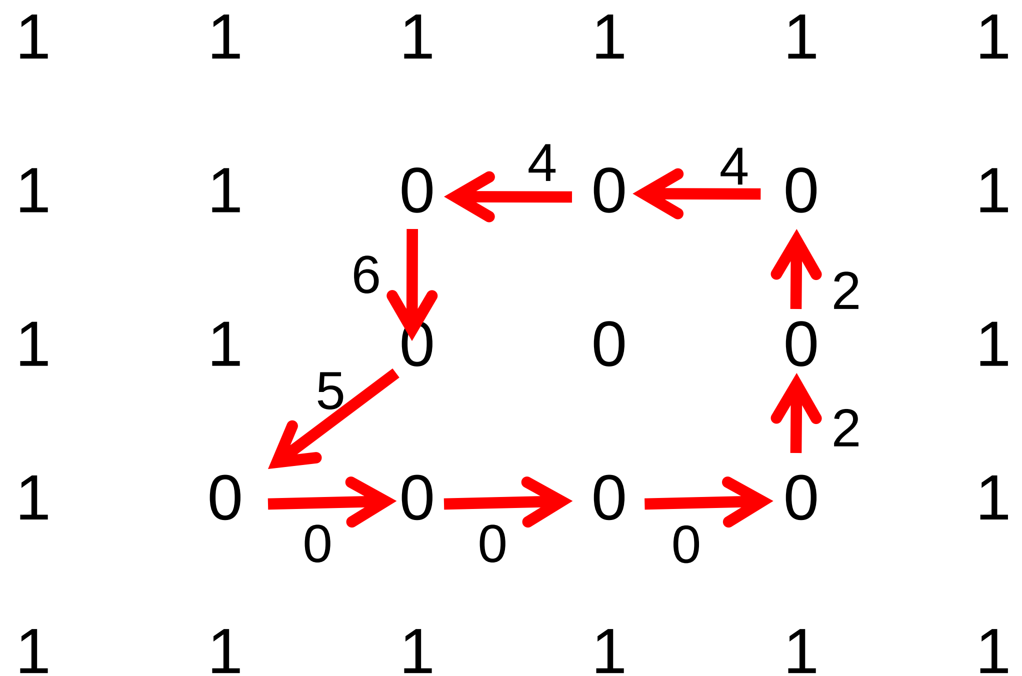
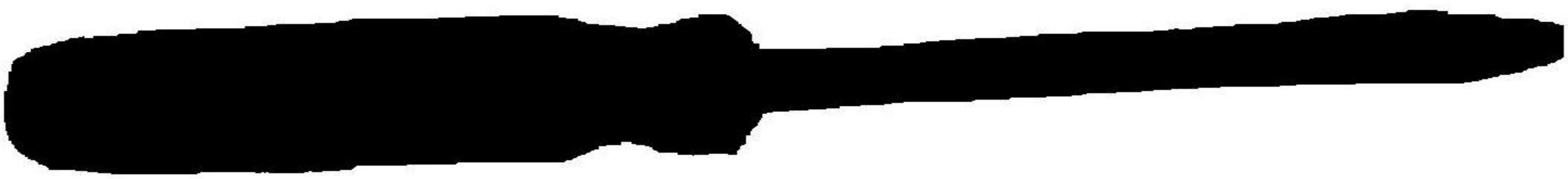


{6,5,0,0,0,2,2,4,4}

CHAIN CODE – IMAGE RECONSTRUCTION

Original image

Reconstructed image



But …

- Length of the chain code is proportional to size
- Chain code is un-wieldy
- The larger the size the longer the time taken for comparison
- Highly noise prone

OUTLINE

- Introduction
- Chain code
- **Incremental circle transform (ICT)**
  - Implementation
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INCREMENTAL CIRCLE TRANSFORM

- Simple pattern recognition method.
- Maps boundary points with circle as contour element
- Represents boundary contour as a vector function.
- Applicable on closed curve.
- Processing time is less.

ALGORITHM FOR FINDING THE ICT

- Finding the starting pixel
- The starting point as the center of the circle draw a circle of fixed radius.
- Find the intersection point of the circle at the boundary of contour.
- Store the inter section point
- The intersection point will be the center for next circle
- Repeated until reaches its starting point
- Regenerate the feature using the ICT points
- Find the orientation of the feature

DEFINITION

For a closed curve α(t),
$0 \leq t \leq L$, and a fixed positive constant r and each $t \in [0,L]$, $\Delta r\ \alpha(t)$ denotes vector

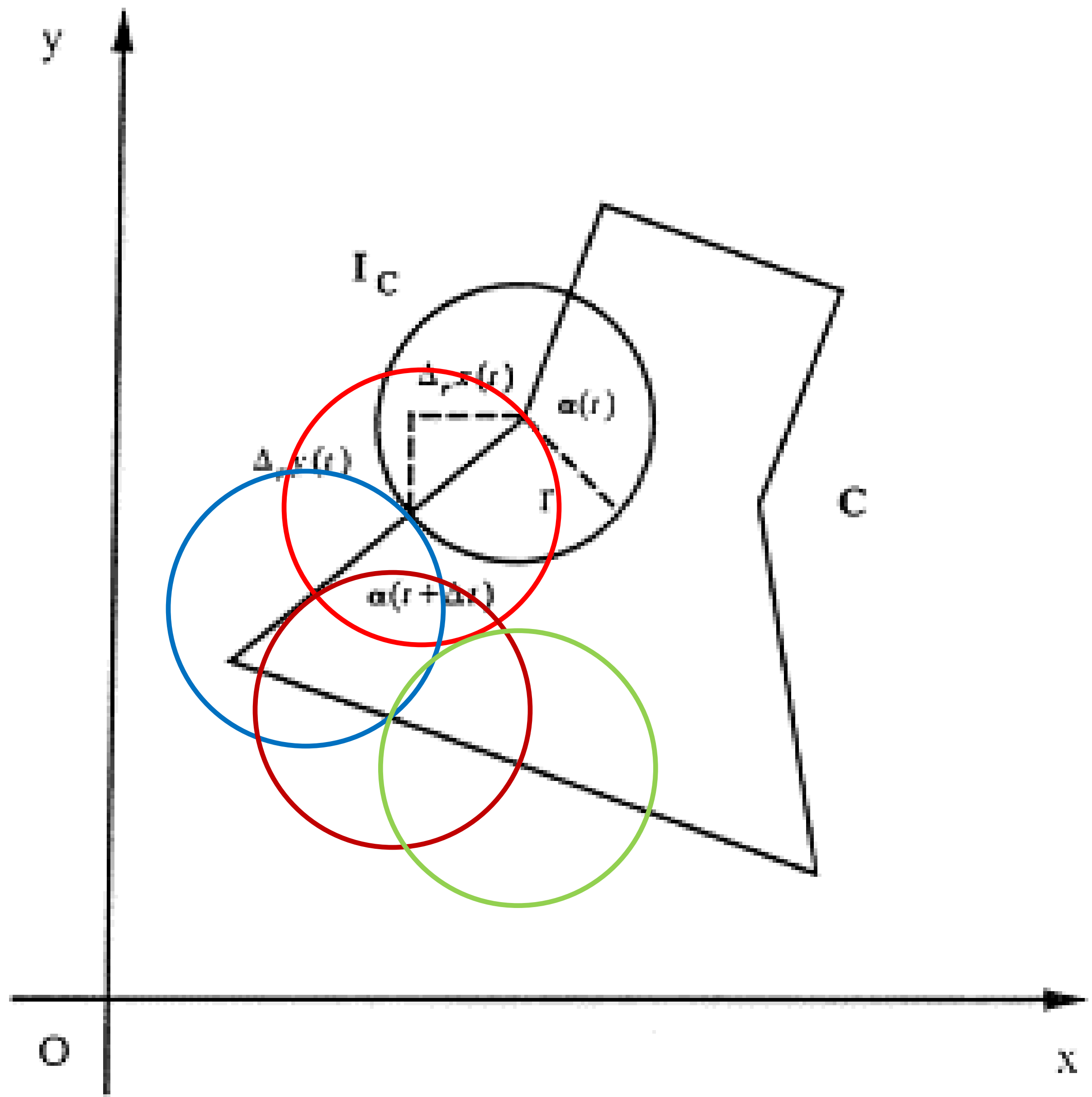
$\Delta r\ \alpha(t)=(\Delta_r\ x\ (t)\ ,\ \Delta_r\ y\ (t)\ )$

where

$\Delta_r x^2\ (t)+\ \Delta_r y^2\ (t)\ =r^2$

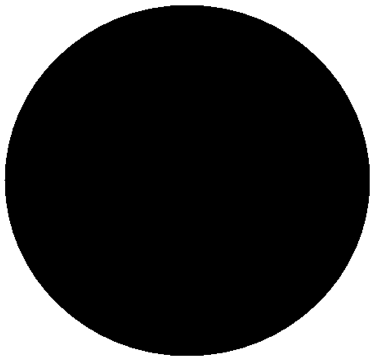
and

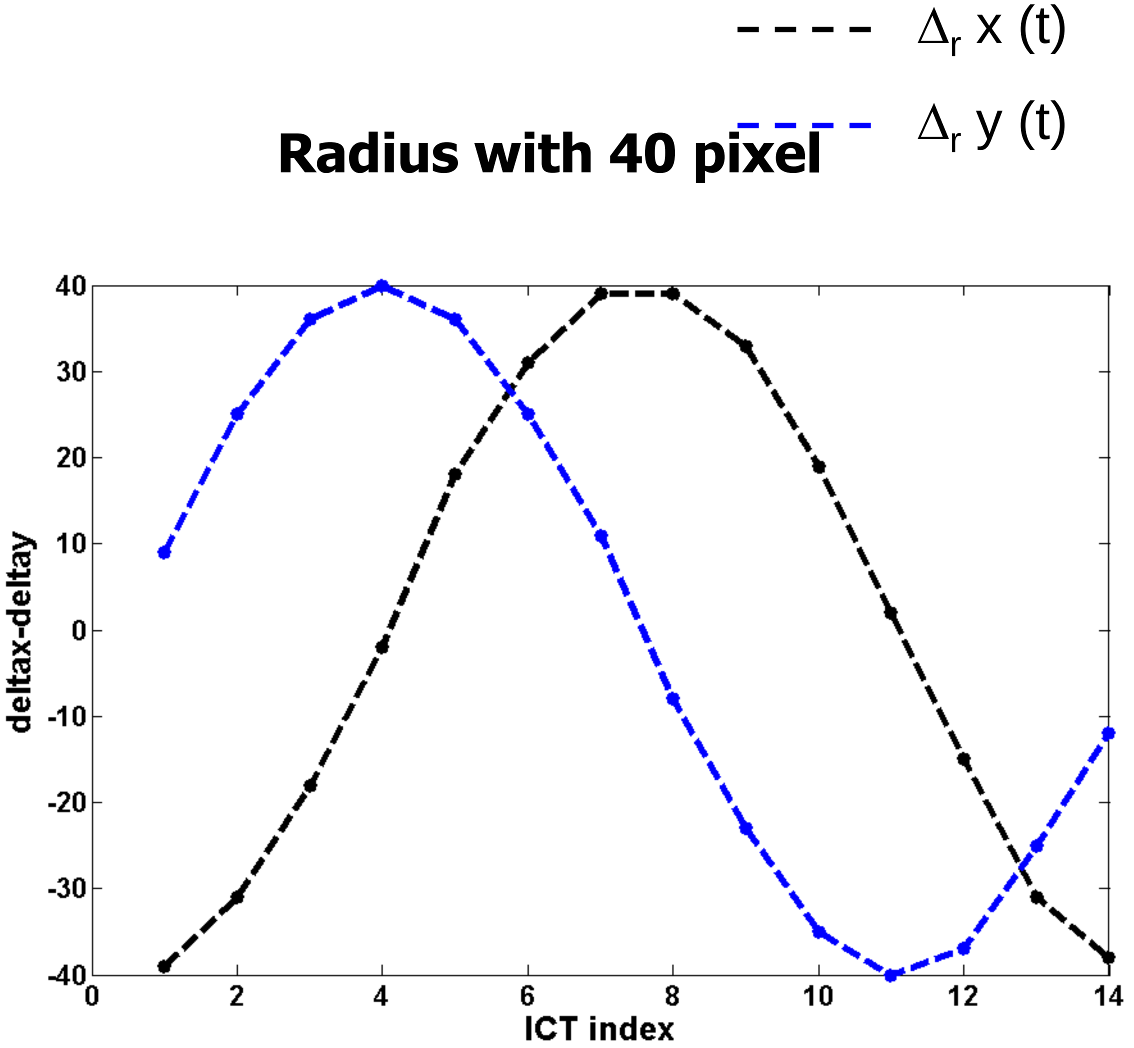
$\alpha(t+\ \Delta t)=\ \alpha(t)+\ \Delta_r\alpha(t)$



ICT VECTOR - CIRCLE

Radius with 40 pixel



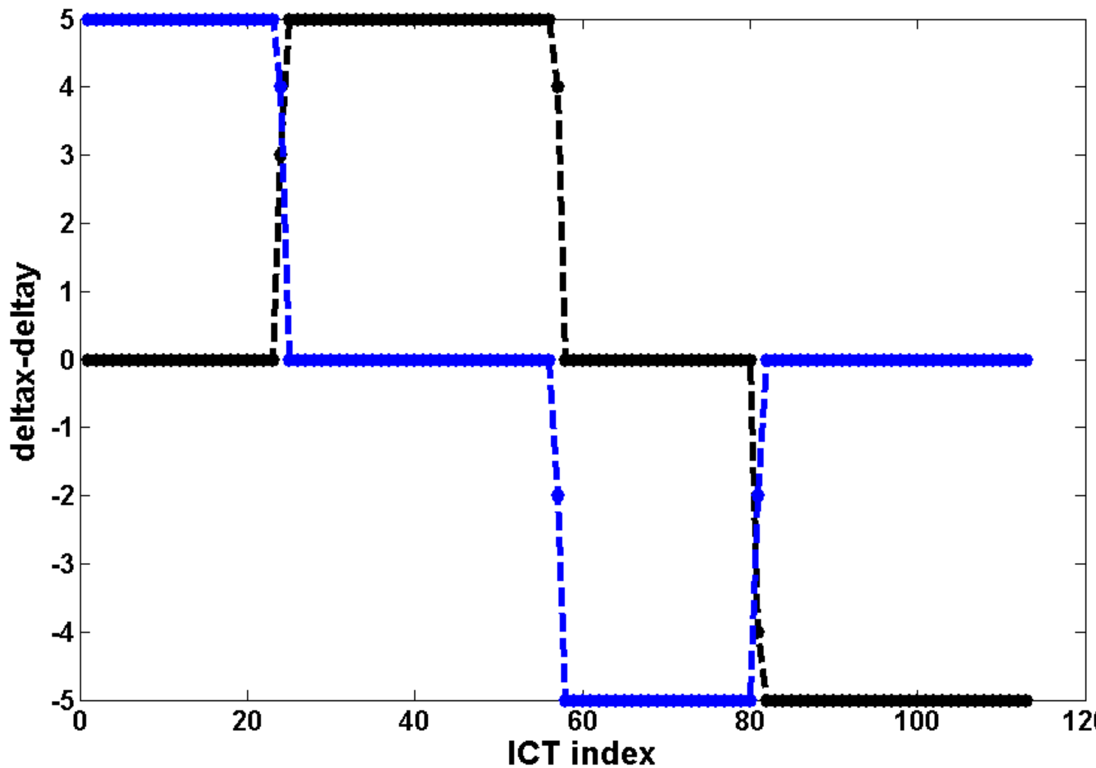


ICT VECTOR - RECTANGLE

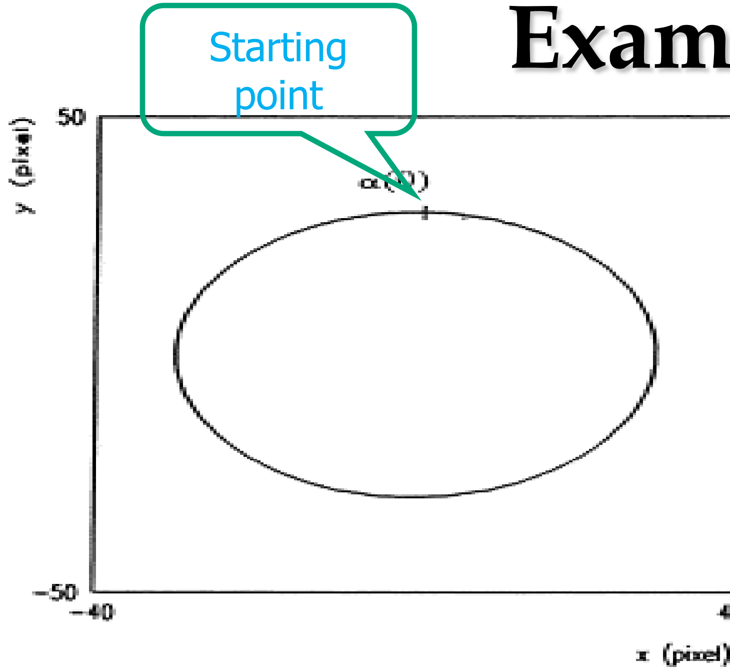
- - - - $\Delta_r x(t)$

- - - - $\Delta_r y(t)$

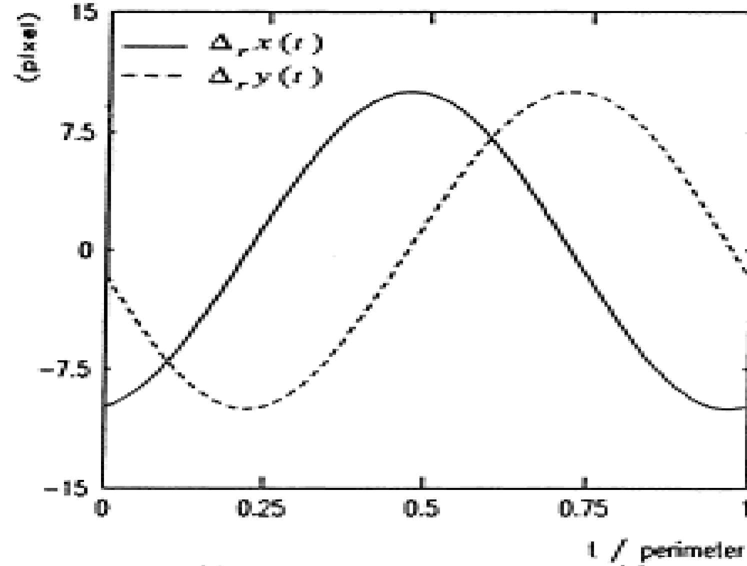
Radius with 10 pixel



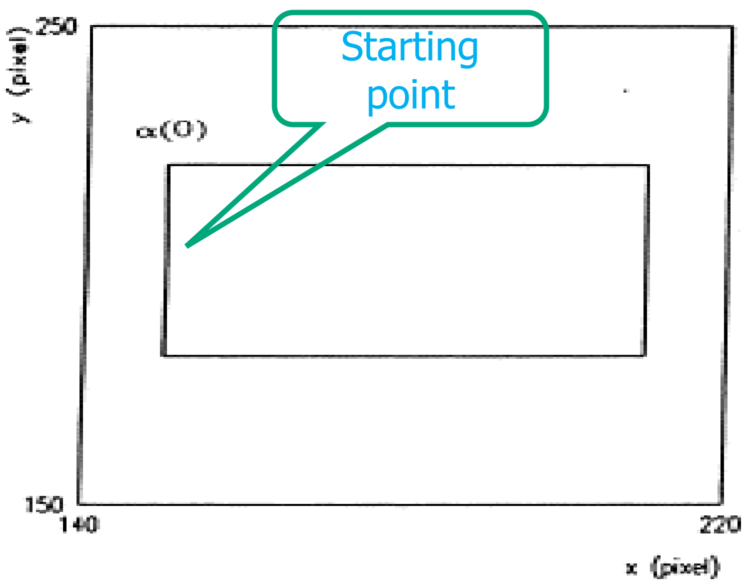
Example of ICT



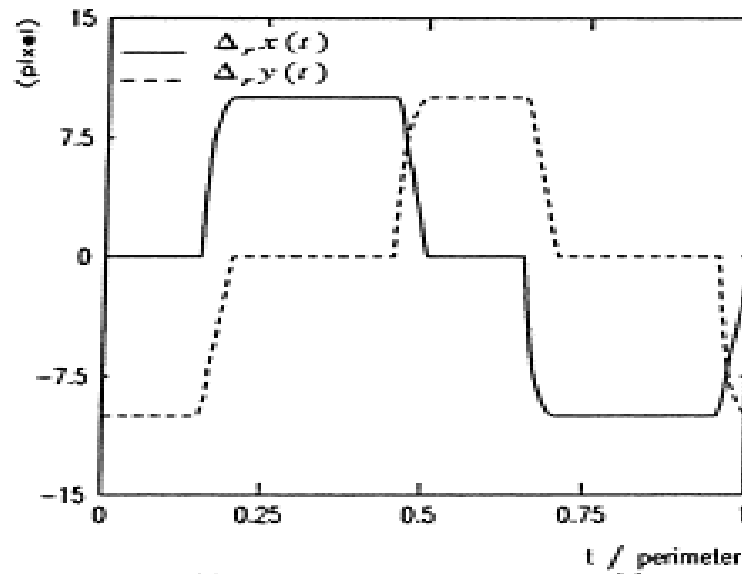
(a) Circle



(b) Incremental Circle Transform of (a)



(c) Rectangle

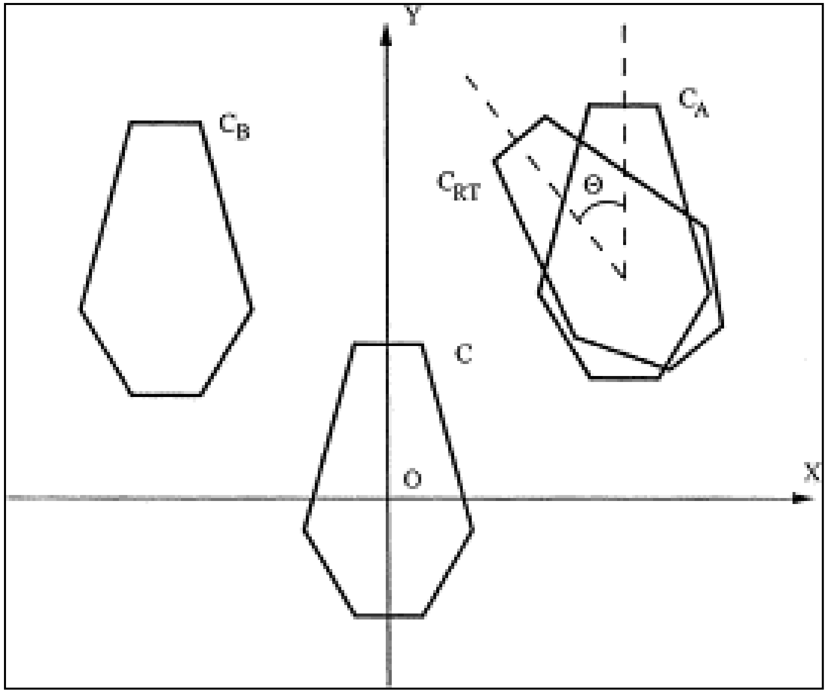


(d) Incremental Circle Transform of (c)

Lemma 1: Translation invariance

If starting points of the contours C. CA, CB are chosen to coincide with one another, then

$$\Delta_r \alpha(t) = \Delta_r \alpha_A(t) = \Delta_r \alpha_B(t), 0 < t < L$$



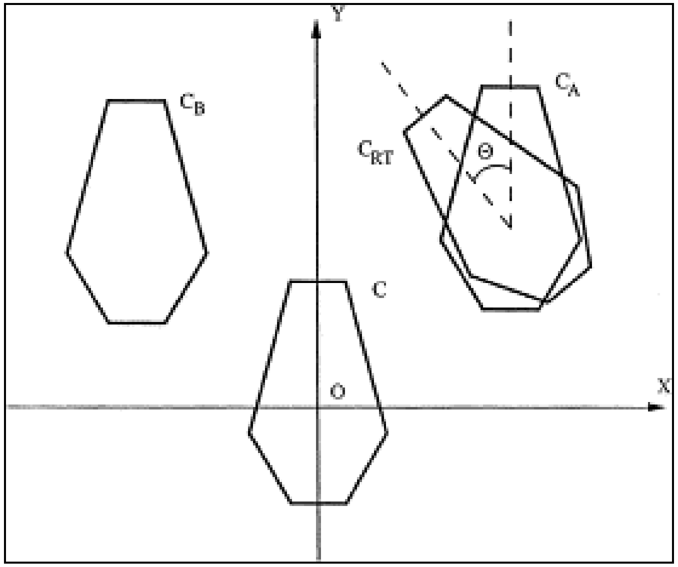
Any dislocated contour can be represented by a combination of translation and rotation of its primitive contour whose center is at the origin of the x-y plane.

Lemma 2: Rotational invariance

Rotation matrix between two contours in the x-y plane is the same as the rotation matrix between the corresponding ICTs of the contours in the Δx- Δy plane regardless of position of the contours in the x-y plane

$$\alpha_{RT}(t) = R\alpha_A(t) \quad \text{where}$$

$$R = \begin{bmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{bmatrix}$$



For corresponding points

$$\alpha_{RT}(t+\Delta t) = \alpha_{RT}(t) + \Delta_r\alpha_{RT}(t)$$

$$\alpha_A(t+\Delta t) = \alpha_A(t) + \Delta_r\alpha_A(t)$$

Follows from definition

$$\alpha_{RT}(t+\Delta t) = R\alpha_A(t+\Delta t)$$

Subtracting

$$\Delta_r\alpha_{RT}(t) = \alpha_{RT}(t+\Delta t) - \alpha_{RT}(t)$$
$$= R\alpha_A(t+\Delta t) - \alpha_A(t)) = R\Delta_r\alpha_A(t)$$

$$\boxed{\Delta_r\alpha_{RT}(t) = R\Delta_r\alpha\ \ (t)}$$

Lemma 3: Closedness

Line integral of ICT along a simple closed curve is symmetric with respect to its center of mass is zero

If C is the symmetric contour, the statement implies that

$$\int_C \Delta_r\, x(t)dt = \int_C \Delta_r\, y(t)dt = 0$$

Utilised to determine the posture of an object if the corresponding points of the boundary contours of two objects are known. Let

$$\mathbf{M} = \Delta_r \alpha(t) \cdot \Delta_r \alpha^{\mathrm{T}}(t),$$
$$\mathbf{T} = \Delta_r \alpha_{\mathrm{RT}}(t) \cdot \Delta_r \alpha_{\mathrm{RT}}^{\mathrm{T}}(t).$$

the 2×2 *matrices* ***M*** *and* ***T*** *are similar, and*

where $$\oint_{CRT} T dt = R \int_C M dt R^{-1}$$

Orientation: the rotation R diagonalizing the matrix represents the attitude of an object w.r.t base coordinate of the x-y image plane

$$\begin{bmatrix} p & 0 \\ 0 & q \end{bmatrix} = \boldsymbol{R} \cdot \begin{bmatrix} a & b \\ b & c \end{bmatrix} \cdot \boldsymbol{R}^{-1},$$

where

$$a = \oint_{\mathbf{C}} \Delta_r x^2(t)\, \mathrm{d}t,$$

$$b = \oint_{\mathbf{C}} \Delta_r x(t) \Delta_r y(t)\, \mathrm{d}t,$$

$$c = \oint_{\mathbf{C}} \Delta_r y^2(t)\, \mathrm{d}t,$$

p, q : eigenvalues of the matrix $\mathbf{M_I}$.

The absolute orientation, θ_a, is determined as follows:

$$\theta_a = \begin{cases} \frac{1}{2} \cdot \tan^{-1}\left(\frac{2b}{c-a}\right) & \text{if } c < a, \\ \frac{1}{2} \cdot \left(\pi - \tan^{-1}\left(\frac{2b}{c-a}\right)\right) & \text{if } c > a \text{ and } b \geqslant 0, \\ \frac{1}{2} \cdot \left(-\pi - \tan^{-1}\left(\frac{2b}{c-a}\right)\right) & \text{if } c > a \text{ and } b < 0, \\ \frac{\pi}{4} & \text{if } a = c \text{ and } b > 0, \\ -\frac{\pi}{4} & \text{if } a = c \text{ and } b < 0, \\ \text{undefined} & \text{if } a = c \text{ and } b = 0. \end{cases}$$

□

ICT-Algorithm

Finding the starting pixel

Find the intersection point of the circle at the boundary of contour

Store the inter section point

The intersection point will be the center for next circle

Repeated until reaches its starting point

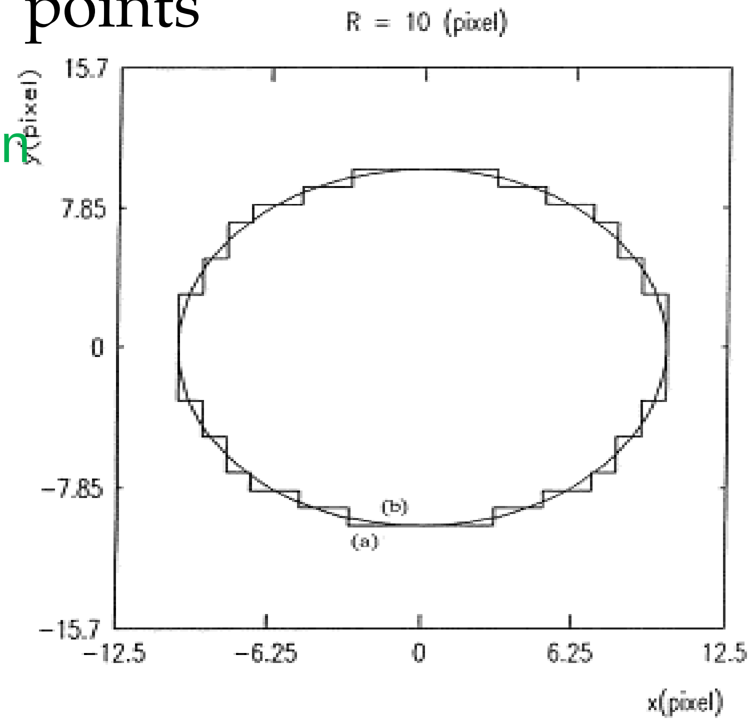
Regenerate the feature using the ICT points

Find the orientation of the feature

Actual circle, digitized circle based on connectivity of neighborhood

The radius of ICR, R is perimeter/10

For orientation detection of several objects the following algorithm is realised



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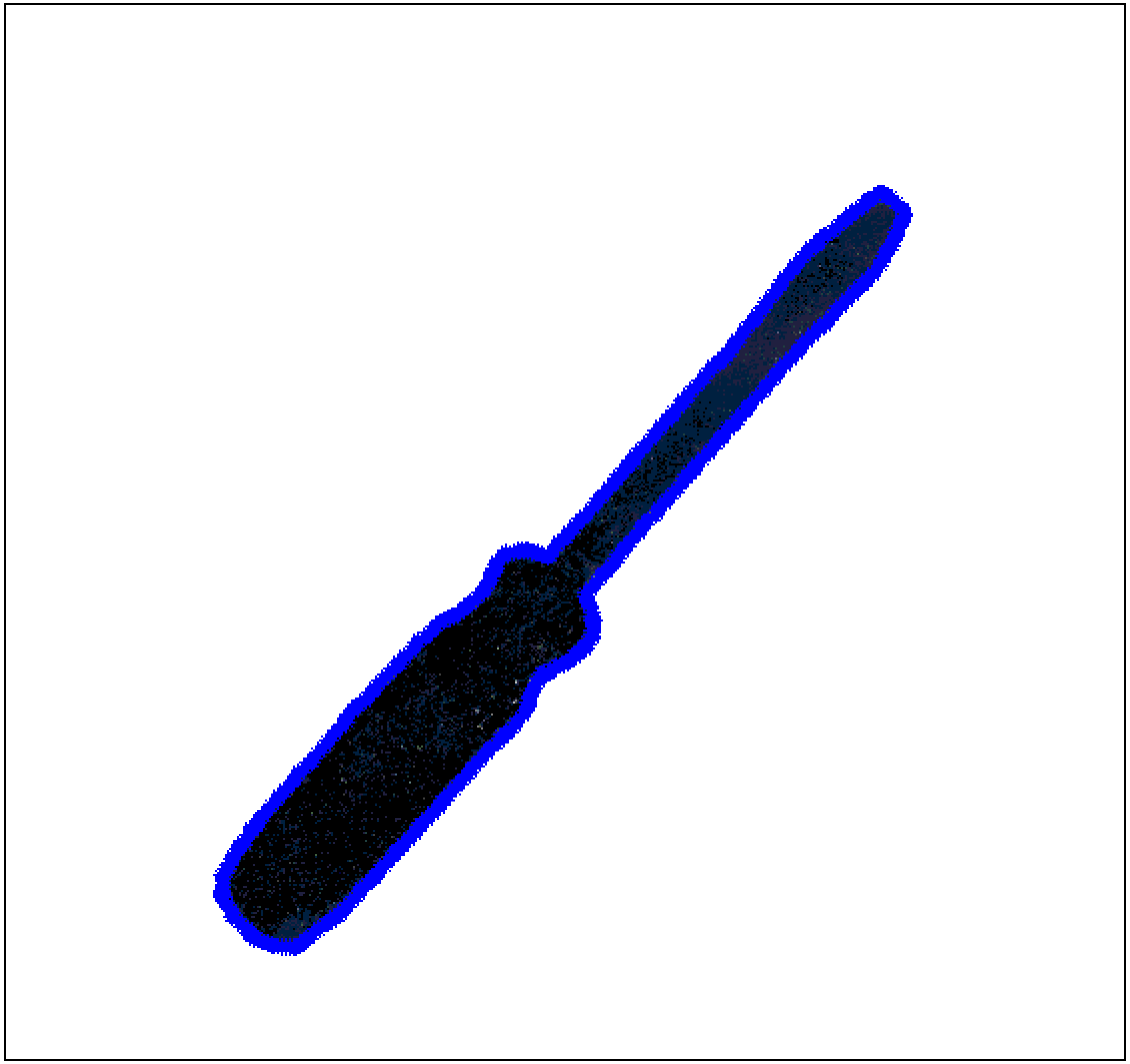
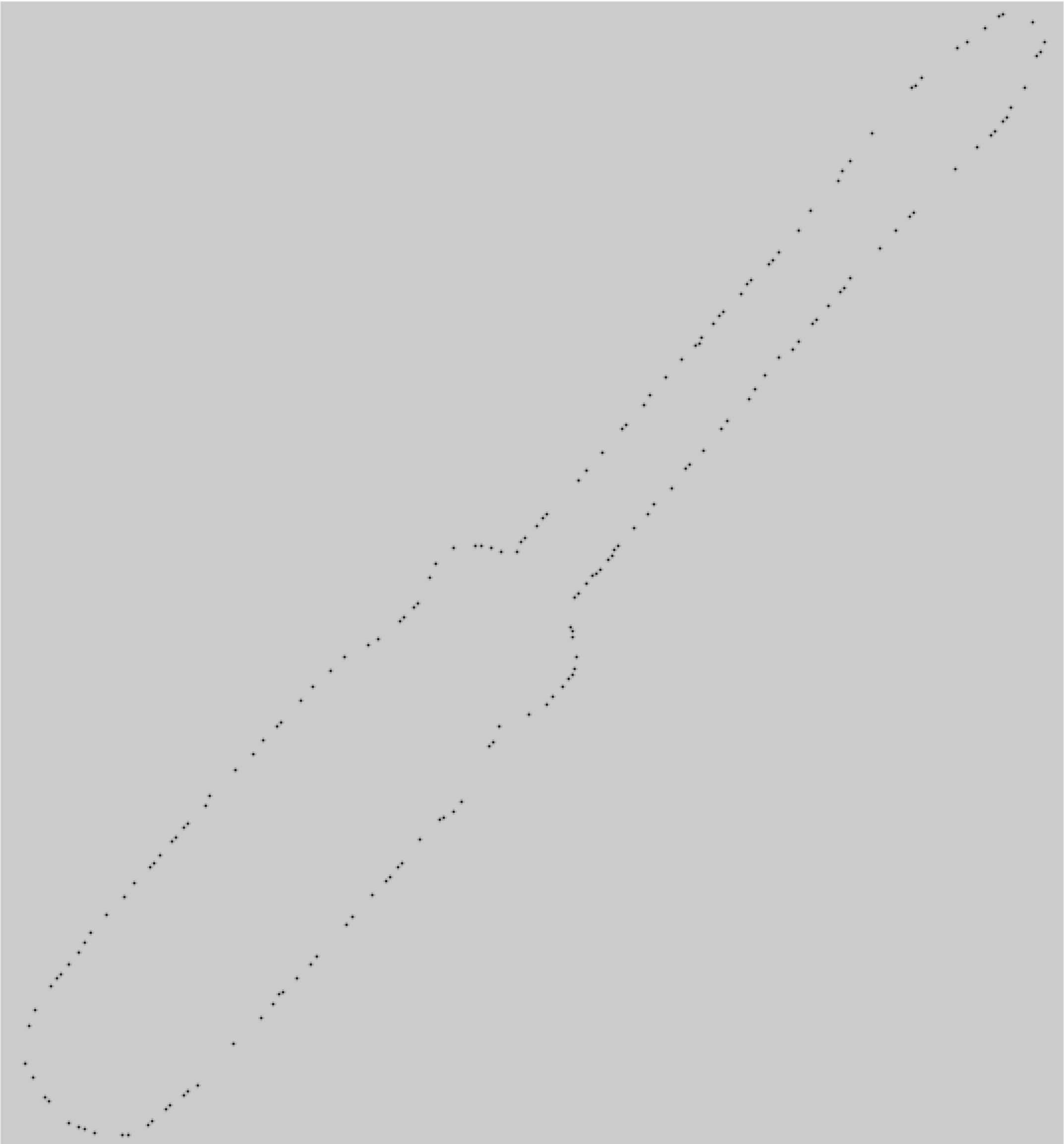
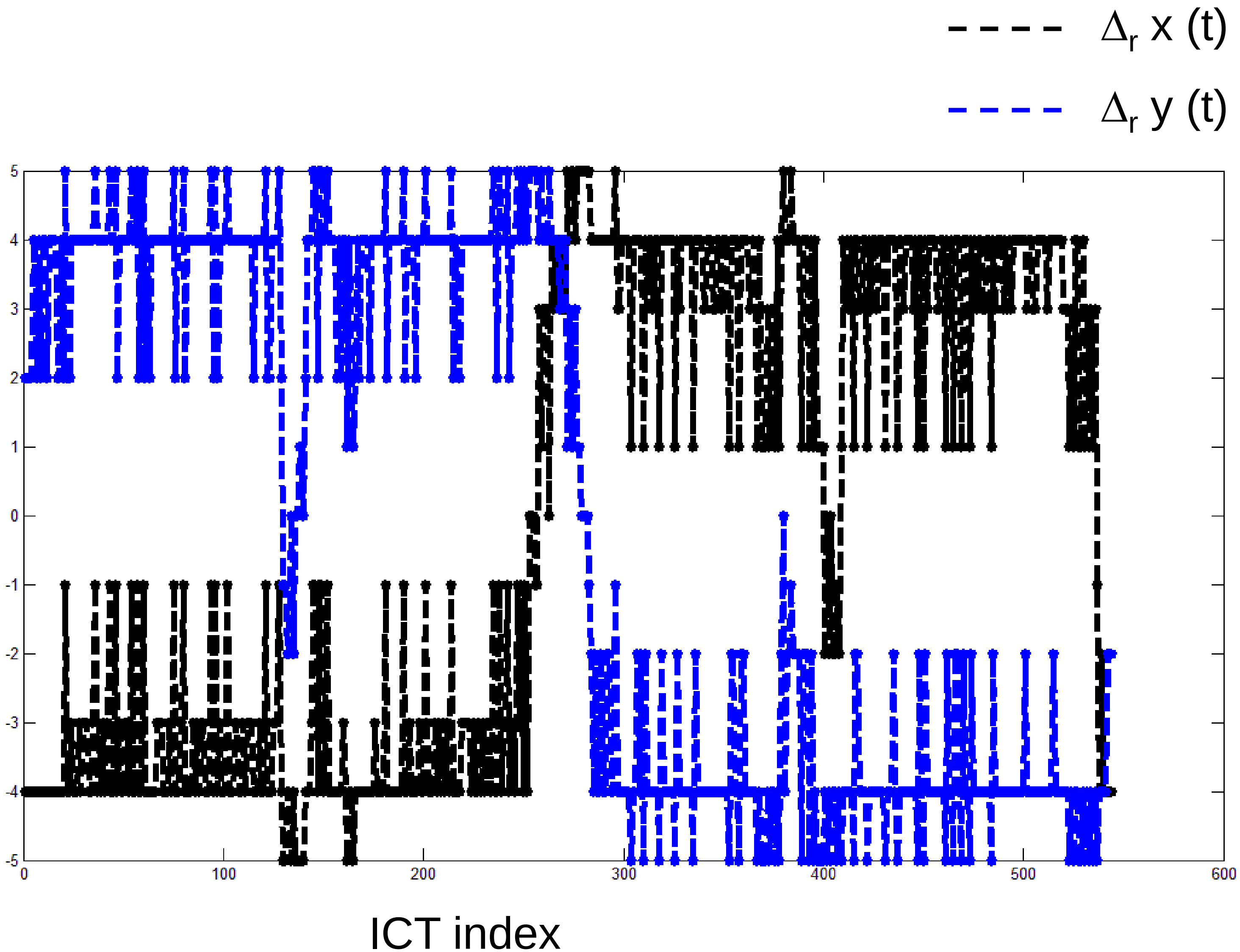
Finding ICT points with ICT circle with radius pixel 5



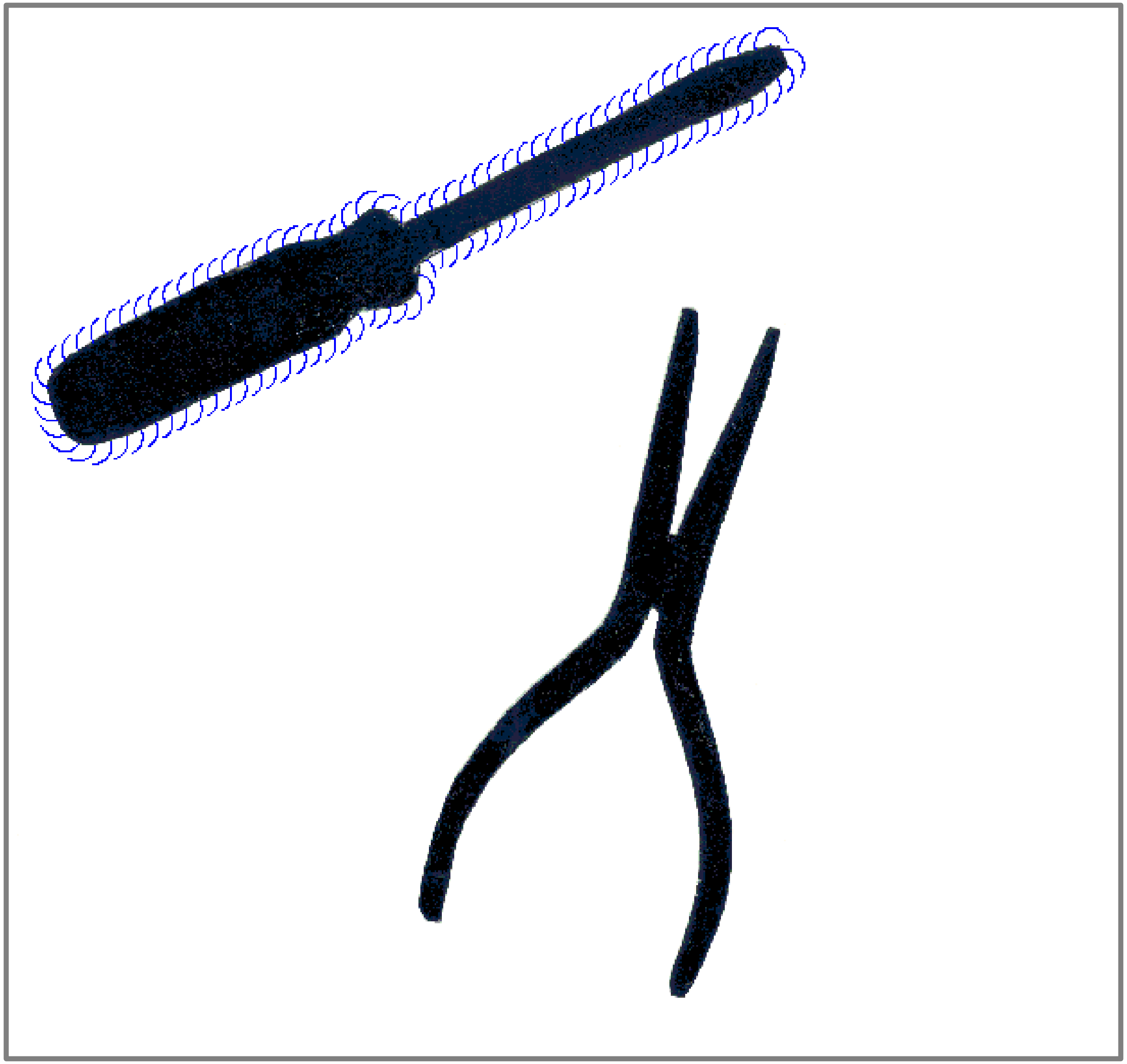
Reconstructed feature using ICT points



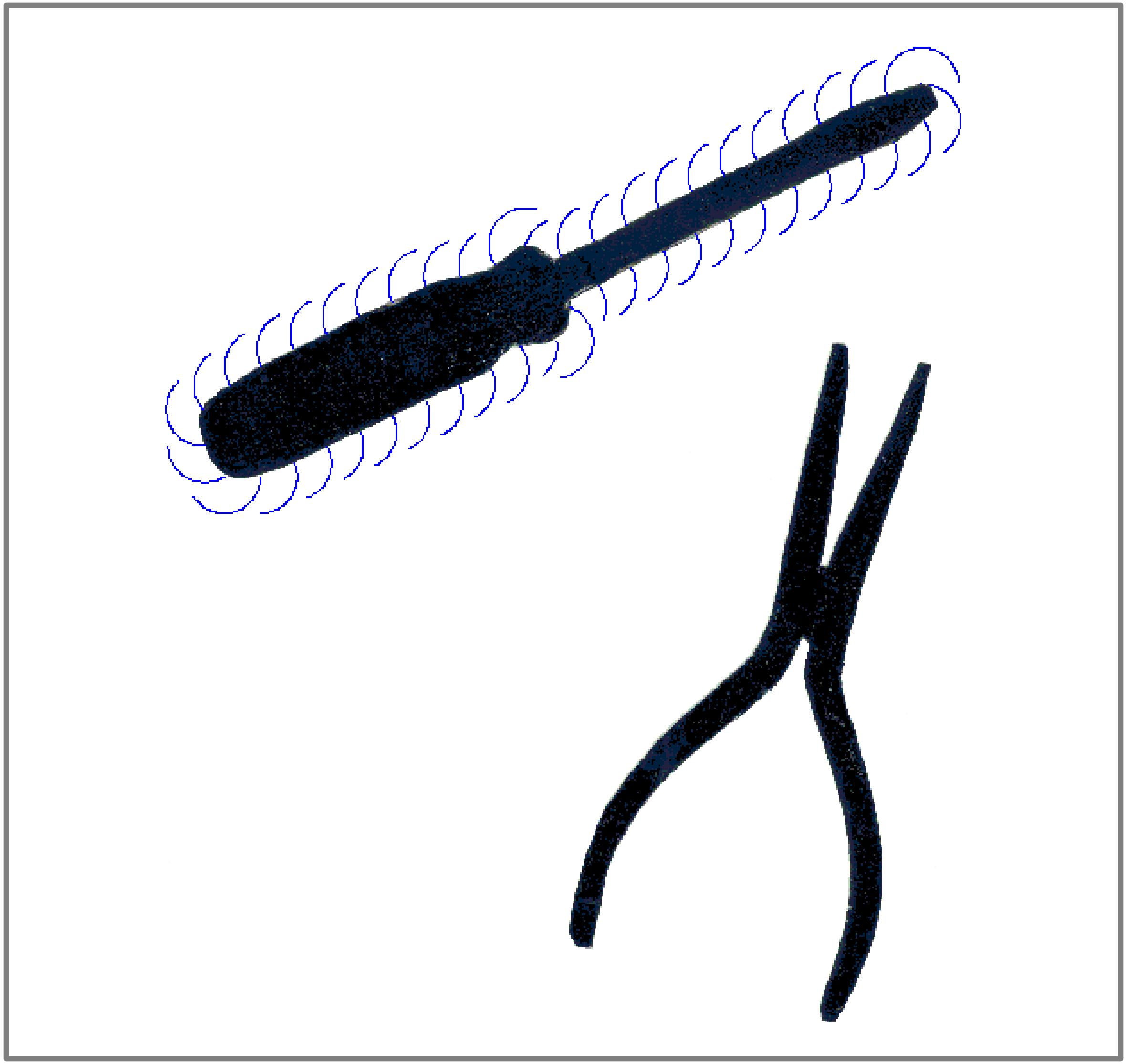
ICT Vector graph



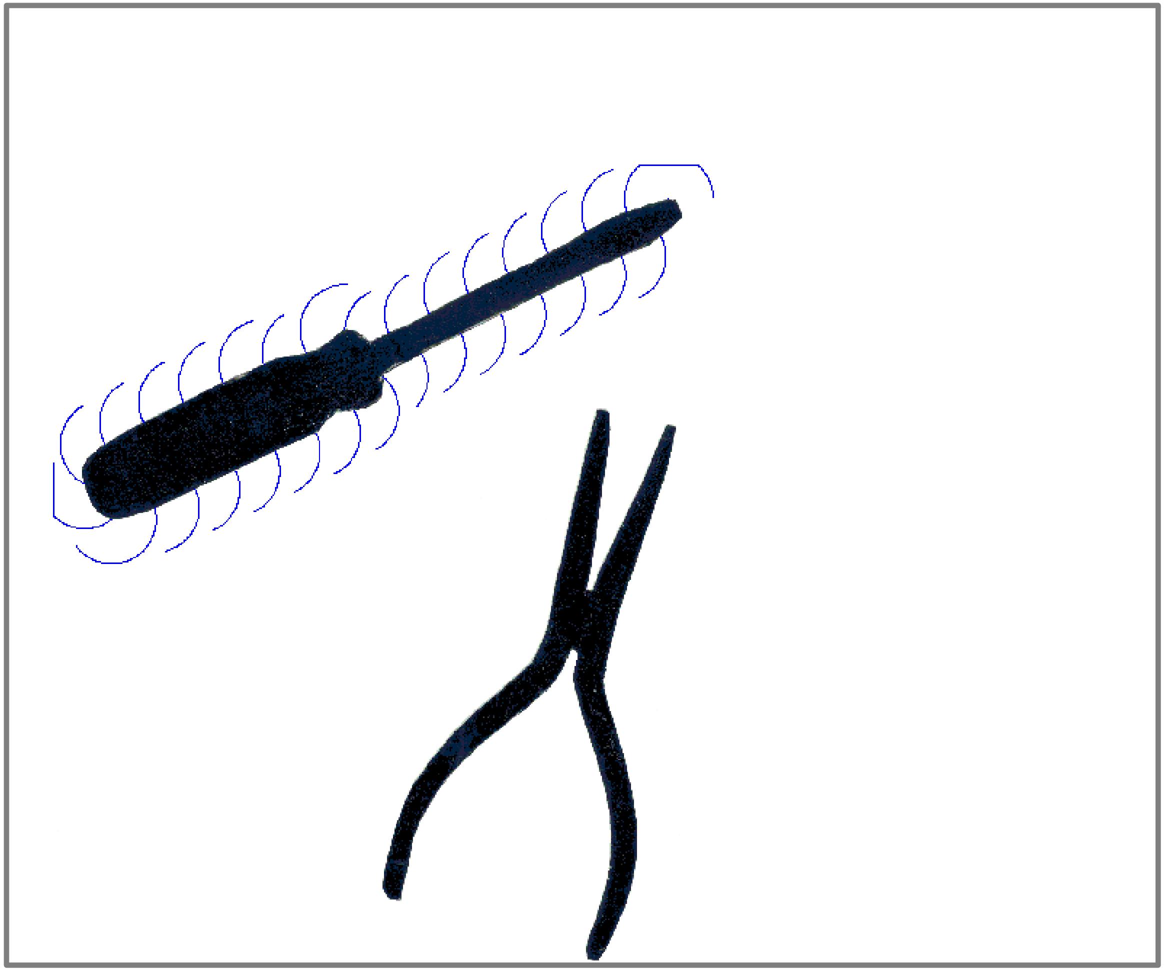
Finding ICT points with ICT circle with radius pixel perimeter/100



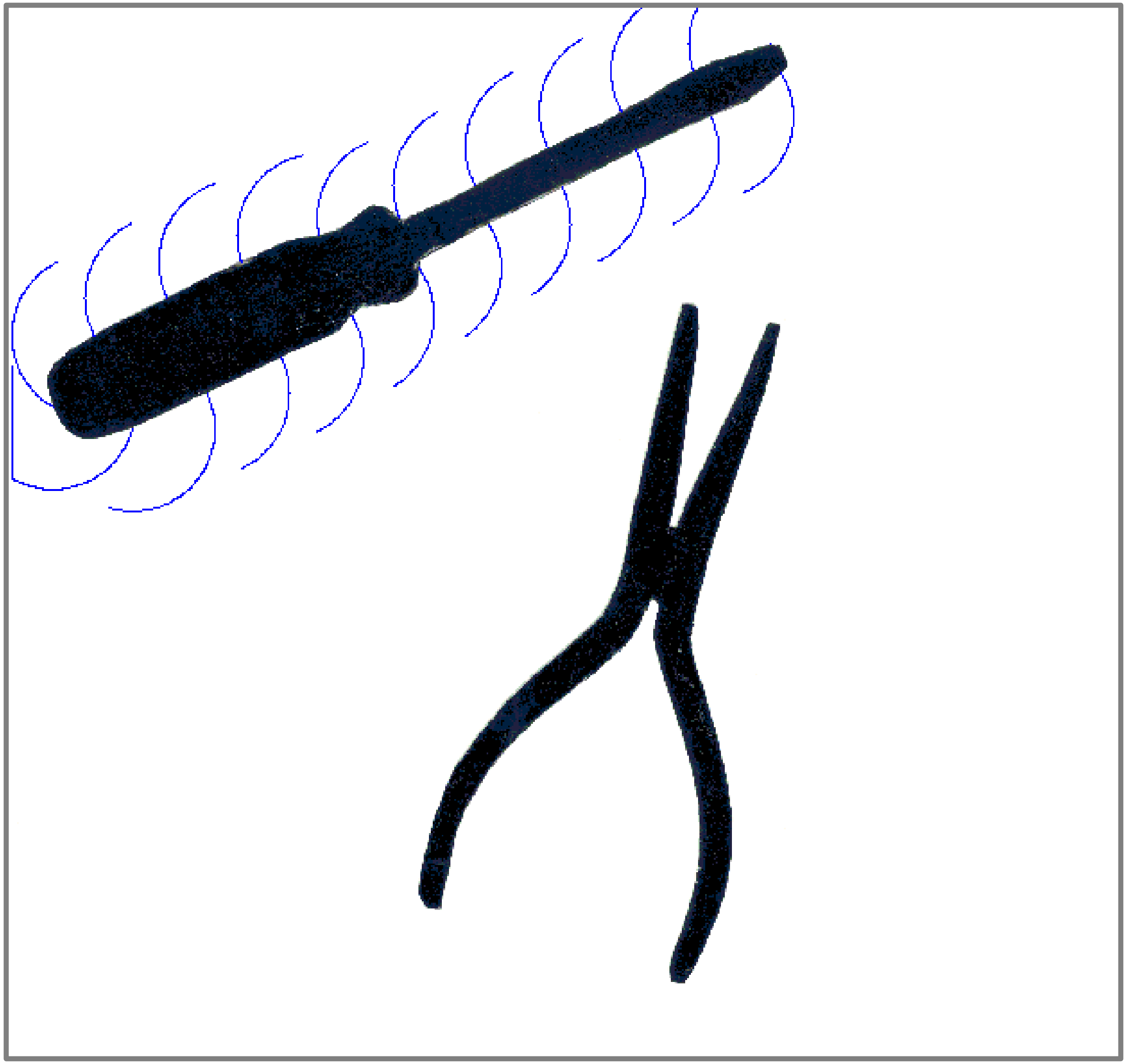
Finding ICT points with ICT circle with radius pixel perimeter/40



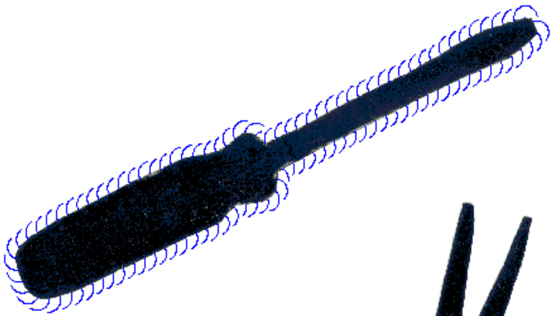
Finding ICT points with ICT circle with radius perimeter/30



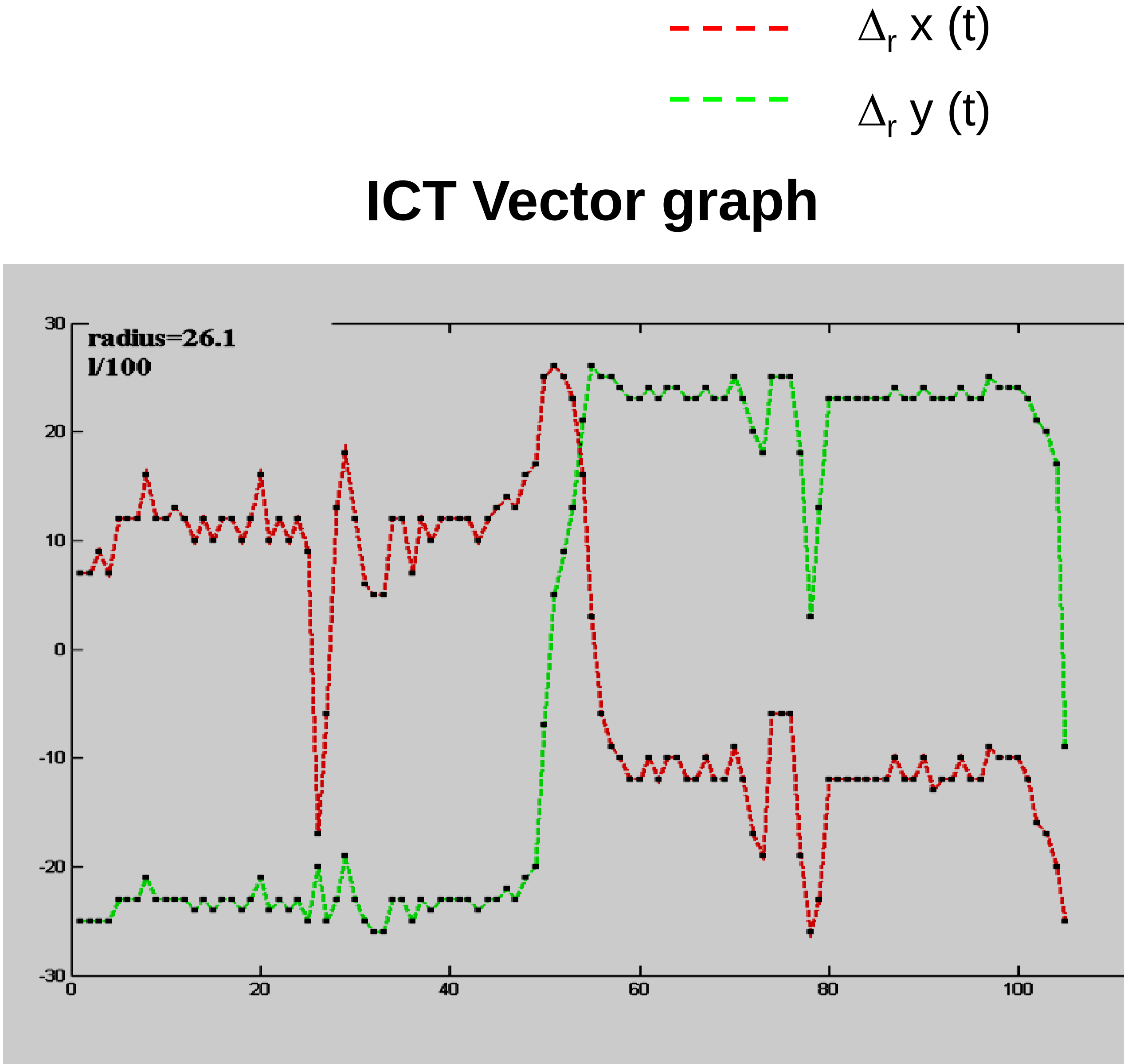
Finding ICT points with ICT circle with radius perimeter/20



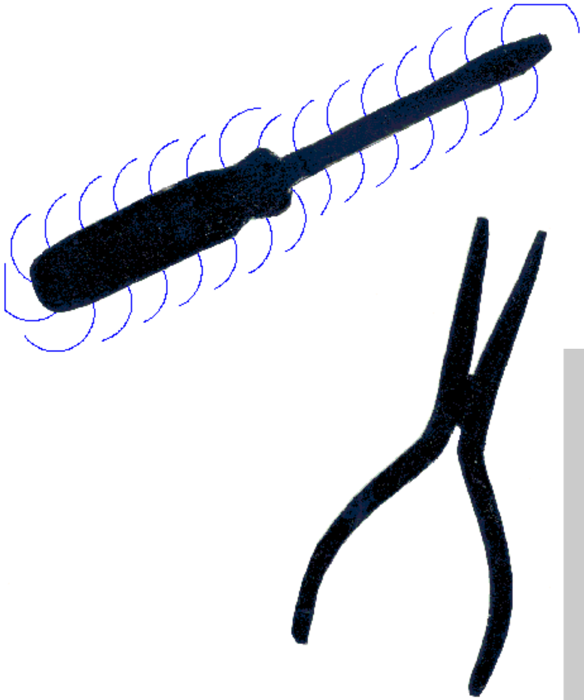
Finding ICT points with ICT circle with radius pixel perimeter/100



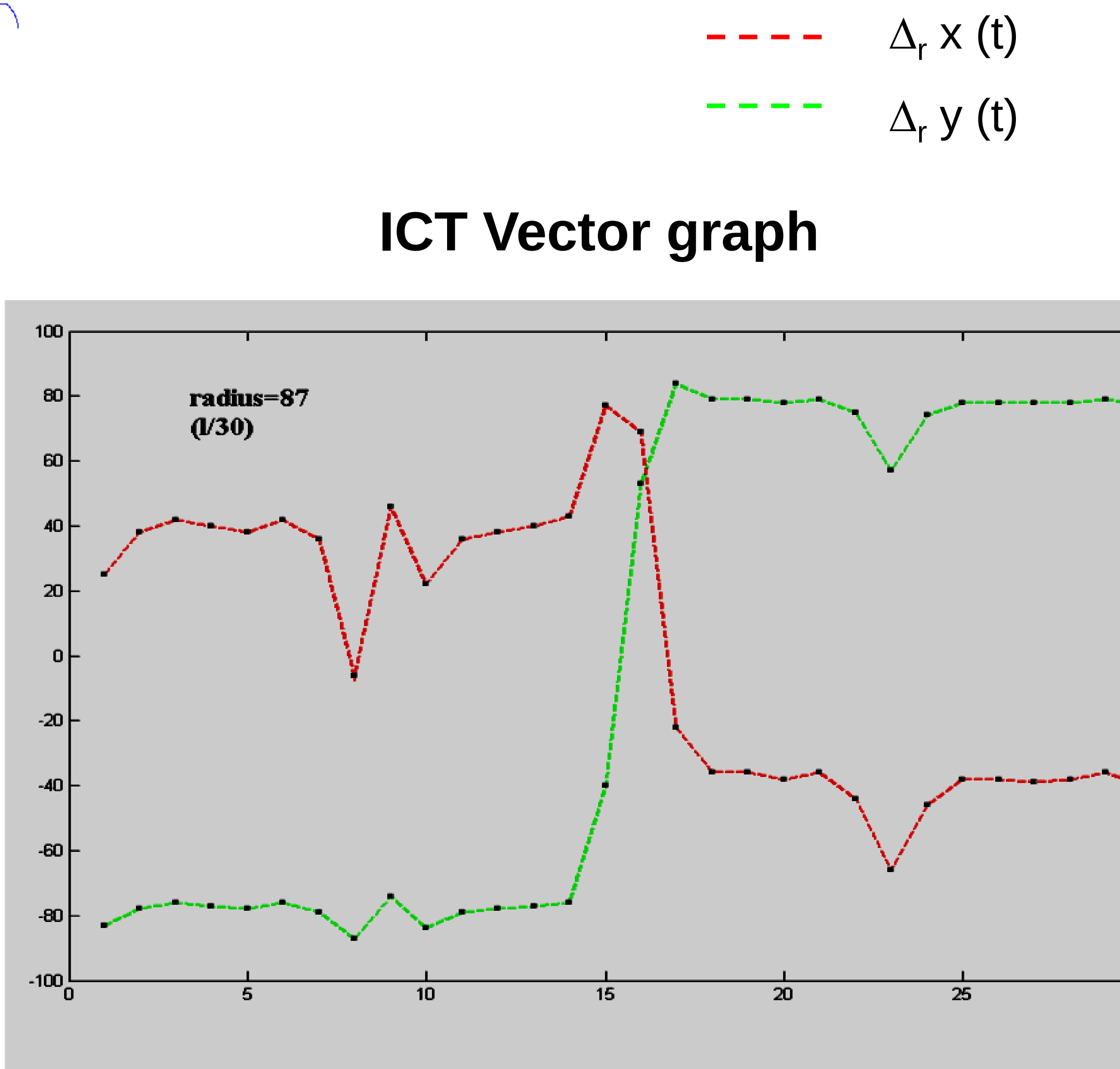
ICT Vector graph



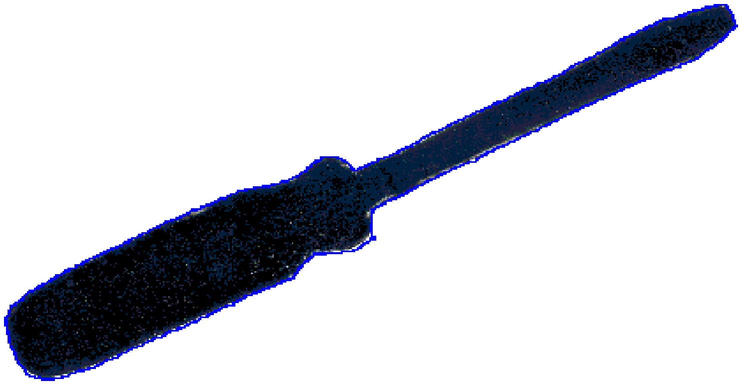
Finding ICT points with ICT circle with radius perimeter/30



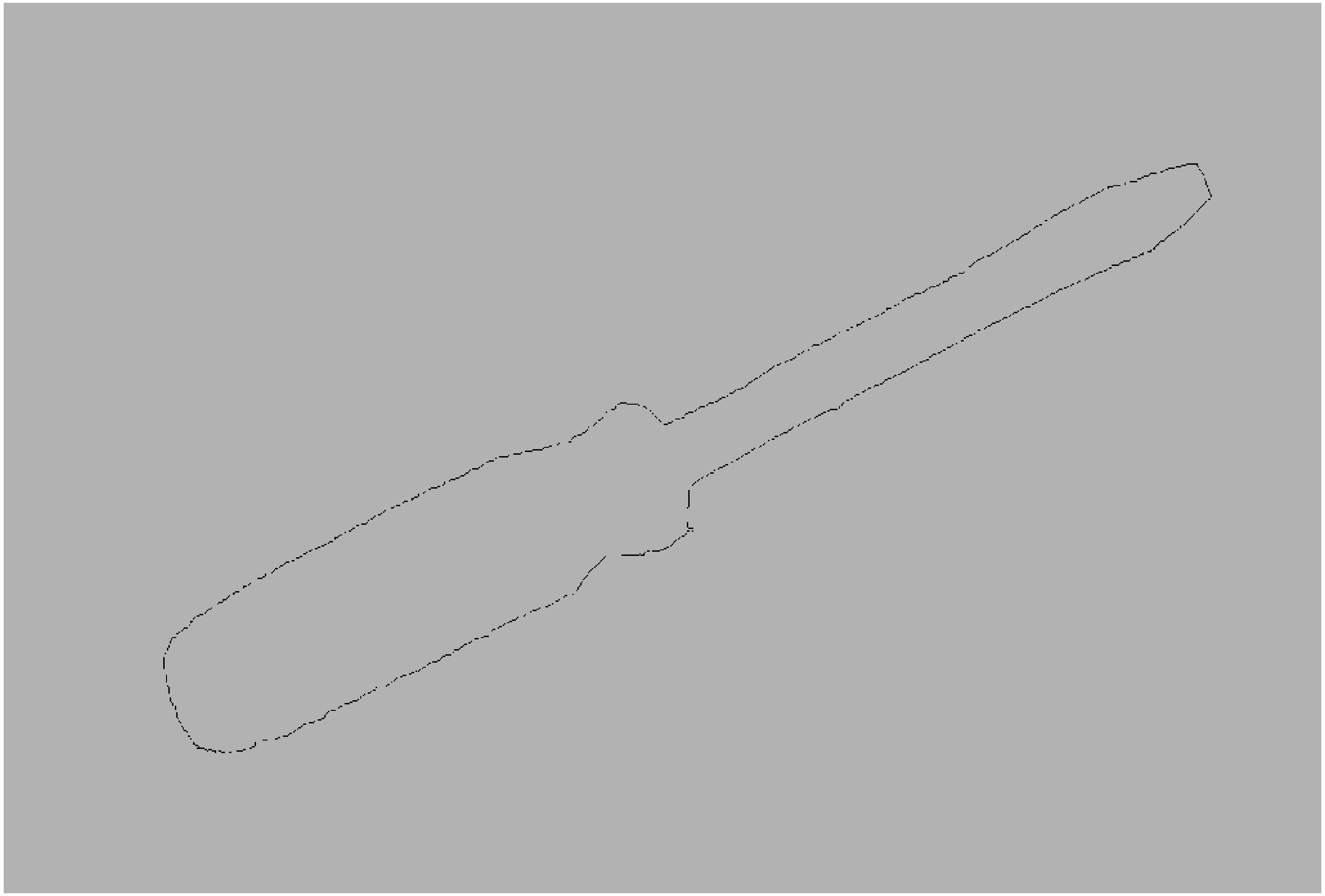
ICT Vector graph



Finding ICT points with ICT circle with radius pixel 5

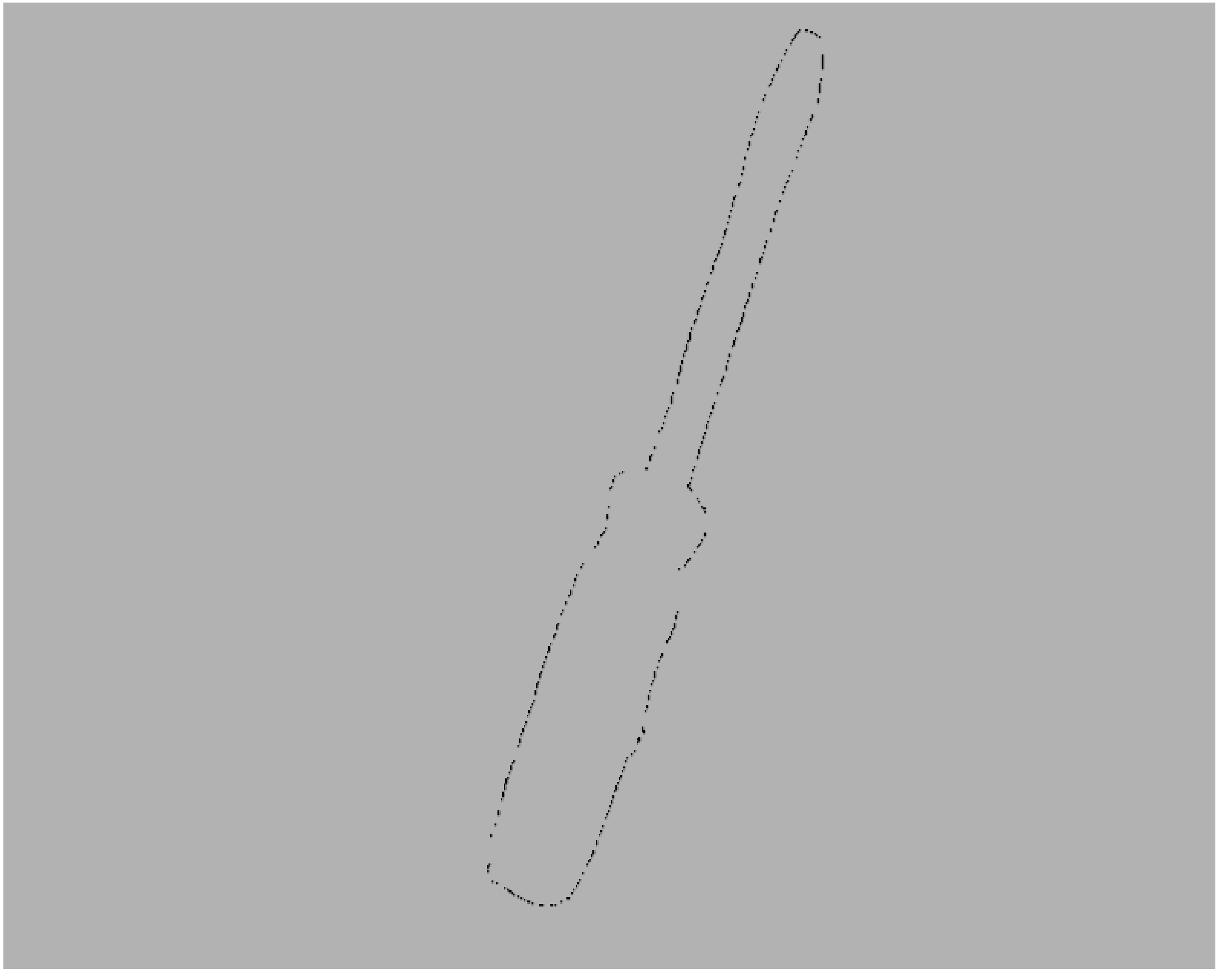


Reconstructed feature using ICT points



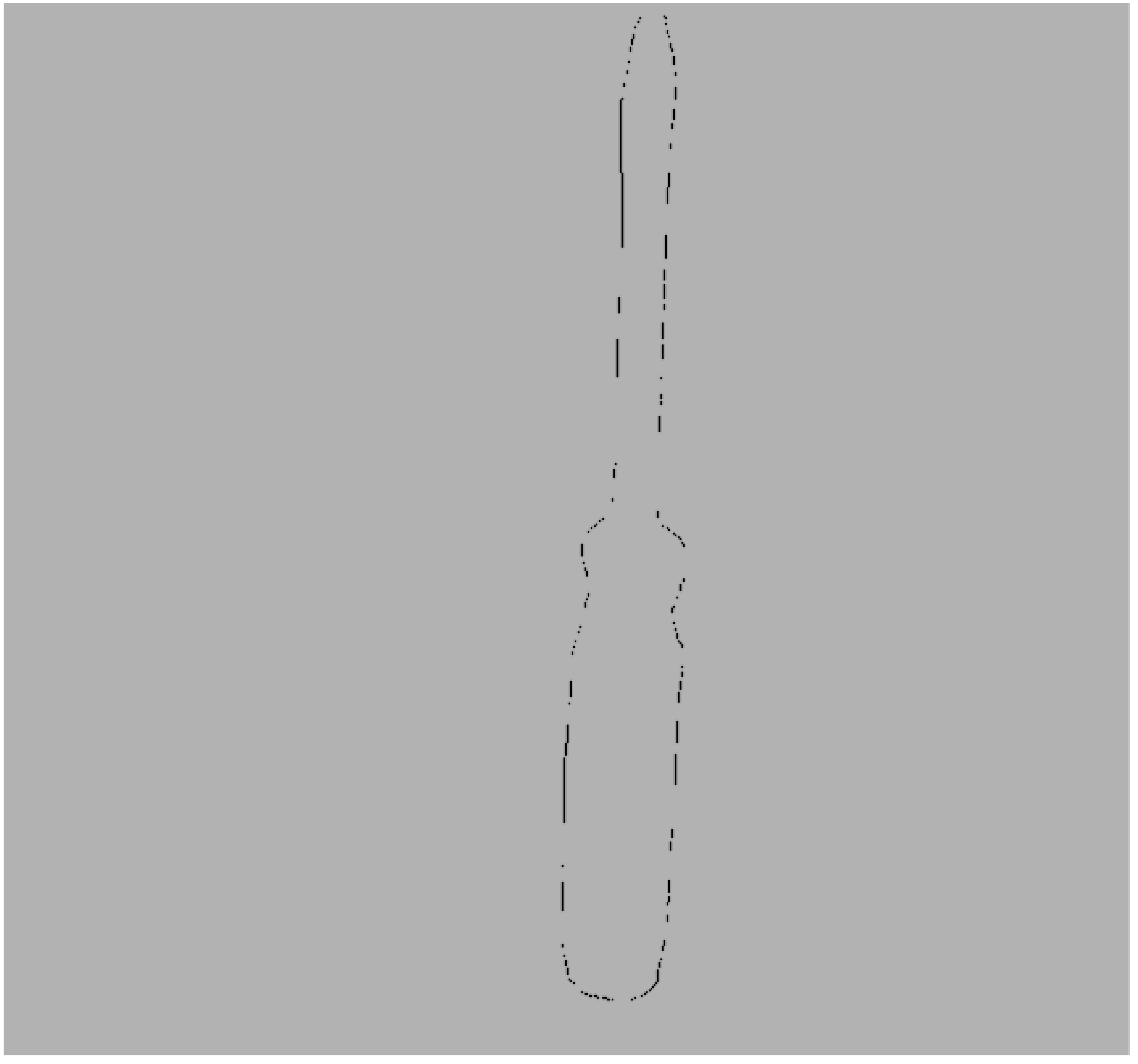
Finding ICT points with ICT circle with radius pixel 5

Reconstructed feature using ICT points



Finding ICT points with ICT circle with radius pixel 5

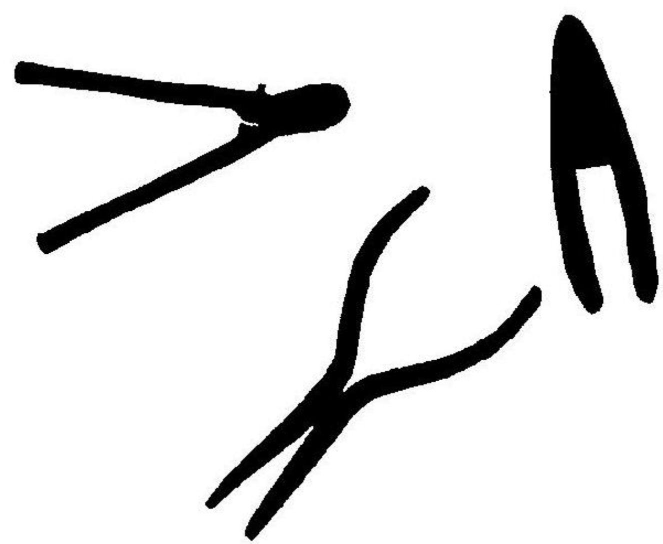
Reconstructed feature using ICT points



ICT VECTOR – IMAGE RECONSTRUCTION

Original image

Reconstructed image



CALCULATION OF ORIENTATION OF FEATURE

$$\theta_a = \begin{cases} 1/2\tan^{-1}\left(\dfrac{2b}{c-a}\right) & if\ c < a \\ 1/2\left(\Pi - \tan^{-1}\left(\dfrac{2b}{c-a}\right)\right) & if c > a\, and \quad b \geq 0 \\ 1/2\left(-\Pi - \tan^{-1}\left(\dfrac{2b}{c-a}\right)\right) & if c > a\, and \quad b < 0 \\ \Pi/4 & if\ a = c \quad and \quad b > 0 \\ -\Pi/4 & if\ a = c \quad and \quad b < 0 \\ undefined & if \quad a = c \quad and \quad b = 0 \end{cases}$$

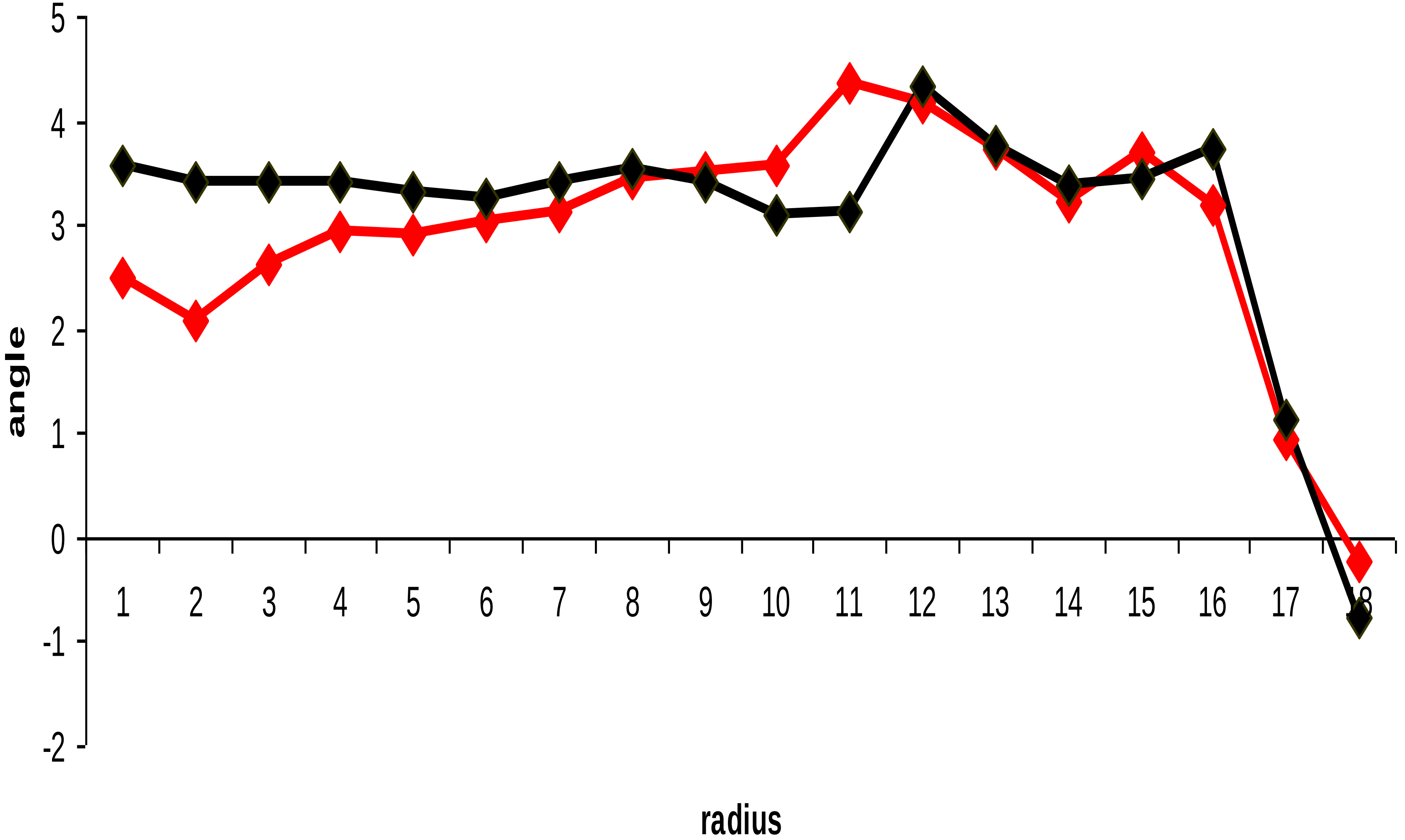
Where,

$$a = \sum \Delta_r x^2(t) d(t)$$

$$b = \sum \Delta_r x(t) \Delta_r y(t) dt$$

$$c = \sum \Delta_r y^2(t) dt$$

ANGLE MEASUREMENT – EFFECT OF RADIUS



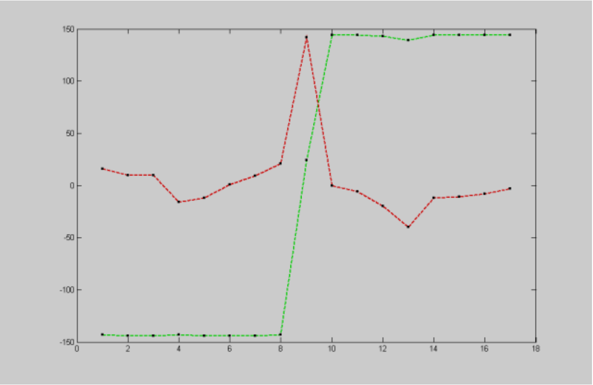
OUTLINE

- Introduction
- Chain code
- **Incremental circle transform (ICT)**
  - Implementation
  - **Object recognition**
- Classification of Eddy Current Impedance Signals
- Application ICT for the calculation of Fractal dimension

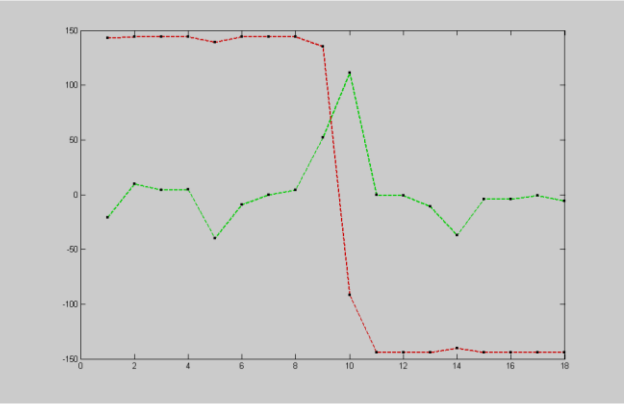
ICT Vector graph

De-rotation

Theta 2.9

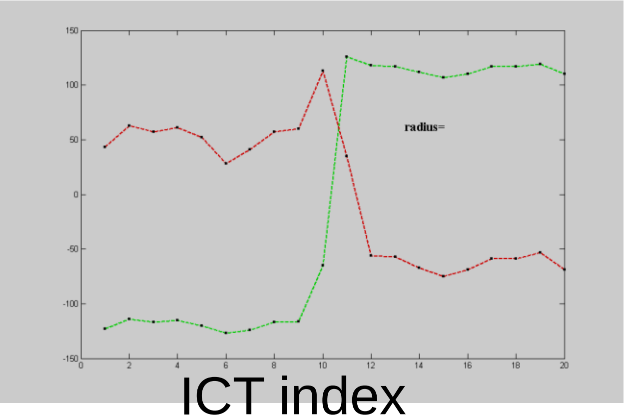


ICT index

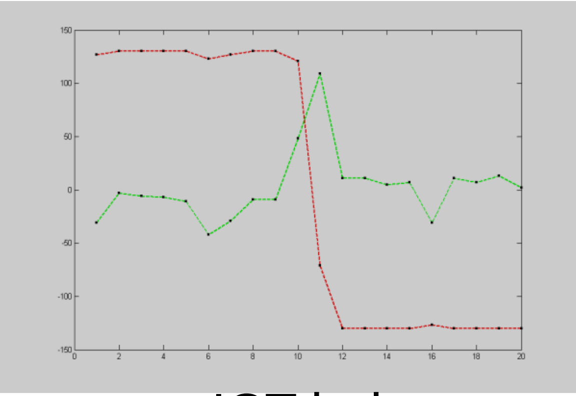


ICT index

Theta 30.16



ICT index



ICT index

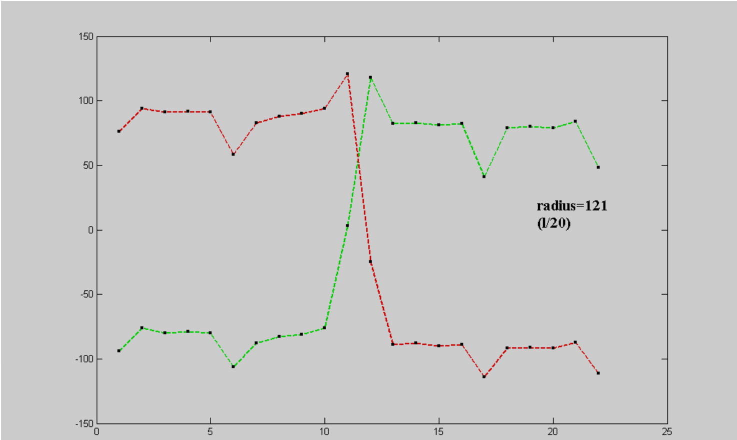
Δ_r x (t)

Δ_r y (t)

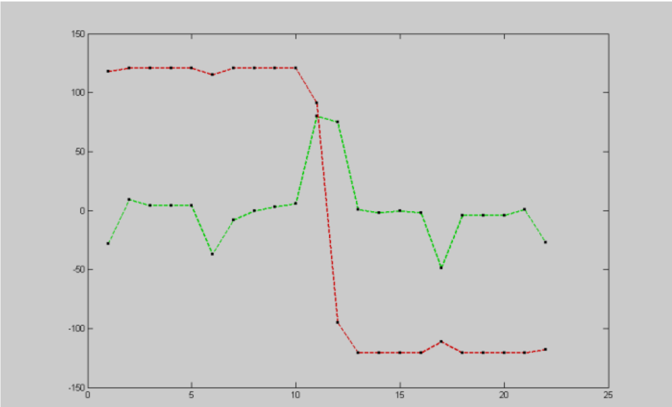
ICT Vector graph

De-rotation

Theta 46.9

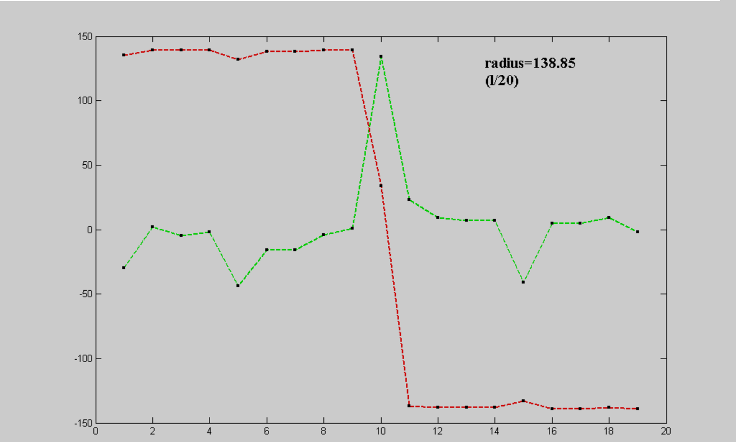


ICT index

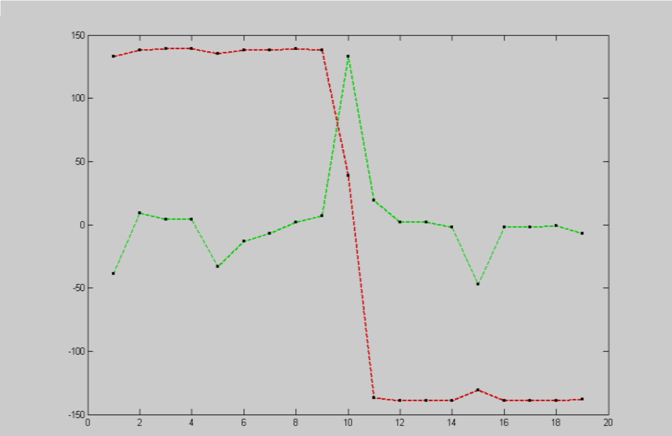


ICT index

Theta 86.9



ICT index



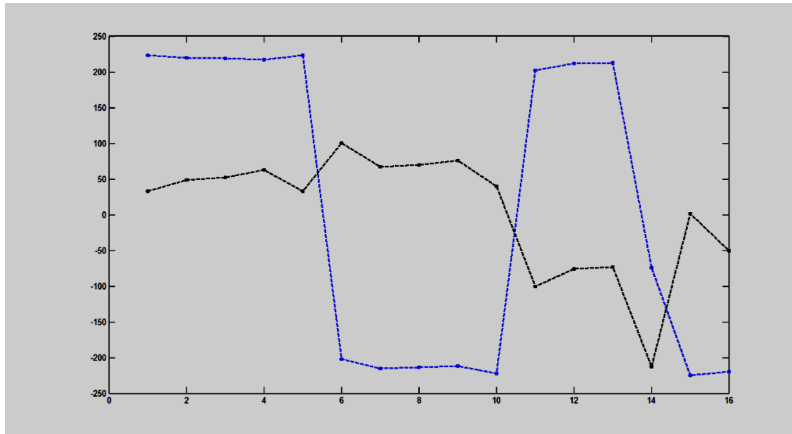
ICT index

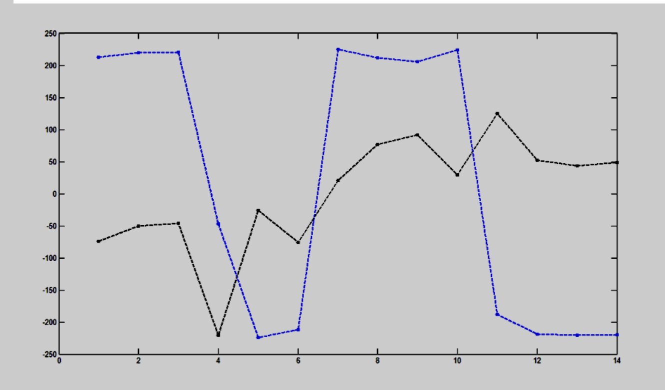
$\Delta_r\, x\ (t)$

$\Delta_r\, y\ (t)$

ICT Vector graph De-rotation

Theta 83

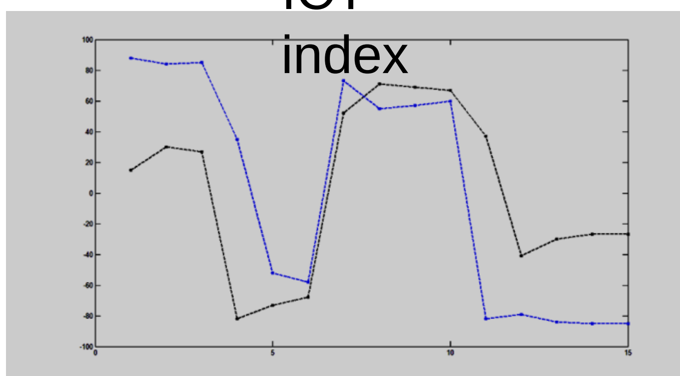


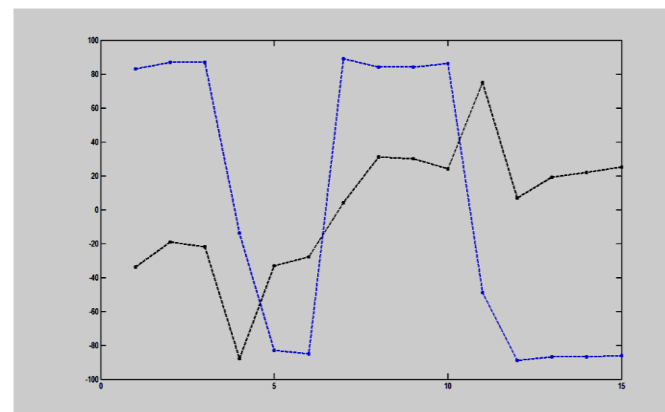


ICT index

ICT index

Theta 55





ICT index

ICT index

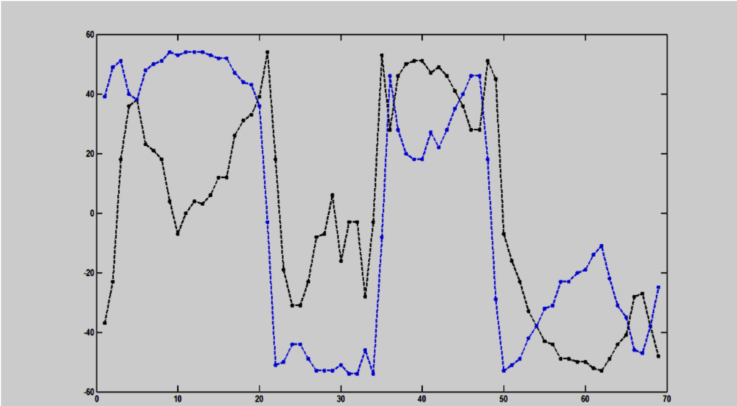
- - - - $\Delta_r\, x\,(t)$

- - - - $\Delta_r\, y\,(t)$

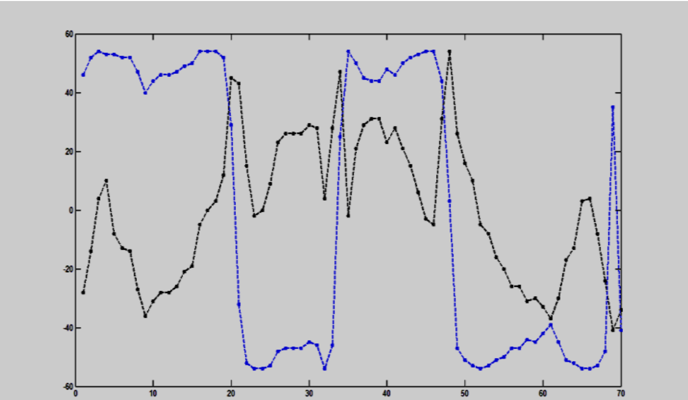
ICT Vector graph

De-rotation

Theta 53

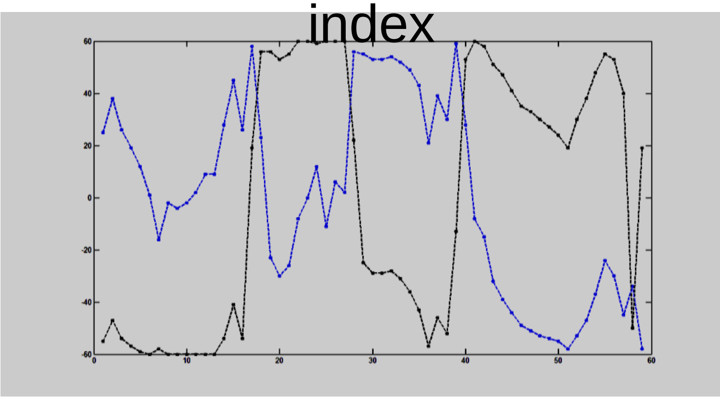


ICT index

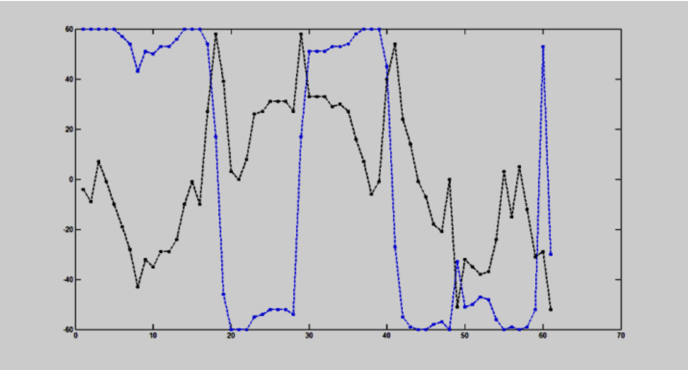


ICT index

Theta 87



ICT index



ICT index

- - - - Δ_r x (t)

- - - - Δ_r y (t)

OUTLINE

- Introduction
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NDT and its role

Non-Destructive Testing (NDT)

- **Component can be used testing**
- **Increasingly used in Industry**

Purpose of NDT:

- **Determination of material properties**
- **Detection, characterization, location and sizing of defect**

Benefits:

- **Increase in quality**
- **Safety**

NDT and its role

Different techniques in NDT:

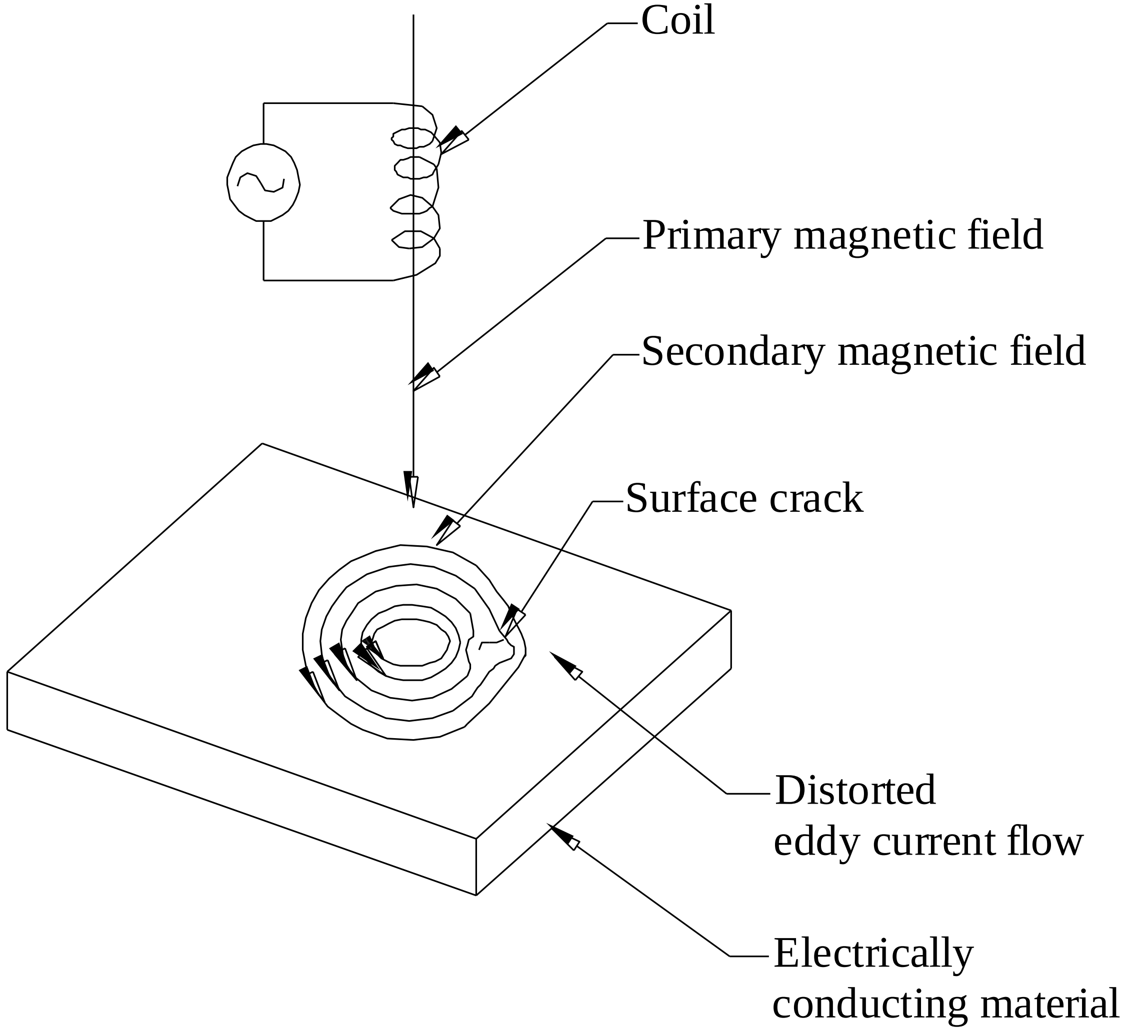
- Liquid penetrant testing
- Magnetic particle testing
- Eddy current testing
- Ultrasonics testing
- X-ray radioagraphy
- Acoustic emission

NDT and its role

Different techniques in NDT:

- Liquid penetrant testing
- Magnetic particle testing
- **Eddy current testing**
- Ultrasonics testing
- X-ray radioagraphy
- Acoustic emission

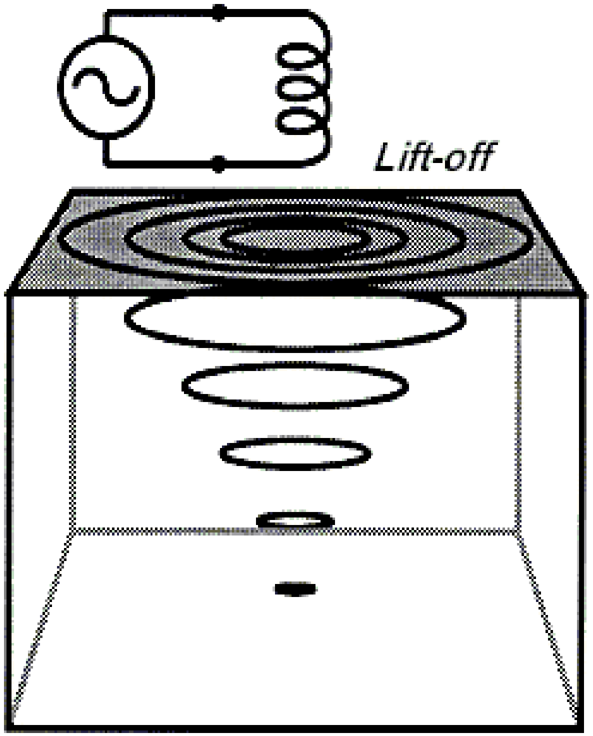
Eddy Current Testing

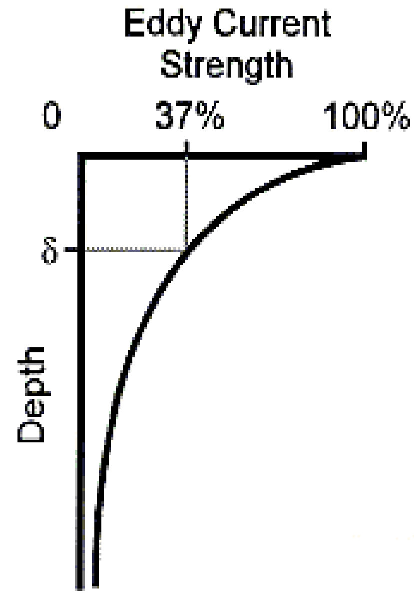


✓ **Widely used NDT technique**

✓**It works on the principles of <u>electromagnetic induction</u> and detects surface and sub-surface <u>defects within a depth of 10 mm in metallic materials</u>**

- **Induced currents in electrically conducting materials**
- **Distorted by defects and discontinuities**





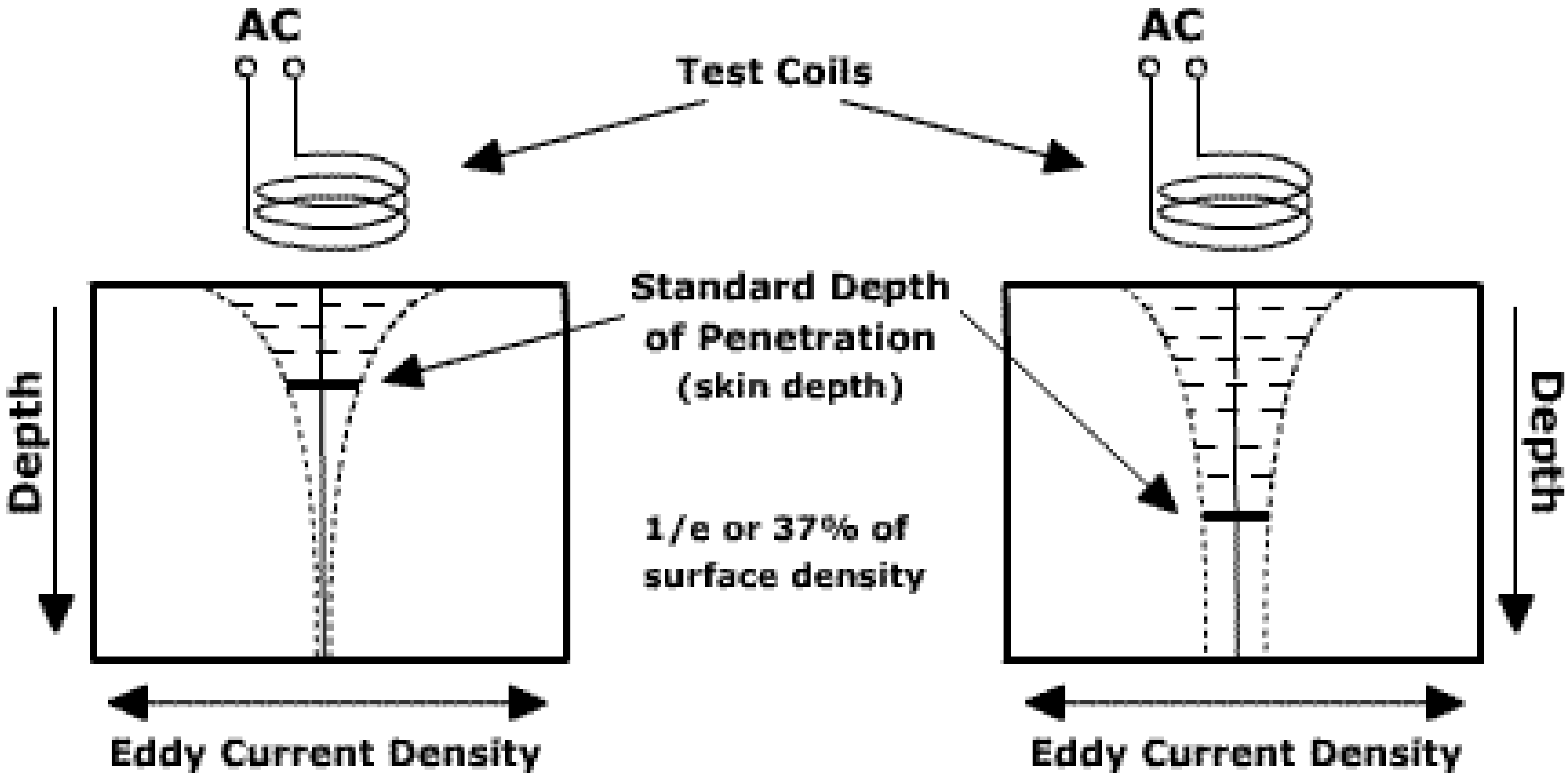
$$\delta = 50\sqrt{\rho/(f.\mu_r)}$$

f = Frequency
σ = Conductivity
μ = Permeability

Standard Depth of Penetration- δ

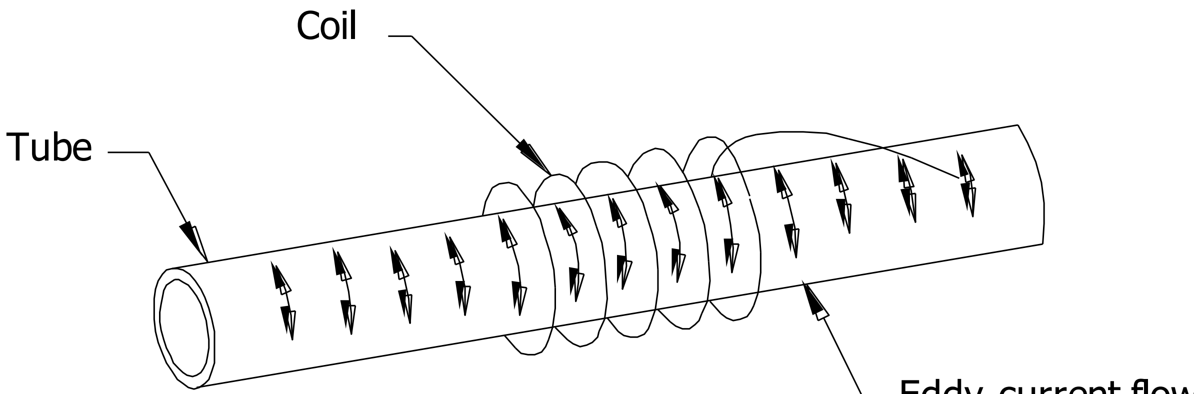
Eddy current density decreases with depth and also lags in phase w.r.t. surface density

Eddy Current Depth of Penetration

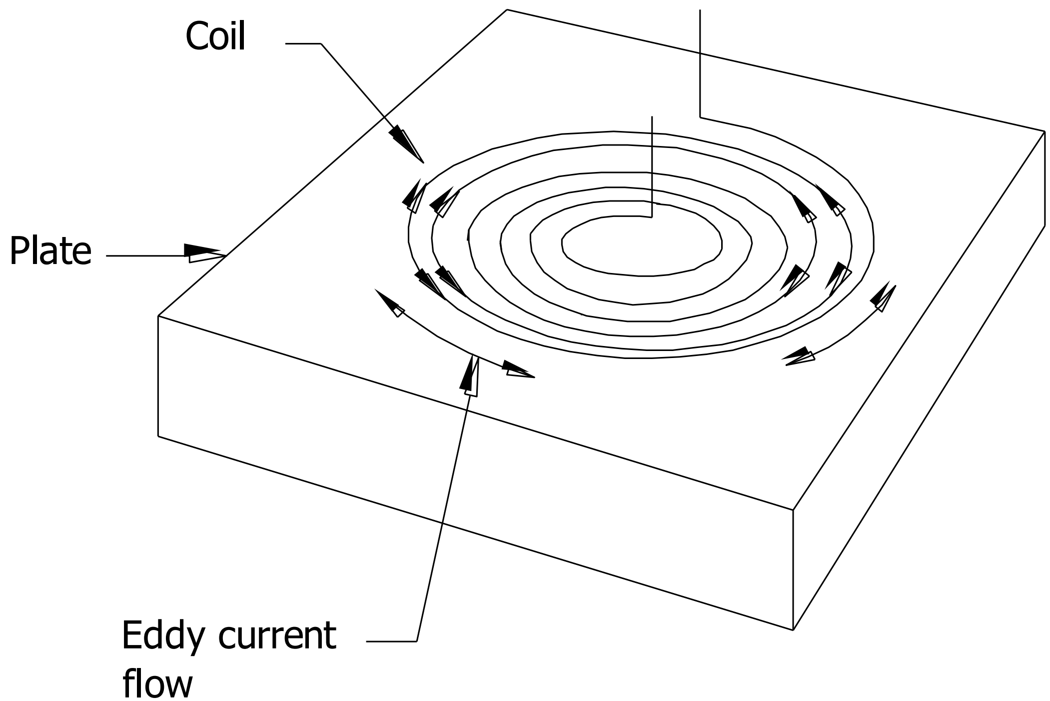


High Frequency
High Conductivity
High Permeability

Low Frequency
Low Conductivity
Low Permeability



Coil
Tube
Eddy-current flow



Coil
Plate
Eddy current flow

Eddy Current Testing Features

- ✓ TESTING ANY METALLIC MATERIAL
- ✓ HIGH INSPECTION SPEEDS POSSIBLE (> 5 m / s)
- ✓ CAN EFFICIENTLY DETECT VERY FINE SURFACE FATIGUE CRACKS (~ 5 μ WIDTH AND 50 μ DEPTH)
- ✓ HIGH TEMPERATURE TESTING POSSIBLE
- ✓ NON-CONTACT TESTING POSSIBLE (NO COUPLANT REQUIRED LIKE IN ULTRASONICS)
- ✓ RECORDING OF INSPECTION DATA POSSIBLE

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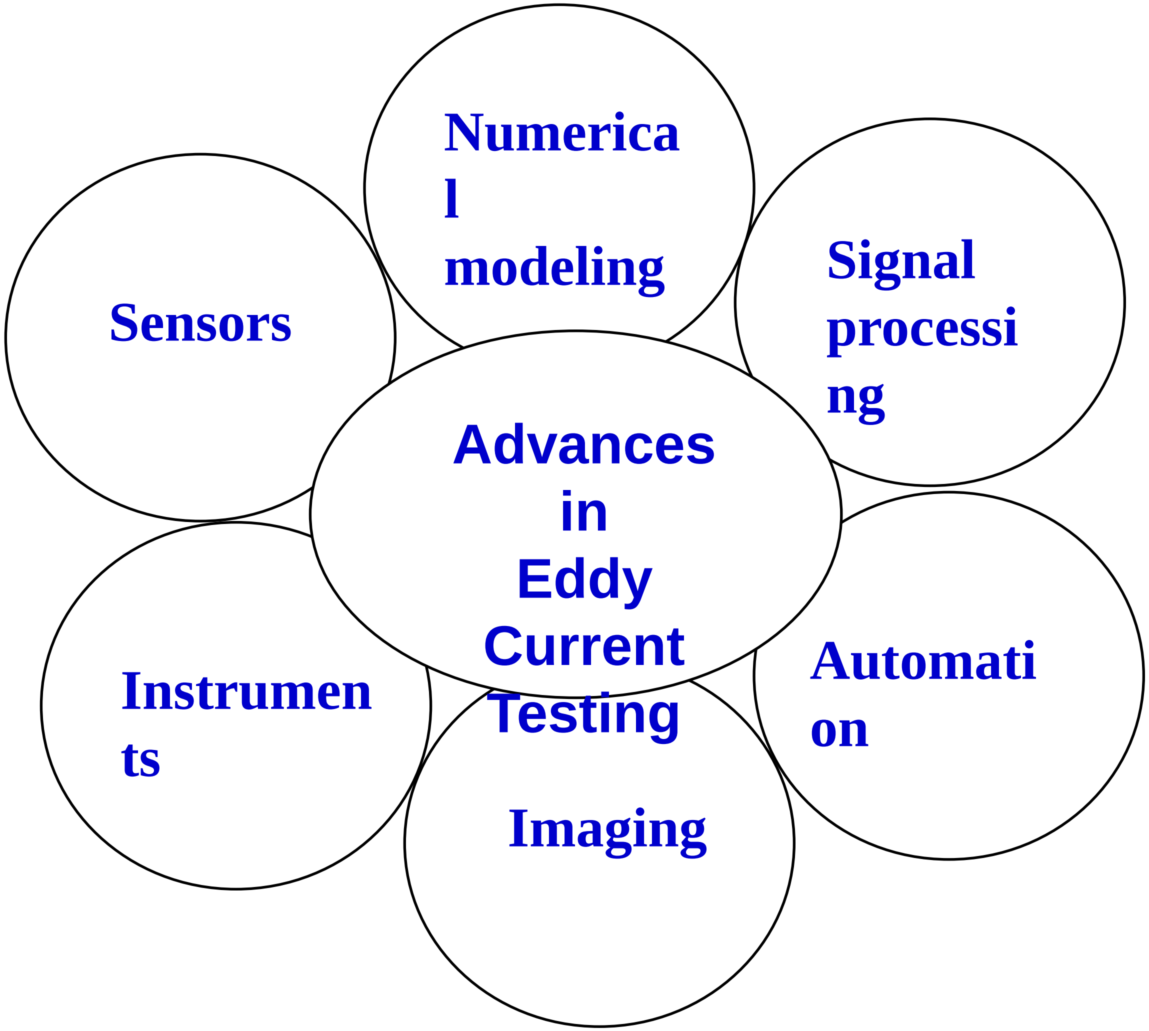
Eddy Current Testing Features

- ✓ HIGH INSPECTION SPEEDS POSSIBLE (> 5 m / s)
- ✓ Possible by Automated Interpretation of Eddy Current Impedance Images



Concurrent developments in allied fields →

- Enhancement in defect characterisation
- Paving the way for development of **automated evaluation**

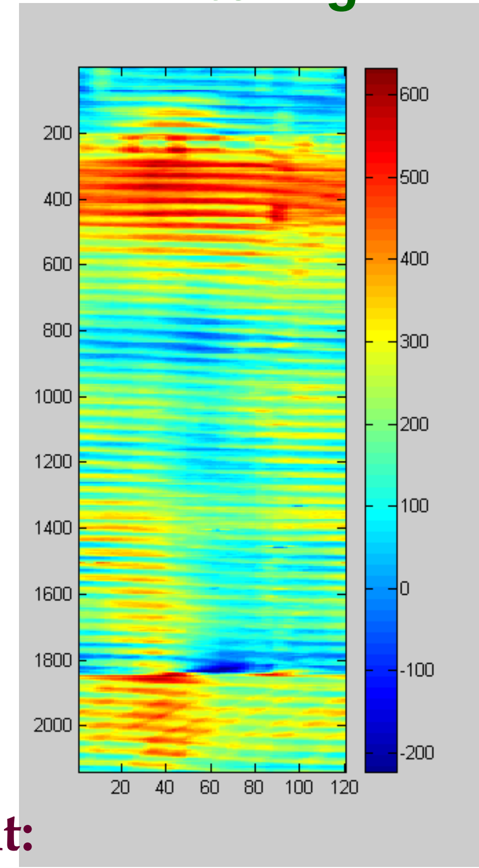
Eddy Current Testing Features

- ✓ **HIGH INSPECTION SPEEDS POSSIBLE (> 5 m / s)**
- ✓ **Possible by Automated Interpretation of Eddy Current Impedance Images**

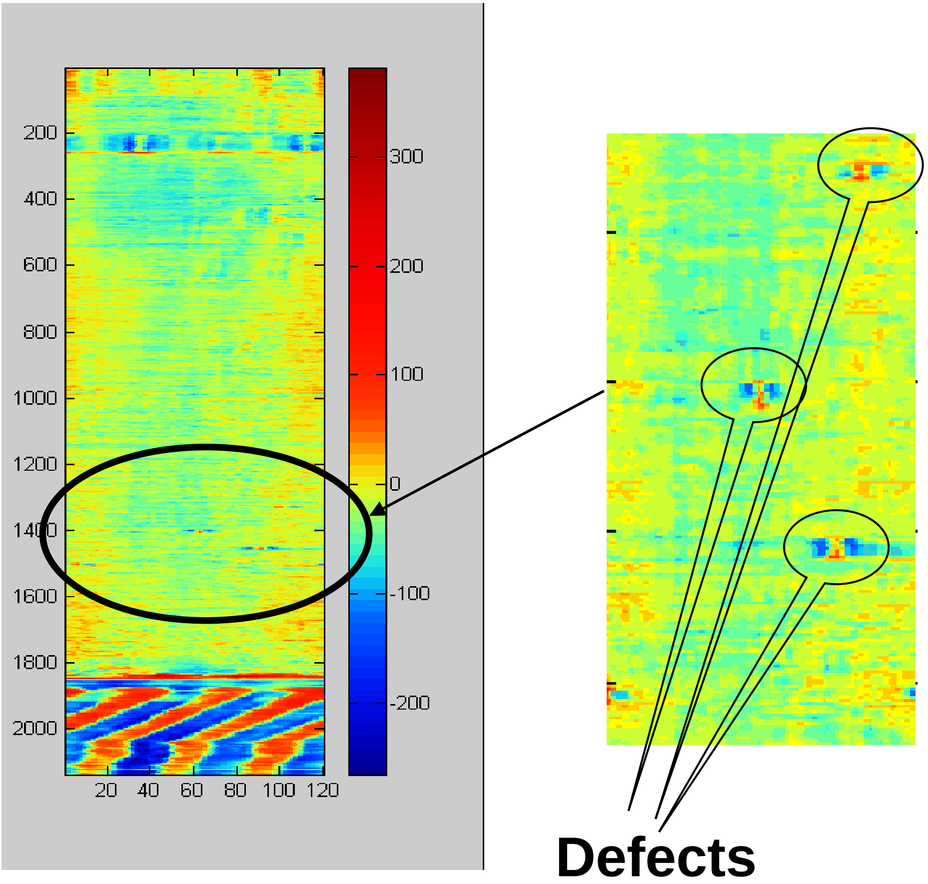
Where is
the defect ?

Challenges:Automatic defect detection from impedance signal
Extraction of signal parameter for effective classification???

2D Image before filtering



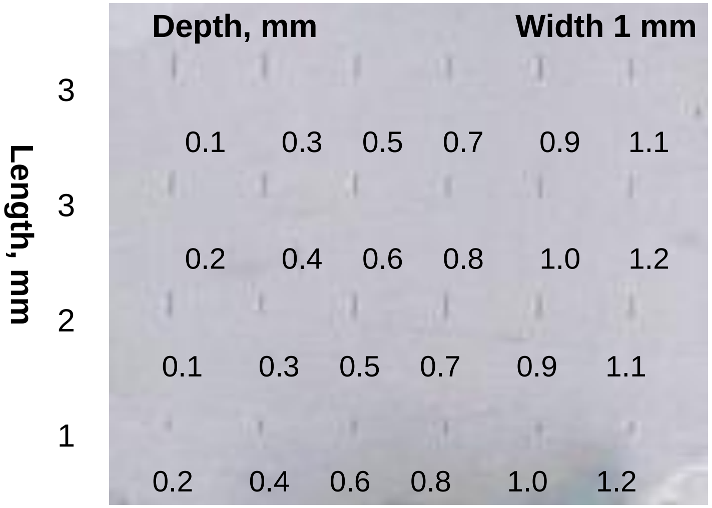
Filtered 2D Image

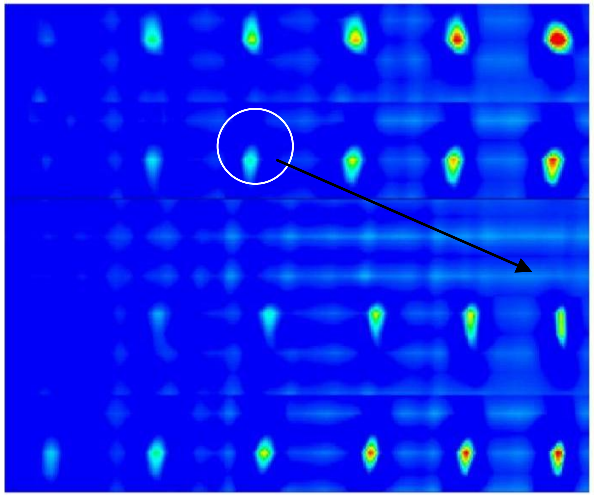


Requirement:

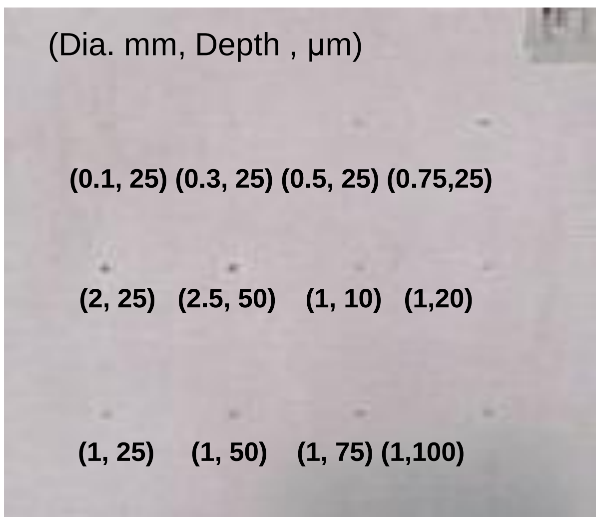
- **Identification of region of interest**
- **Boundary extraction- classification parameter as an input to NN**

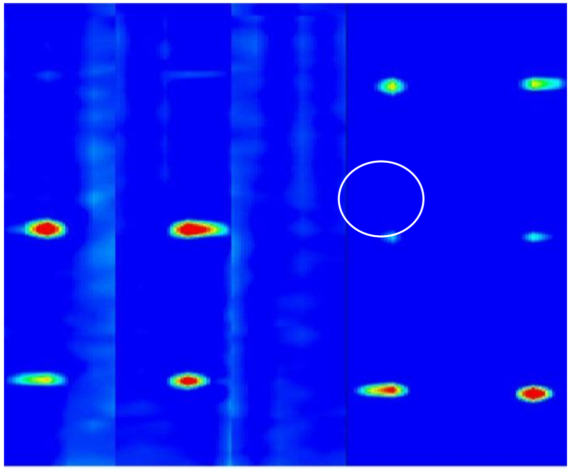
Eddy Current Imaging





What is the defect?

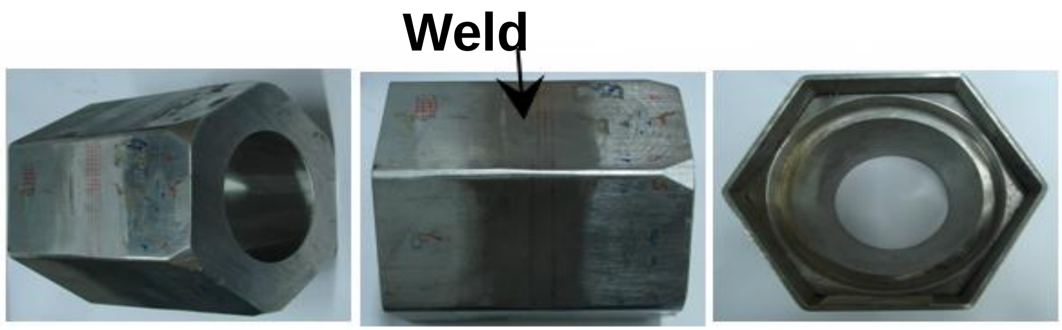




Stainless Steel plates with simulated corrosion

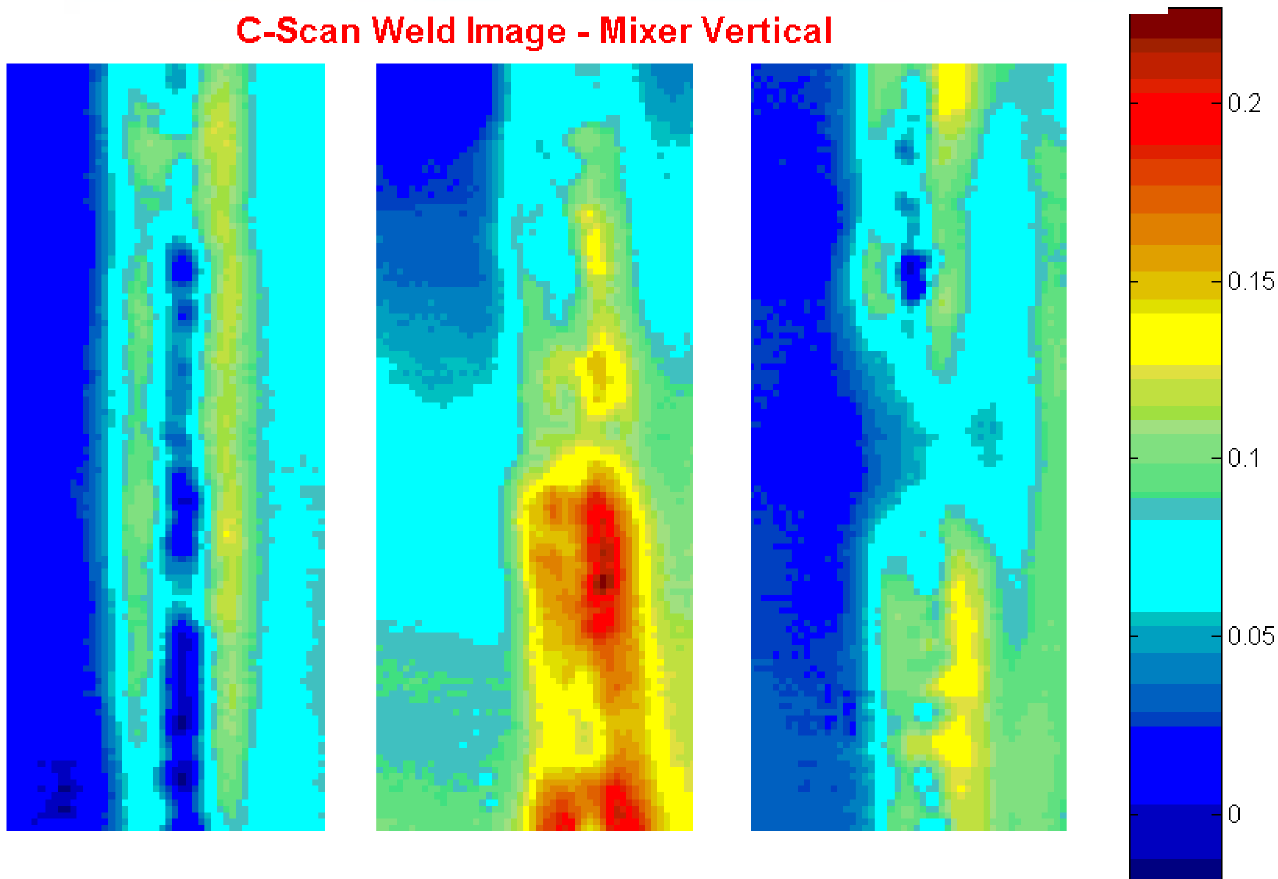
EC imaging

Dual-frequency Eddy Current Imaging of Stainless Steel Welds



Where is the defect?

C-Scan Weld Image - Mixer Vertical



Face 23 (Good weld) Face34 (defect weld) Face 45 (defect weld)

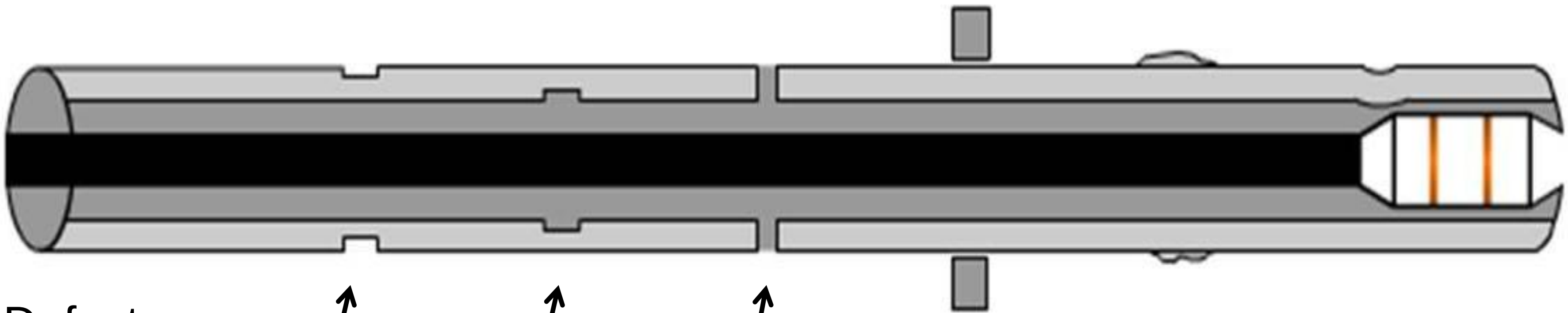
Eddy Current Testing Features

- ✓ HIGH INSPECTION SPEEDS POSSIBLE (> 5 m / s)
- ✓ Possible by Automated Interpretation of Eddy Current Impedance Images

Where is the defect ?

What is the defect ?

Typical Eddy Current Signals - Tubes

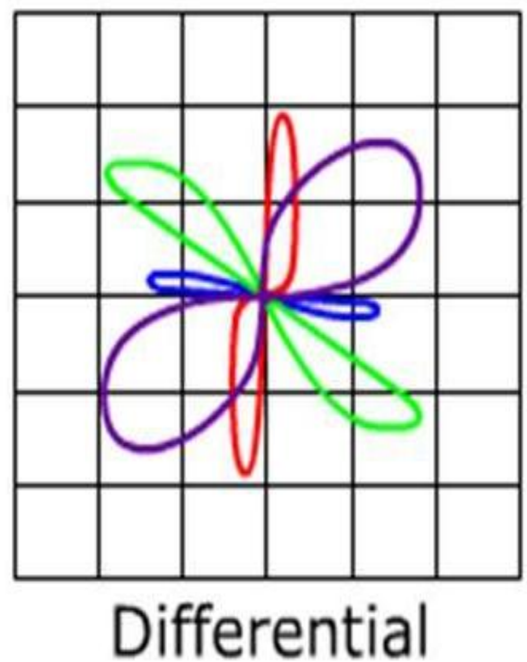


Defects

Flat bottomed hole (OD)

Flat bottomed hole (ID)

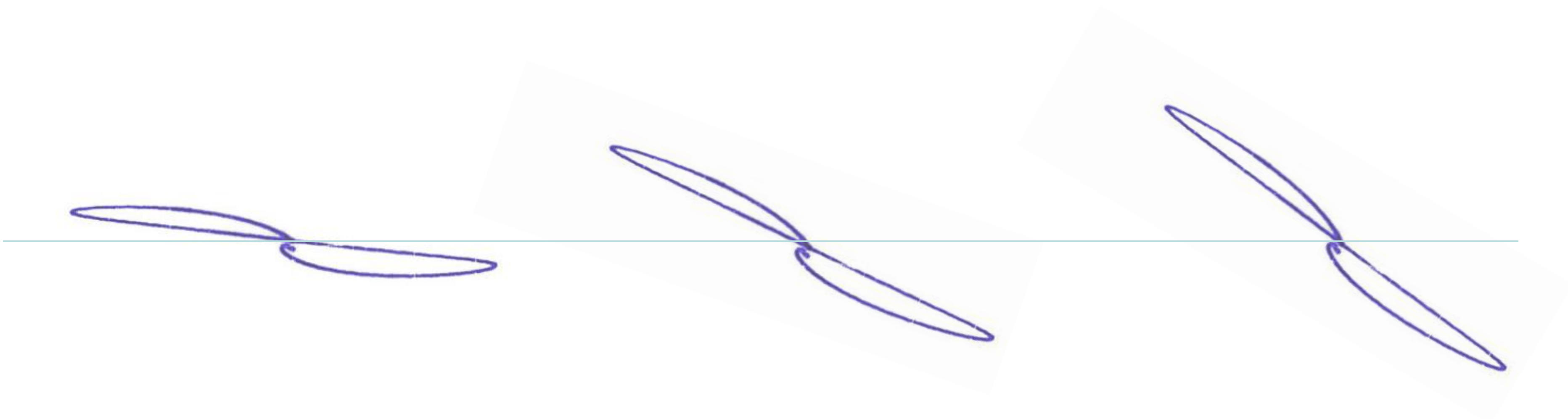
Through hole



Impedance plane diagrams

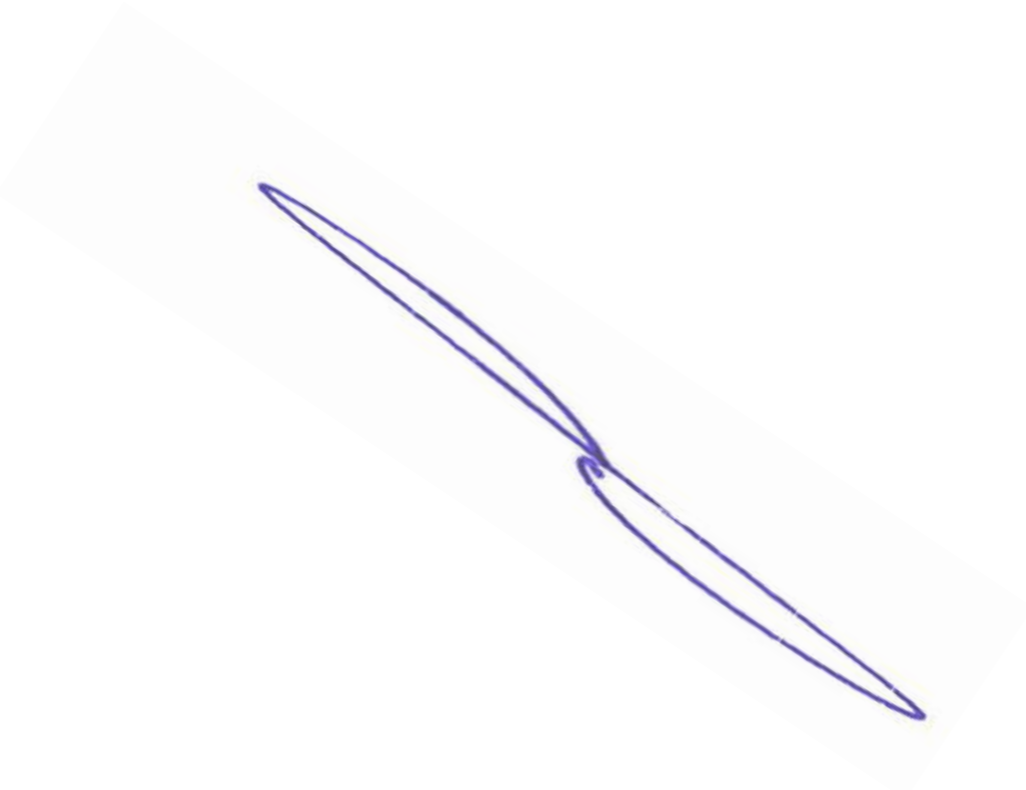
Typical Eddy Current Signals - Tubes

✓**<u>Magnitude</u> of Impedance change is proportional to defect severity (size or volume)**



✓**Orientation (phase) is related to defect location (depth)**

Boundary based Classification



Boundary Representation – Our Problem

Number of Classes --- FEW types of eddy current signals
NOISE : due to electrical noise,
material property variations
Need for speed of inspection
Effective Classification

Problem → Object Recognition

- **Different orientations**
- **Different sizes**

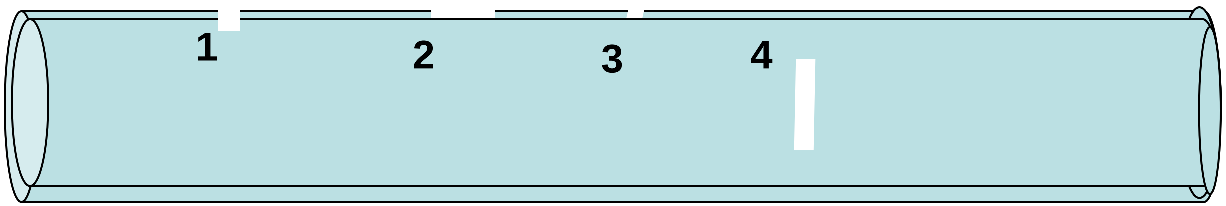
ICT is chosen for

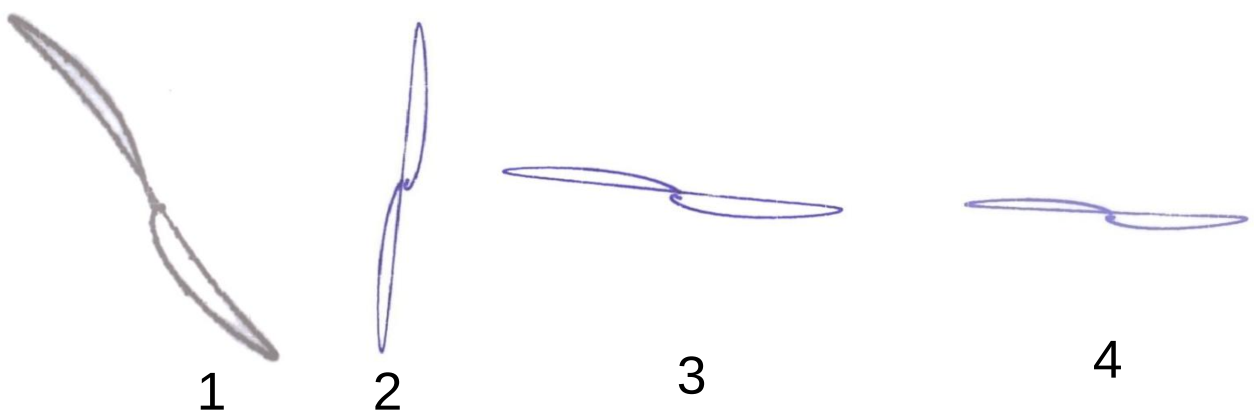
- **Boundary representation**
- **Further classification of defects**

METHODOLOGY

Input images: Artificial defects machined in fuel clad tube of fast breeder test reactor (FBTR)

- **Through hole of 1mm diameter**
- **60% flat bottomed hole –OD**
- **20% ID flat bottomed hole**
- **10%ID circumferential notch**





Scheme of the work

CREATE DATABASE-SET

- **Amplitude calculation, phase angle**
- **Normalisation of magnification**
- **Extract the Chain Code**
- **Chain Code → ICT**
- **Disorient**
- **Compute Reference ICT vector**
- **Reconstruct**

TEST SIGNAL

- **Amplitude calculation, phase angle**
- **Normalisation of magnification**
- **Extract the Chain Code**
- **Chain Code → ICT**
- **Disorient**
- **Compute ICT vector**
- **Reconstruct**

Scheme of the work

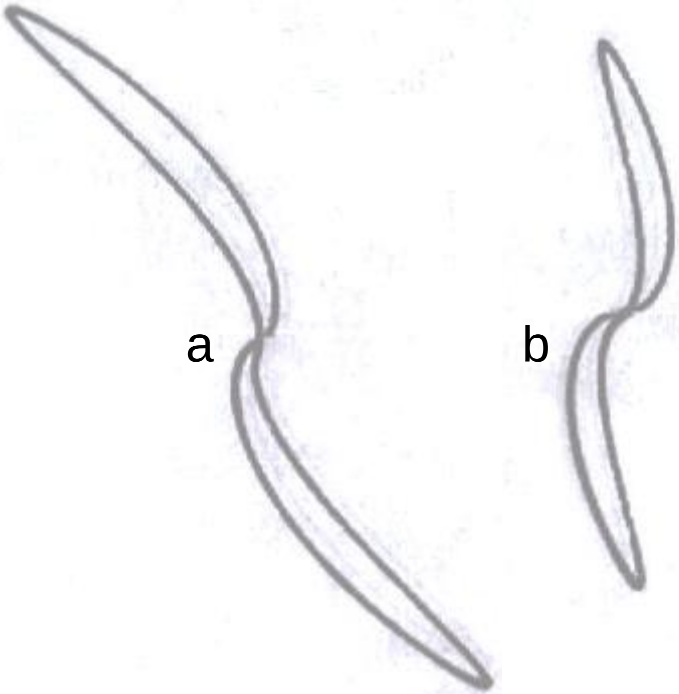
COMPARE TEST SIGNAL WITH DATABASE-SET

Compare Test ICT vector with Reference ICT vectors

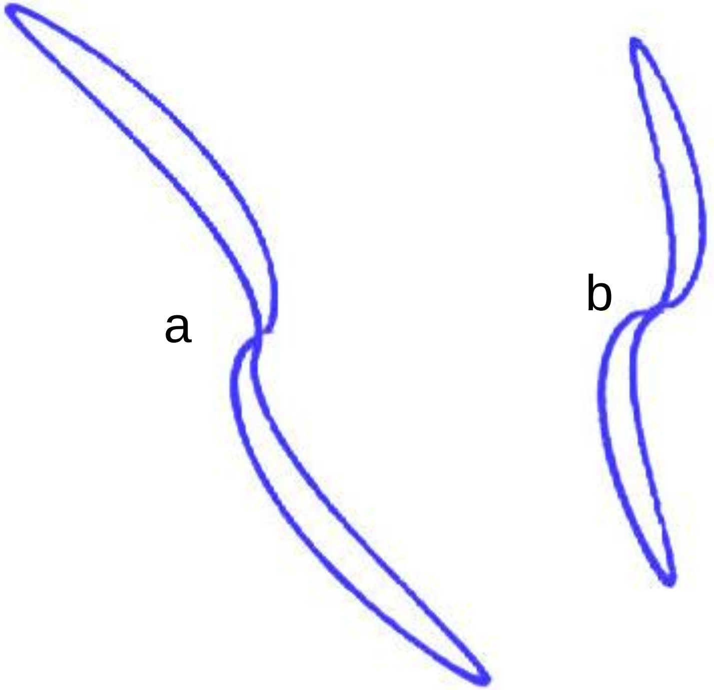
Choose the Class with minimal error

Dataset

Input image

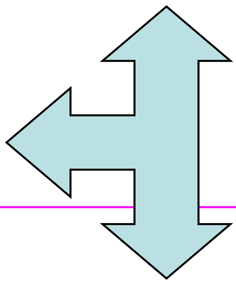


Reconstructed image



a: through hole

b: 60% OD-FBH



Parameters:

a:Angle: 45^0;peak-peak:5.8;

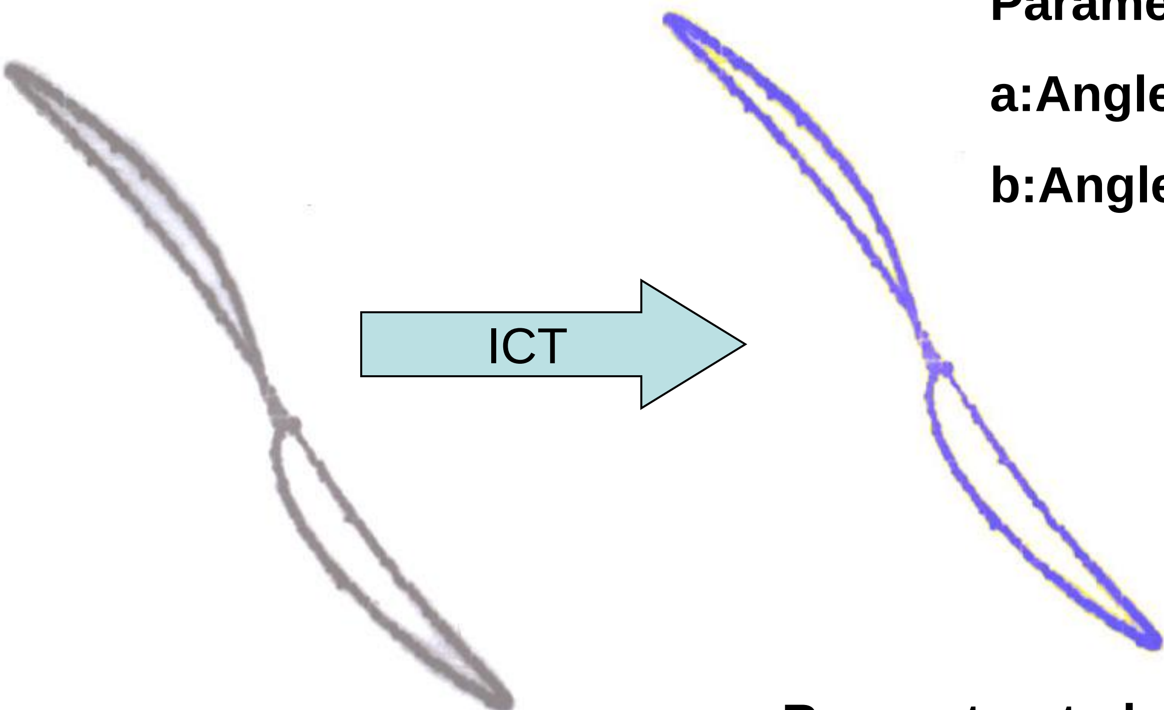
b:Angle: 90^0;peak-peak:4;

Validation

Parameters:

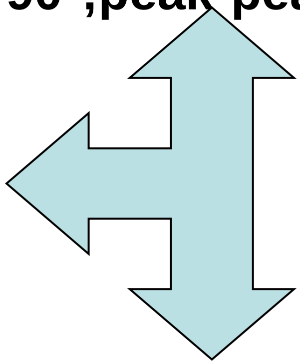
a:Angle: 45^0;peak-peak:5.8;

b:Angle: 90^0;peak-peak:4;



Through hole

Reconstructed image



Through hole

Validation

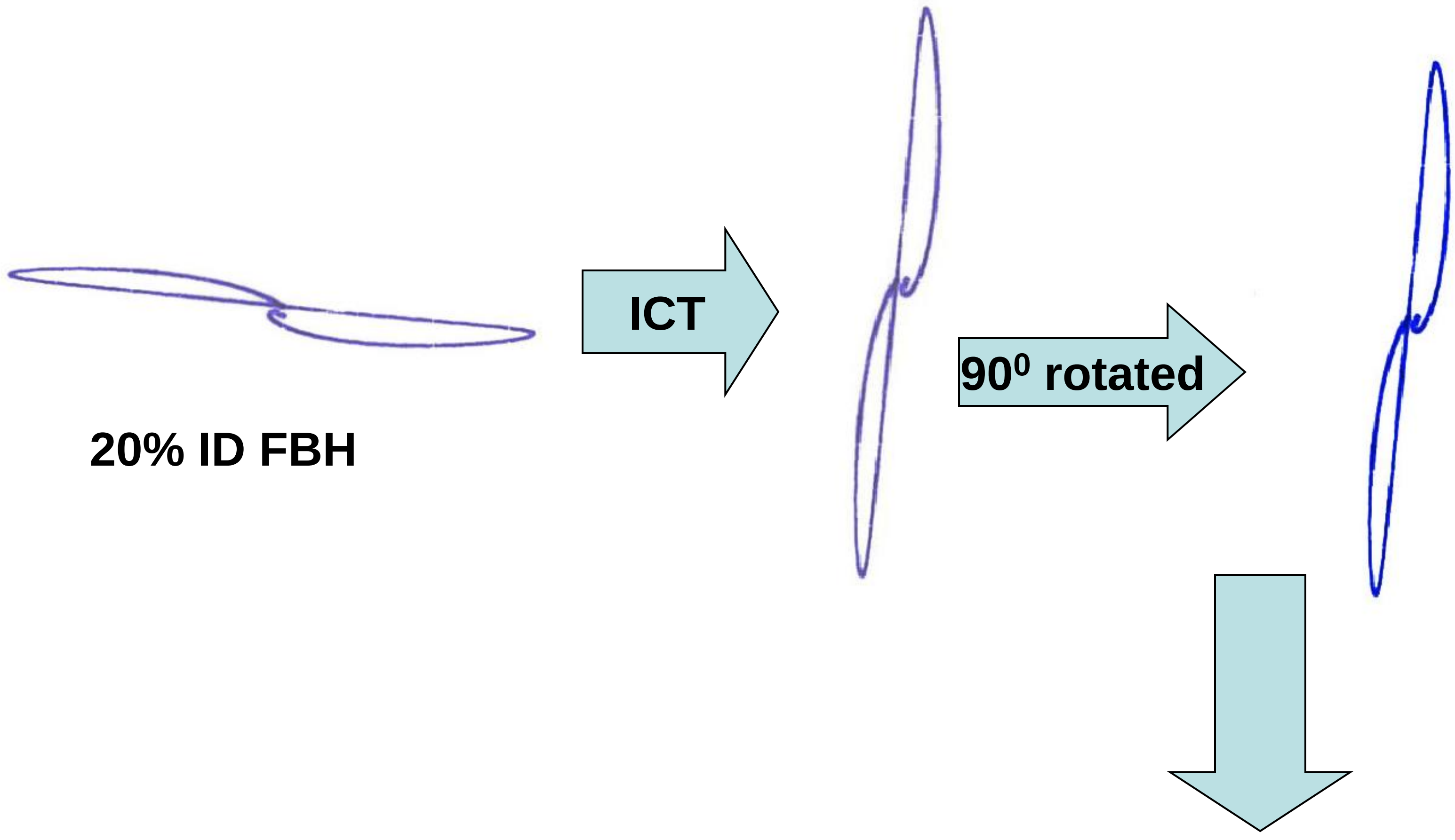
ICT

Input image: 10% ID
Circumferential notch

Parameters:

Angle: 4^0;peak-peak:3.5;

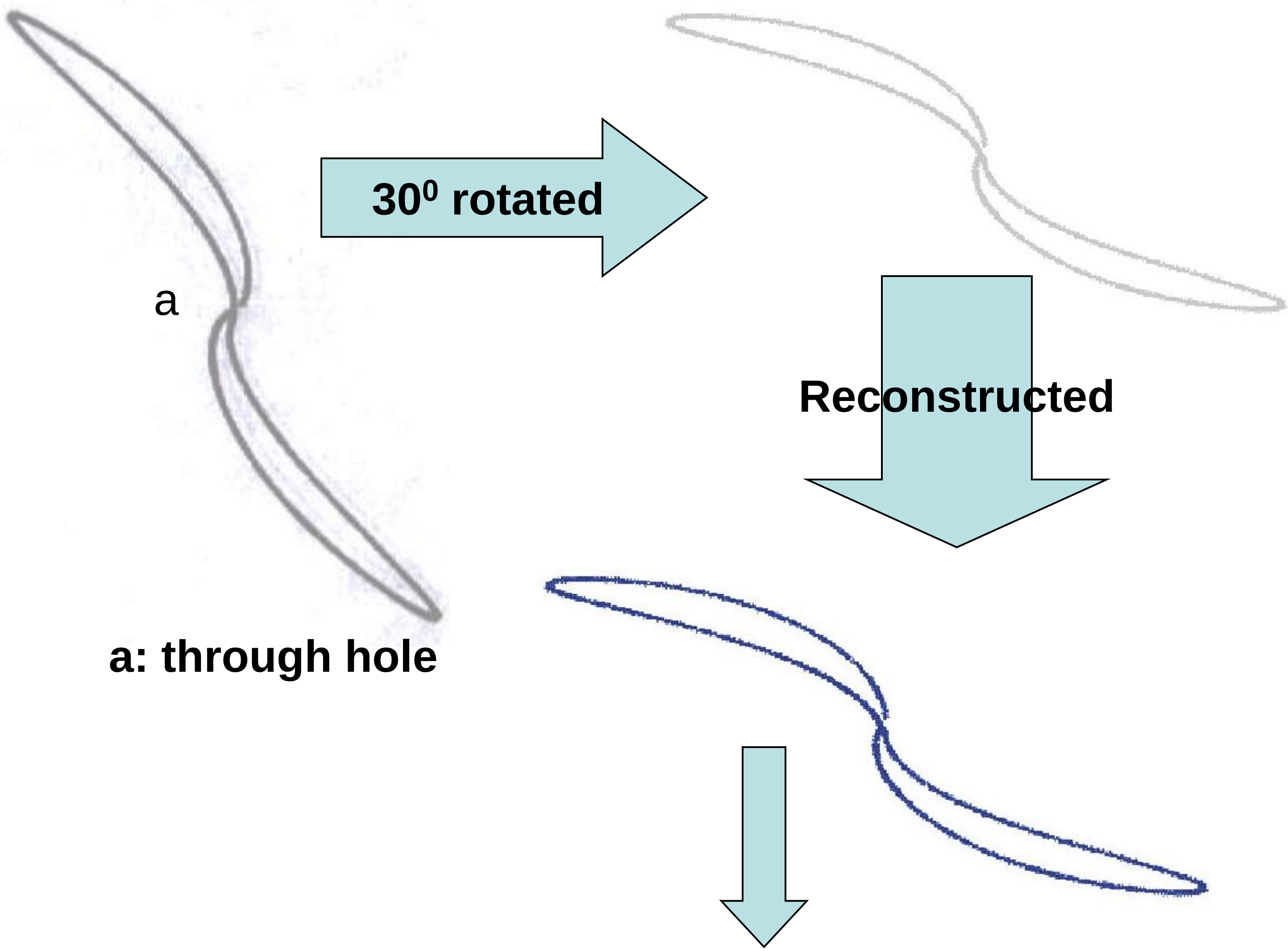
Validation



Parameters:

Angle: 90^0;peak-peak:4;

Validation



Angle:30^0;peak-peak:5.8

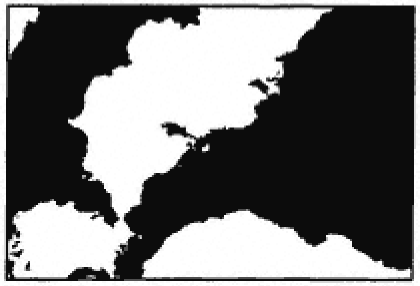
OUTLINE

- Introduction
- Chain code
- Incremental circle transform (ICT)
  - Implementation
  - Object recognition
- Classification of Eddy Current Impedance Signals
- **Application ICT for the calculation of Fractal dimension**

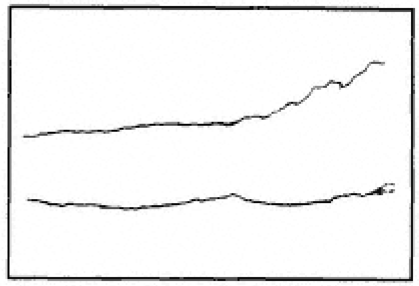
FRACTALS

- It is impossible to determine the nature using Euclidean geometry.
- Benoit Mandelbrot proposed that fractals and fractal geometry could be used to describe real objects, such as trees, lightning, river meanders and coastlines.
- Fractals can be defined as the geometrical shapes that can be subdivided into parts each of which is (at least approximately) a reduced-size copy of the whole.
- has its own dimension called fractal dimension which will be non integer value.

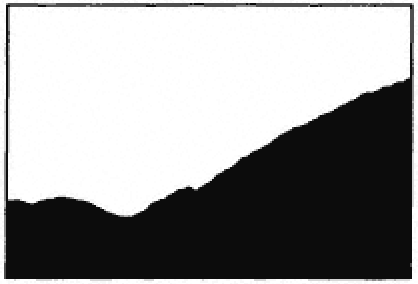
Examples of fractals



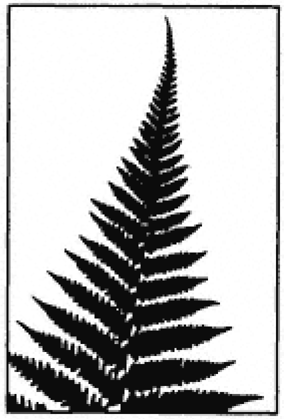
Cloud outlines



Wall cracks

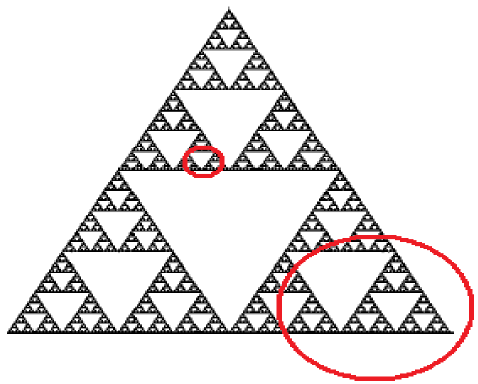


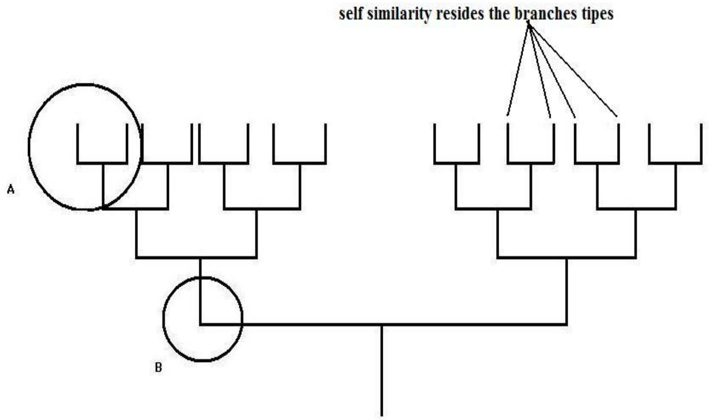
Hillside skyline



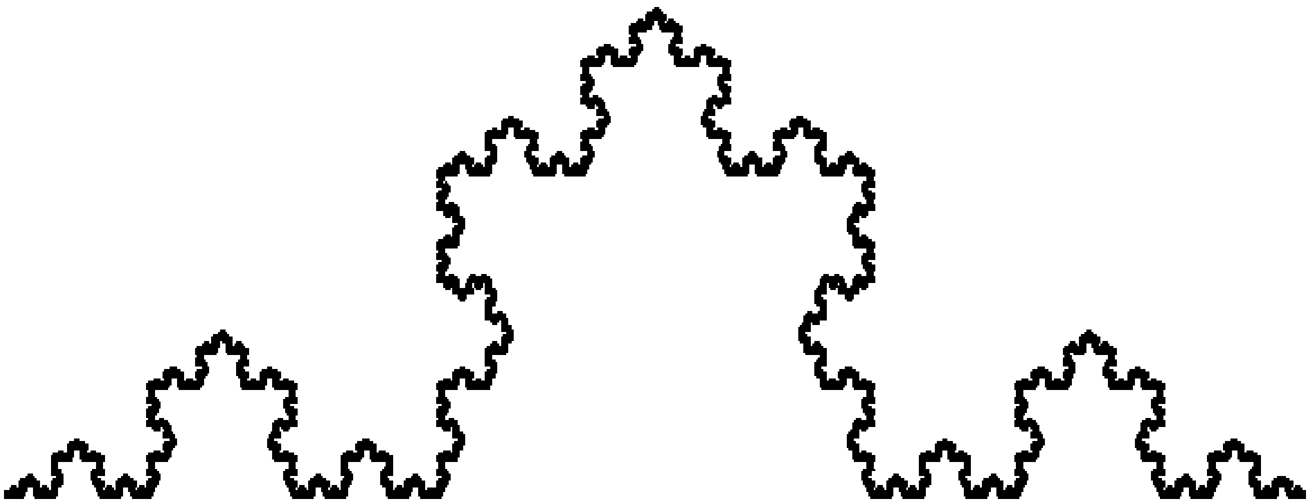
Fern tip

self similarity everywhere



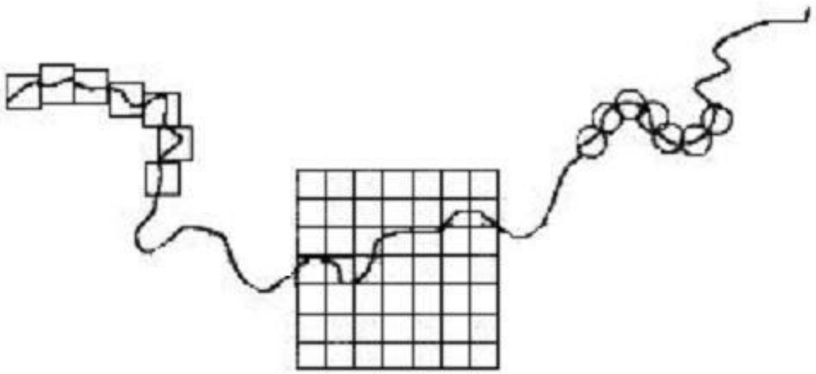


VON KOCH CURVE

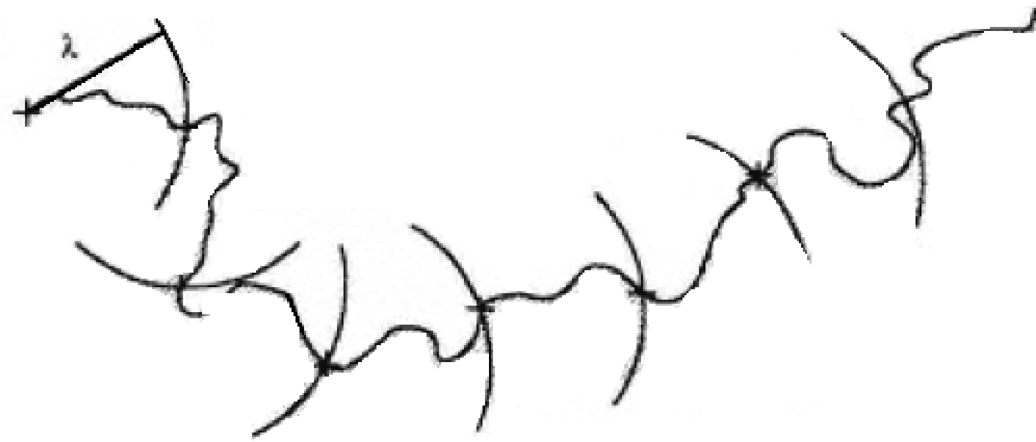


METHODS FOR FINDING THE FRACTAL DIMENSION

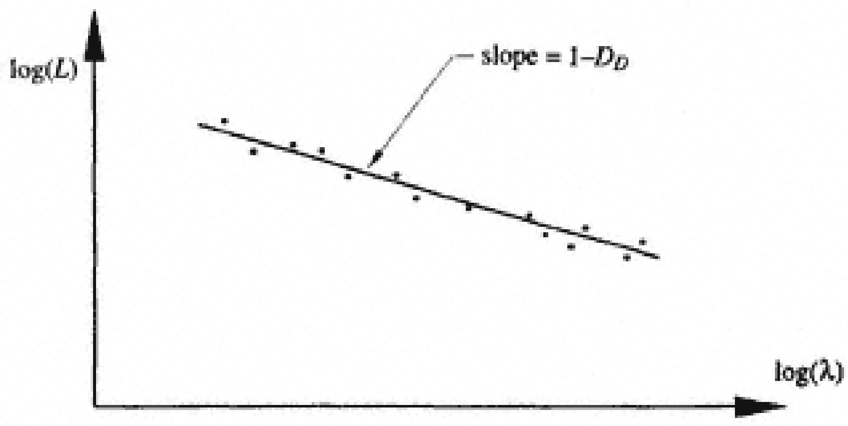
Box counting method

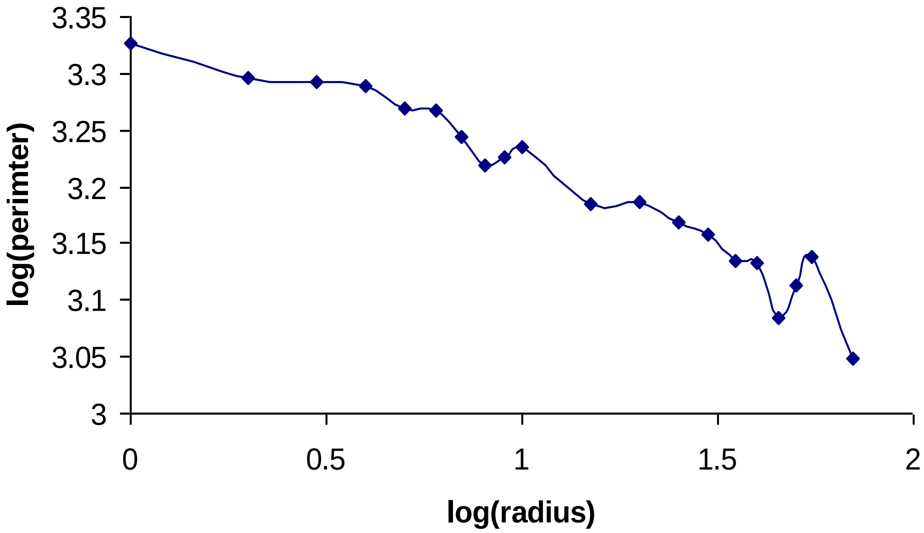


The Structured
Walk Technique



RICHARDSON PLOT





Fractal dimension=1.15


Thank You!