DEMARCATION OF OCEAN WAKES FROM SAR IMAGERY OF ROUGH SEA CONDITION

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PHASES :

PHASE 1: PREPROCESSING –NOISE REMOVAL

PHASE 2: WAKE DETECTION –UNDER ROUGH SEA CONDITION

BACKGROUND STUDY- *Ocean surface signatures*

Many ocean surface signatures in SAR imagery are characterized by relatively low normalized radar cross section values therefore distinguishing among these signatures objectively can be very difficult

SAR IMAGE CHARACTERISTICS

- Low backscatter ocean features due to wavelength polarization and incidence angle
- Oil slicks
- Fish processing discharge
- Natural biogenic slicks
- Rain effects and sea ice

OCEANOGRAPHIC CONDITIONS FOR ROUGH SEA

  - Sea state
  - Wind speed
  - Swell

[1] Armando Marino, J. Maria Sanjuan-Ferrer, Irena Hajnsek, and Kazuo Ouchi, "Ship detection with spectral analysis of synthetic aperture radar: a comparison of new and well-known algorithms," Remote Sens., vol. 7, 2015, pp. 5416-5439; DOI: http://dx.doi.org/10.3390/rs70505416.
[2] Pablo Clemente-Colón, and Xiao-Hai Yan, "Low-backscatter ocean features in synthetic aperture radar imagery," Johns Hopkins Apl Technical Digest, vol. 21, No. 1, 2000, pp. 116-121.
[3] Pasquale Iervolino, Raffaella Guida, and Philip Whittaker, "Roughness parameters estimation of sea surface from sar images," IEEE International Geoscience and Remote Sensing Symposium, 2014, Quebec, pp. 5013-5016.

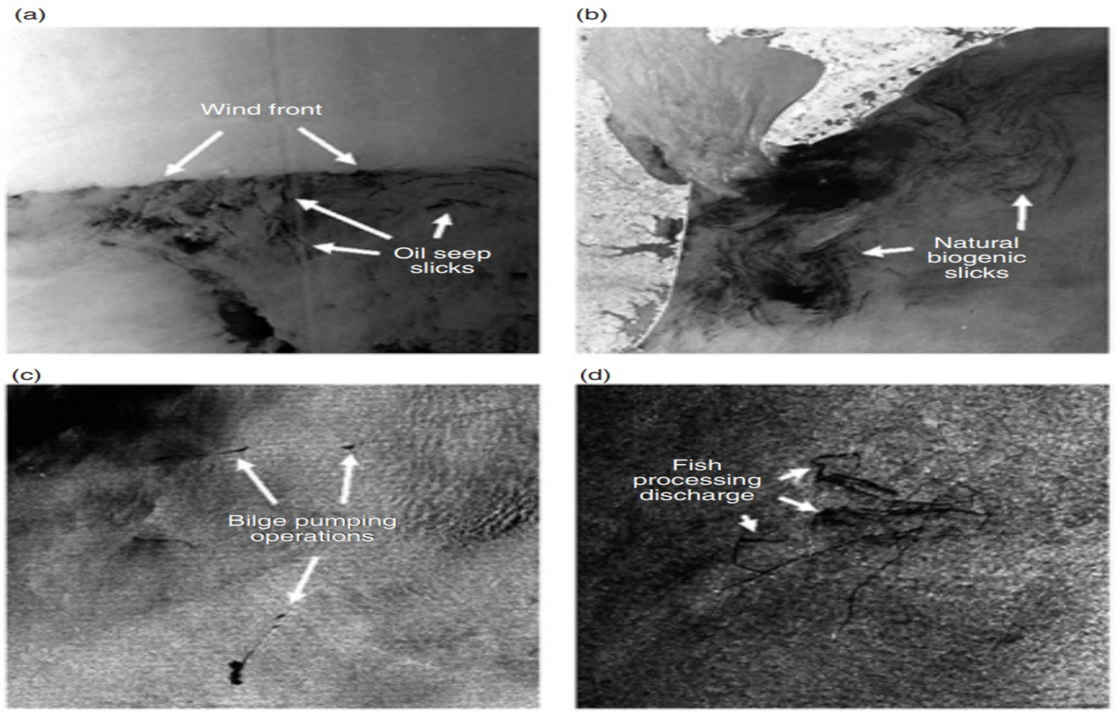


Figure 2. Radarsat images illustrating various oceanographic features. (a) ScanSAR wide image of a wind speed front and oil seep slicks in the Gulf of Mexico on 23 November 1997 at 0009 UT; (b) standard mode SAR image of the Delaware Bay region showing slicks associated with biological activity on 16 July 1998 at 2248 UT; (c) ScanSAR narrow subimage of the La Plata estuary off the coast of Uruguay showing slicks associated with suspected bilge pumping operations on 26 February 1997 at 0900 UT; and (d) ScanSAR wide subimage of the Bering Sea showing slick patterns produced by trawl fishing operations on 3 September 1997 at 1825 UT. (© Canadian Space Agency, 1997, 1998.)

BACKGROUND STUDY –*Denoising & Wake Detection*

Ship wakes are often used as a primary means of detecting a ship in synthetic aperture radar (SAR) images since they last for often many hours, thus leaving a trail that can extend for kilometers.

The wake is always characterized by a dark streak behind ships originated from the turbulent vortex created by the ship.

The appearance of wakes in radar images depends on various parameters:

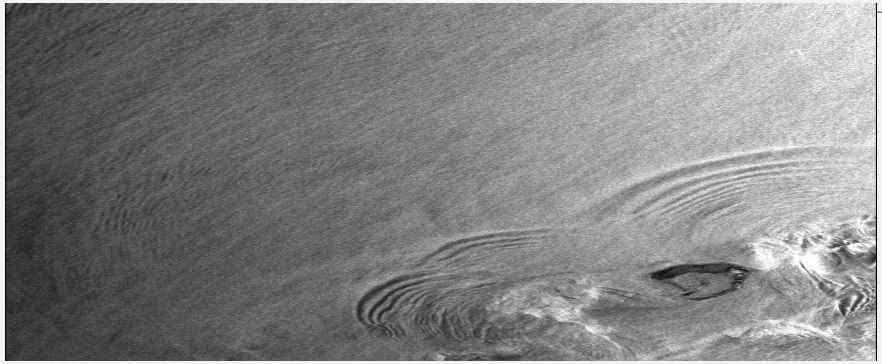
- the shape of the hull
- the sea state
- the observation geometry
- the characteristics of the radar

The probability of the occurrence of back scattering signals will highly contribute noise in the captured SAR image which leads to complexity in detection of ship wakes

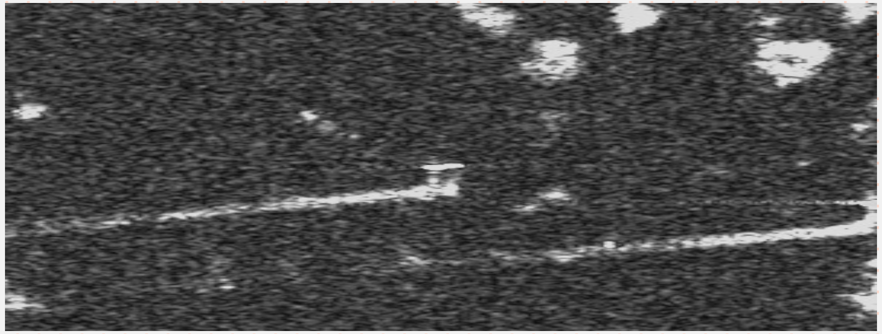
However, wake detection task is still more complicated when the sea state is high, since it hides the wakes

DATA SET COLLECTION

SAR images under normal condition



SAR images under rough sea condition

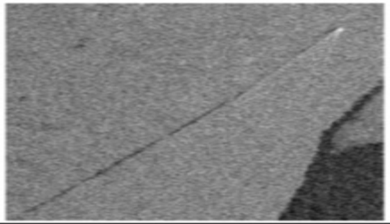
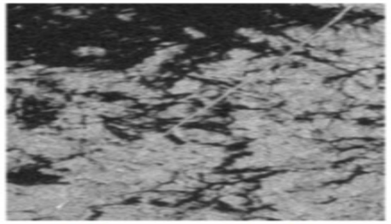
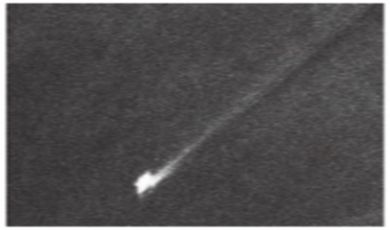


LINKS REFERRED FOR SAR IMAGE DATA COLLECTION

1. *https://earth.esa.int/web/guest/-/ers-sar-tropical-5883*
2. *https://earth.esa.int/handbooks/asar/CNTR1-1-6.html*
3. *https://en.wikipedia.org/wiki/Sea_state*

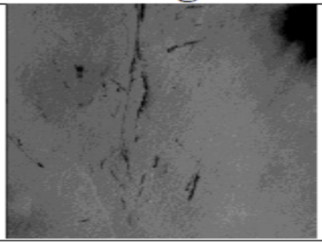
SAR IMAGES OF SHIP WAKES WITH ROUGH SEA CONDITION COLLECTED FROM DIFFERENT SOURCES

Training Dataset –Single target

S.No.	Image	Source details	Description
1.		https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/ers/instruments/sar/applications/tropical/-/asset_publisher/tZ7pAG6SCnM8/content/ship-wakes-south-china-sea Type: Ship wakes Place: South China Sea	Date: 13-Apr-1996 Time: 03:14 Orbit: 05125 Frame: 3483 Satellite: ERS-2 Latitude: 6° 07' N Longitude: 107° 15' E
2.		https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/ers/instruments/sar/applications/tropical/-/asset_publisher/tZ7pAG6SCnM8/content/ship-wakes-south-china-sea Type: Ship wakes Place: South China Sea	Date: 09-Apr-1996 Time: 03:08 Orbit: 24755 Frame: 3447 Satellite: ERS-1 Latitude: 7° 54' N Longitude: 109° 04' E
Location	**Monsoon/sub-system**	**Monsoon season**	
		Average date of arrival	**Average date of withdrawal**
South China	East Asian summer monsoon	April	July
3.		https://www.google.co.in/search?q=ship+wakes+SAR+images Type: Ship wakes **Reference:** Alexander Soloviev, Mikhail Gilman, Kathryn Young, Stephan Brusch, Susanne Lehner. "Sonar measurements in ship wakes simultaneous with TerraSAR-X overpasses," *IEEE transactions on Geoscience and Remote Sensing*, vol. 48, no. 2, 2010, pp. 841-851.	Date: 23-May-2008 TSX image time: 23:22:02 TSX mode: Stripmap TSX polarization: VV Ship name: Alianca Inca Ship length: 148 Wind speed (m/s): 0.5/0.5/0.4
Location	**Monsoon/sub-system**	**Monsoon season**	
		Average date of arrival	**Average date of withdrawal**
Straits of Florida	Humid sub-tropical	May	October

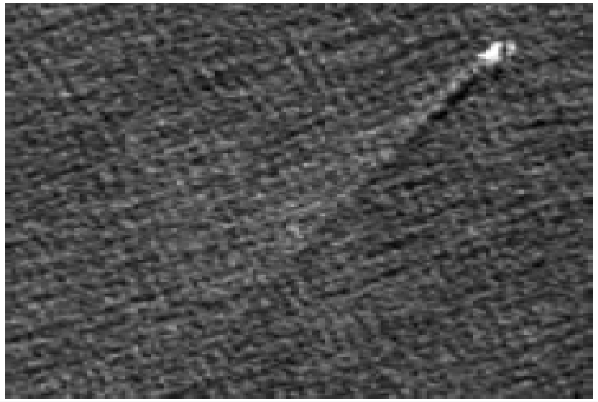
SAR IMAGES OF SHIP WAKES WITH ROUGH SEA CONDITION COLLECTED FROM DIFFERENT SOURCES

Training Dataset –Multiple Target

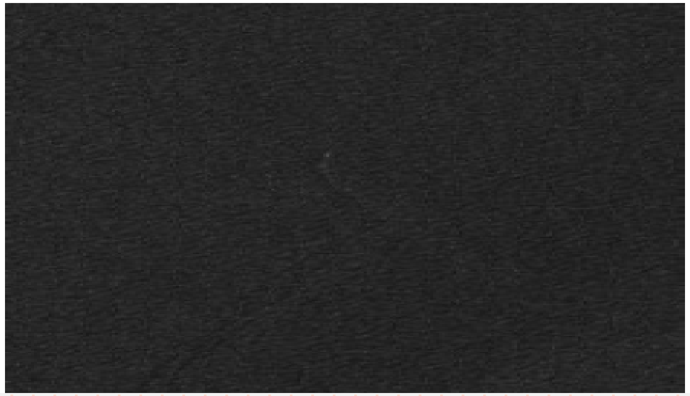
S.No.	Image	Source details	Description
1.		https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/ers/instruments/sar/applications/tropical/-/asset_publisher/tZ7pAG6SCnM8/content/ship-wakes-south-china-sea Type: Ship wakes Place: South China Sea	Date: 15-Apr-1996 Time: 03:20 Orbit: 24841 Frame: 3555 Satellite: ERS-1 Latitude: 2° 32' N Longitude:105° 02' E
Location	Monsoon/sub-system	Monsoon season	
		Average date of arrival	Average date of withdrawal
South China	East Asian summer monsoon	April	July

Testing Dataset

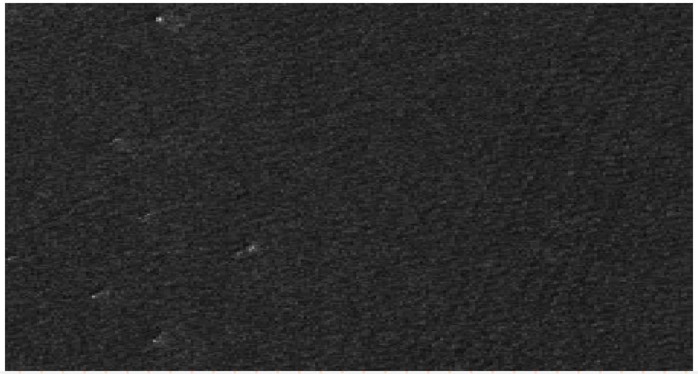
Single Target



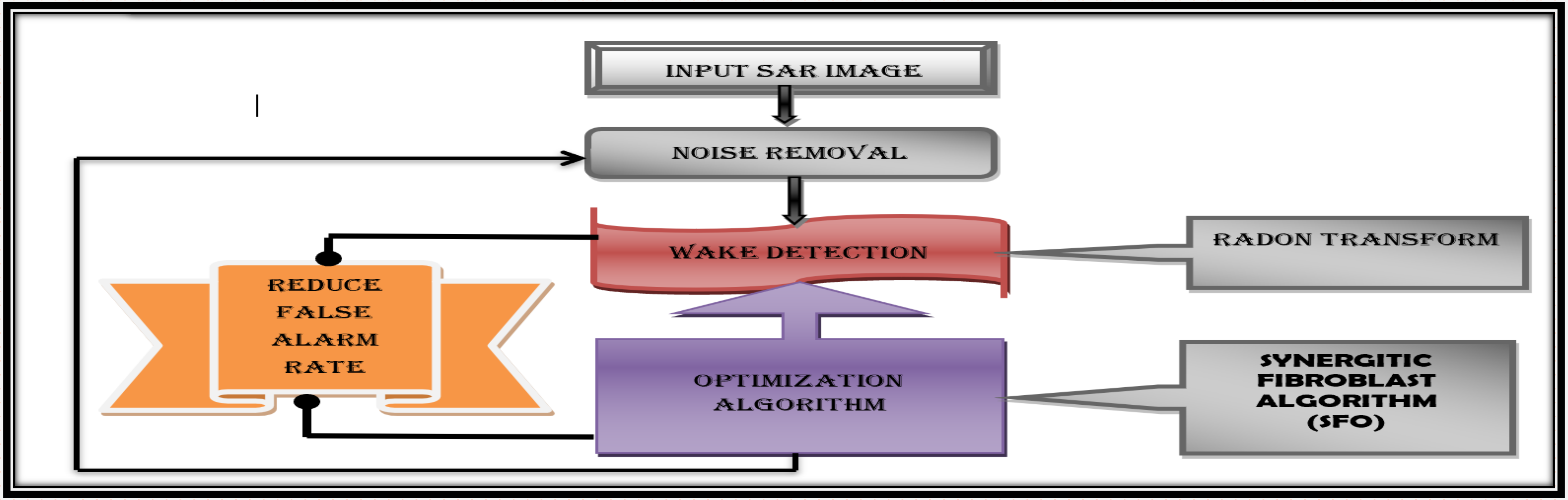
Single Target



Multiple Target



PROPOSED METHODOLOGY



Implementation of proposed phases of the project

- ✓ Phase I : Optimal Denoising method
- ✓ Phase II : Optimal Wake detection method

PHASE I : OPTIMAL DENOISING METHOD

SAR images contain speckle noise which is based on multiplicative noise or rayleigh noise.

Speckle noise is the result of two phenomenon,

- ✓ Coherent summation of the backscattered signals
- ✓ Random interference of electromagnetic signals

The drawback of DWT are:

It is computationally intensive and less efficient for the large proportion of speckle noise where wavelet coefficients are suppressed in both decomposition and reconstruction phase that leads to produce ineffective denoised SAR image.

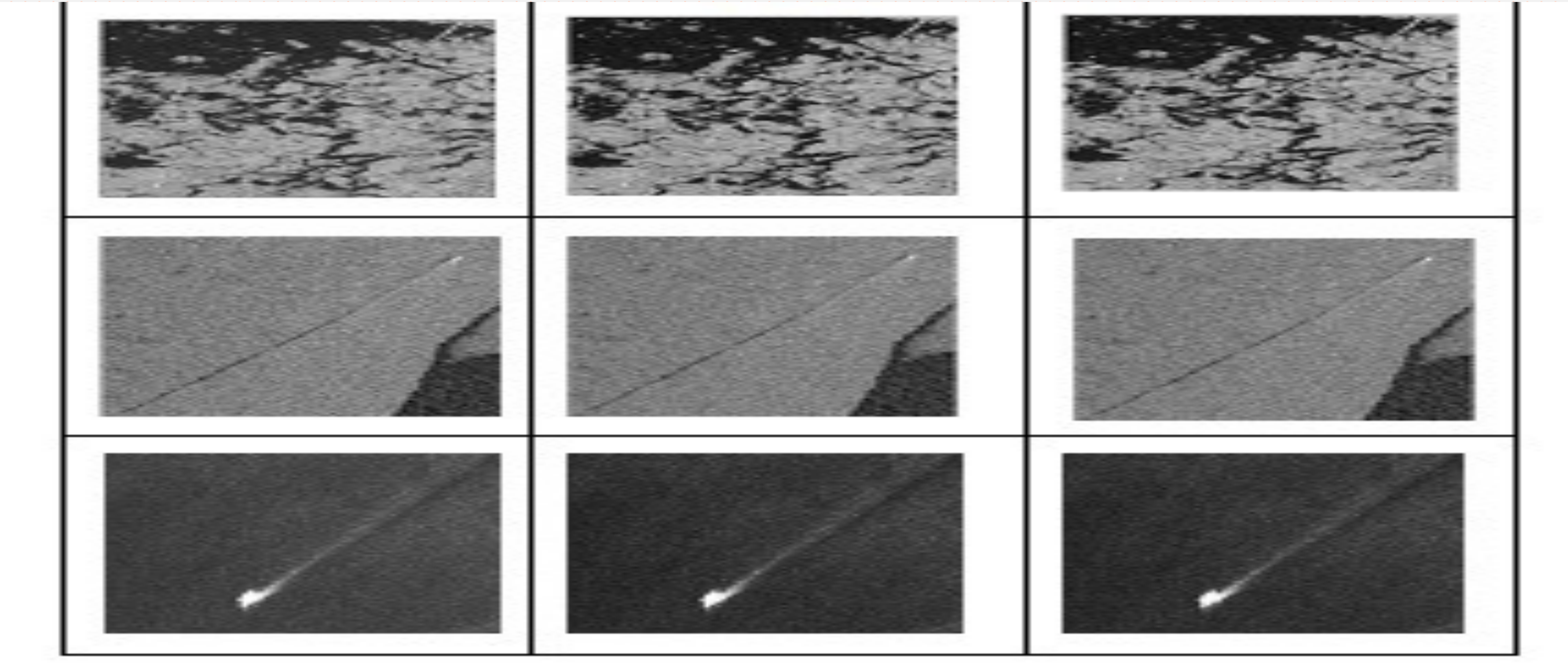
ALPHA (α) is a sparsity parameter that plays an important role for the selection of penalized threshold which is choosen by novel optimization technique

Synergistic Fibroblast Optimization (SFO) algorithm

VISUAL ASSESSMENT OF DENOISING METHODS

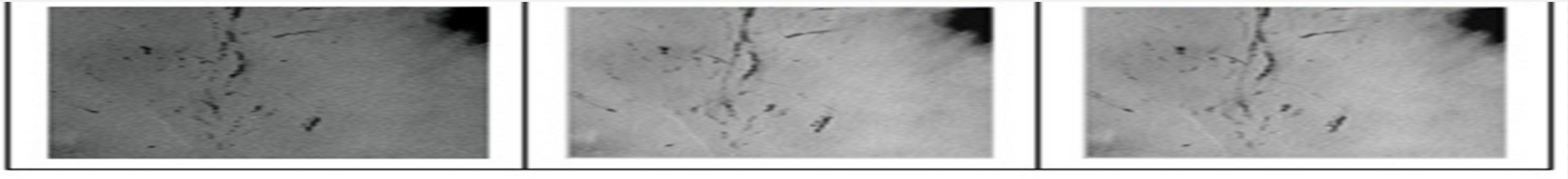
Training Dataset –Single Target

Original Image | Wavelet filter based db family | Optimized Wavelet filter based db family



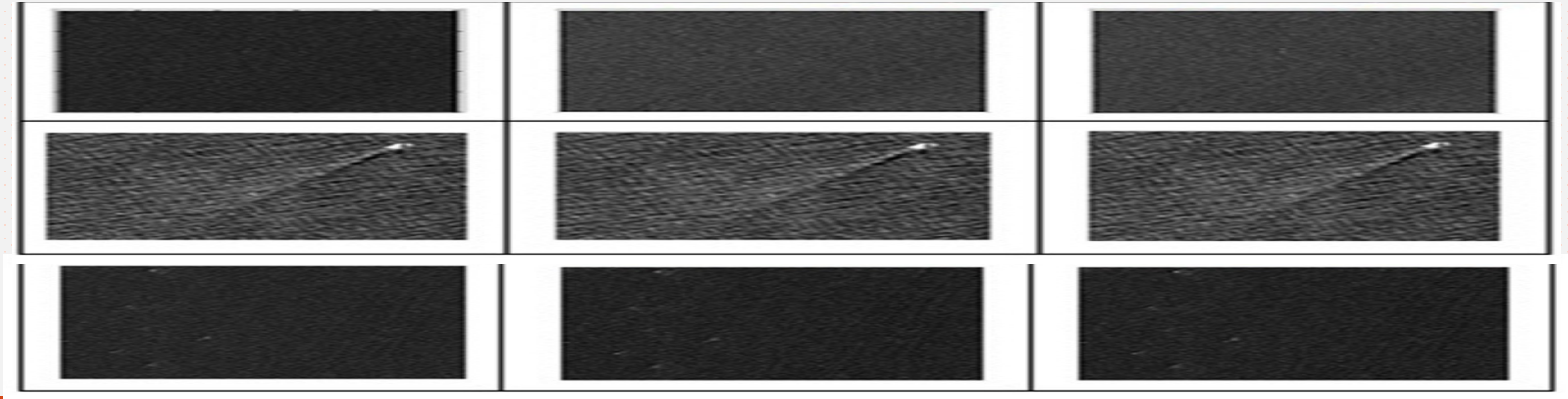
Training Dataset –Multiple Target

Original Image | Wavelet filter based db family | Optimized Wavelet filter based db family



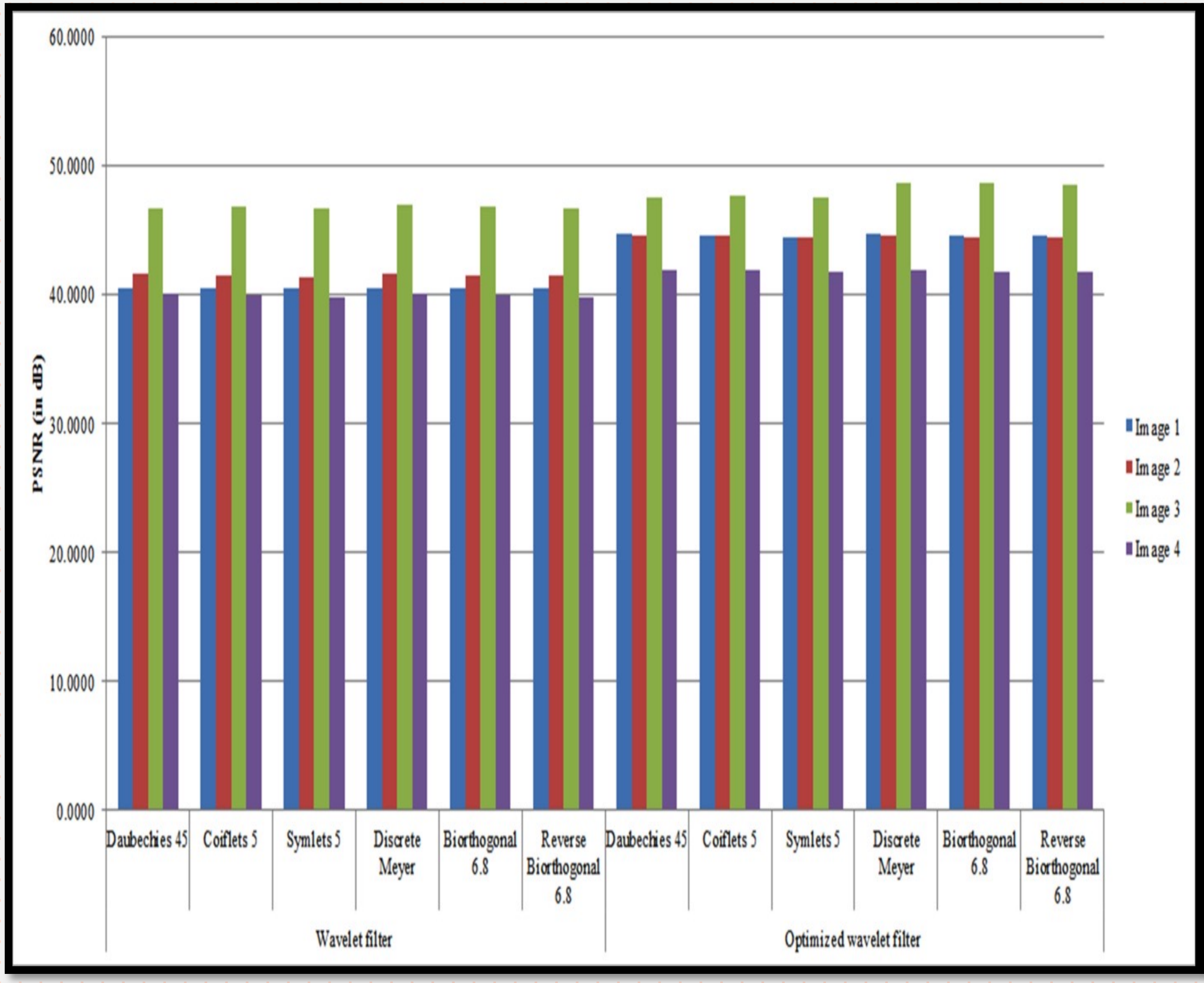
Testing Dataset

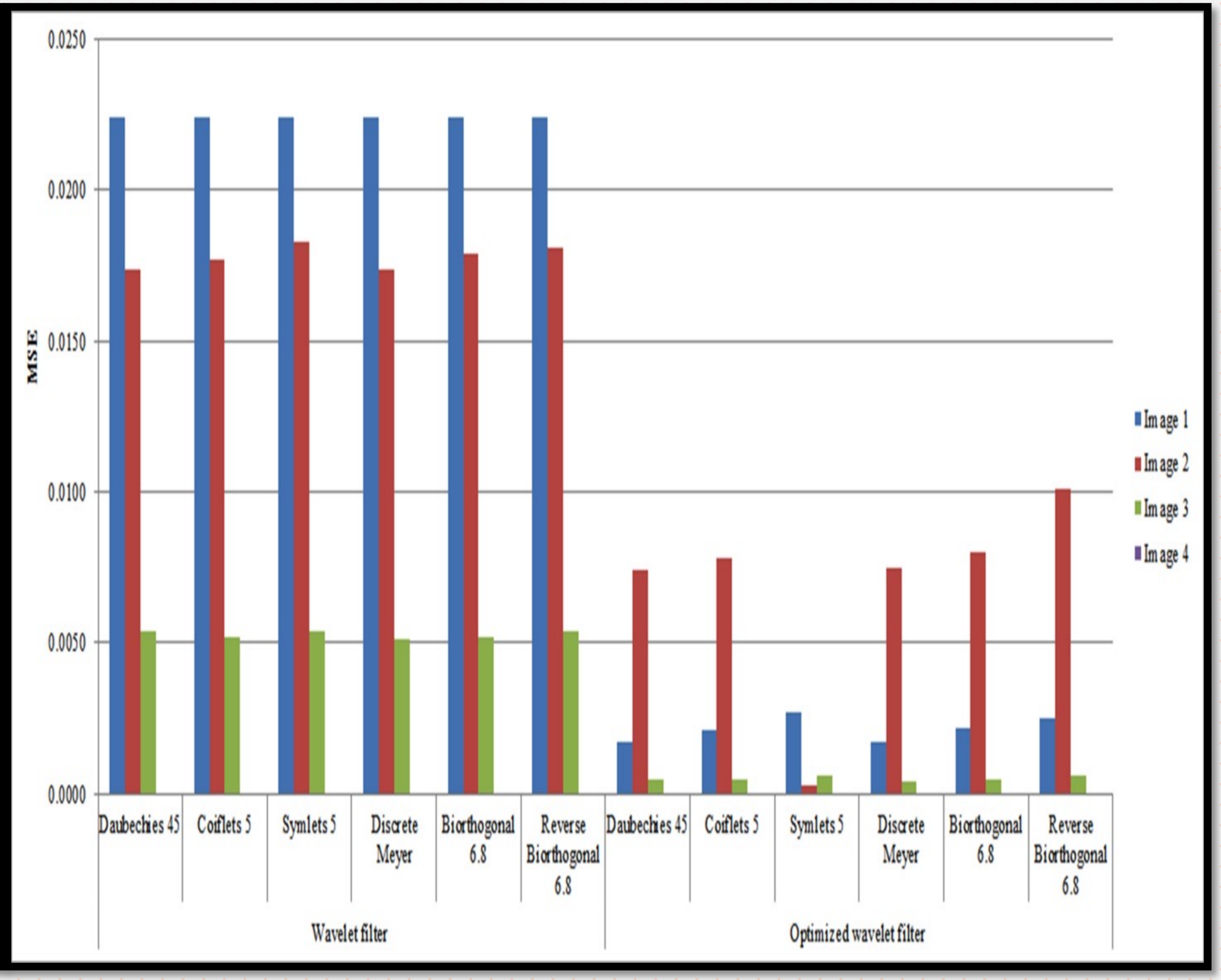
Original Image | Wavelet filter based db family | Optimized Wavelet filter based db family



Training Dataset

contd....

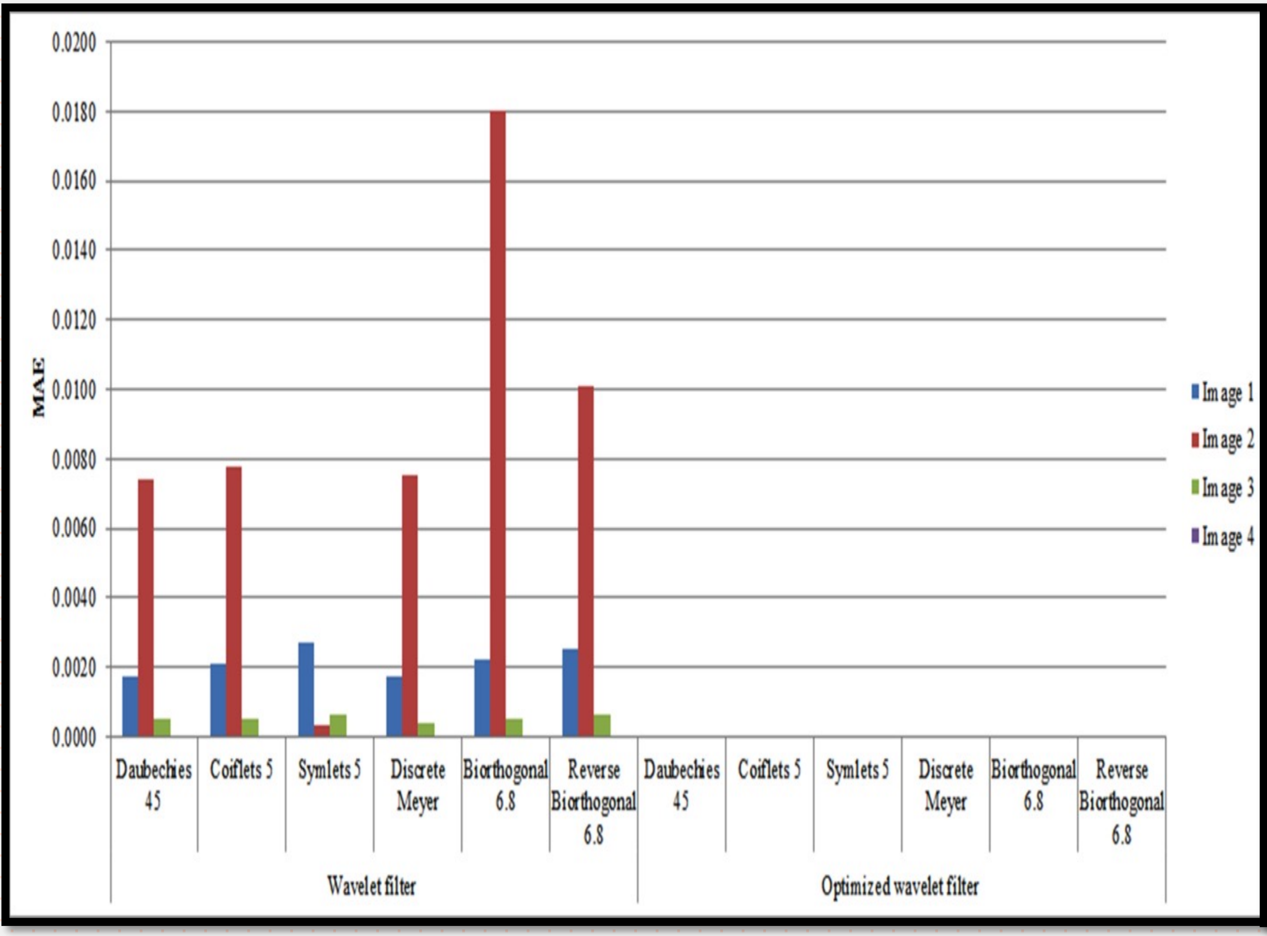




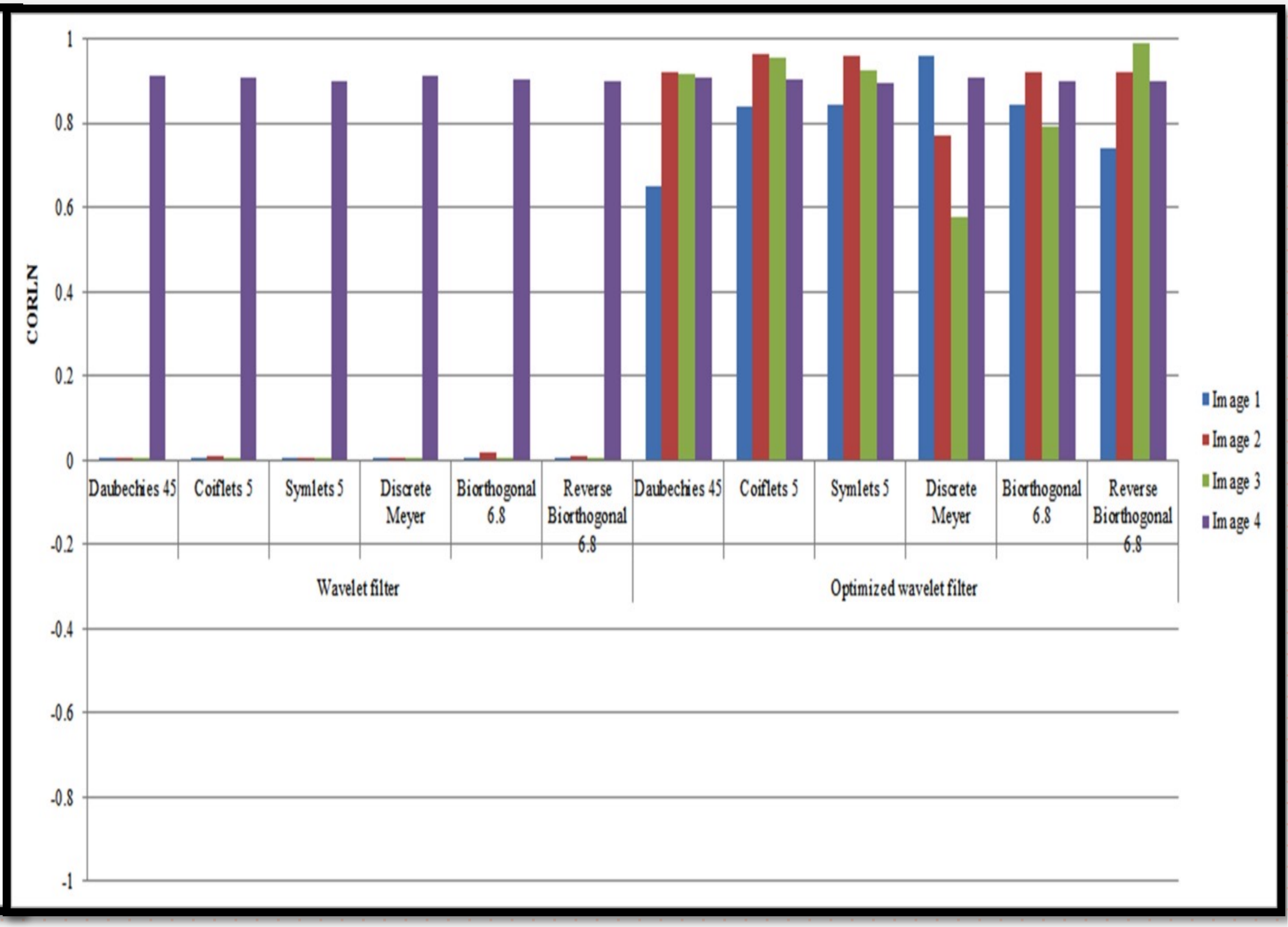
Objective evaluation of PSNR – training dataset

Objective evaluation of MSE – training dataset

Training Dataset



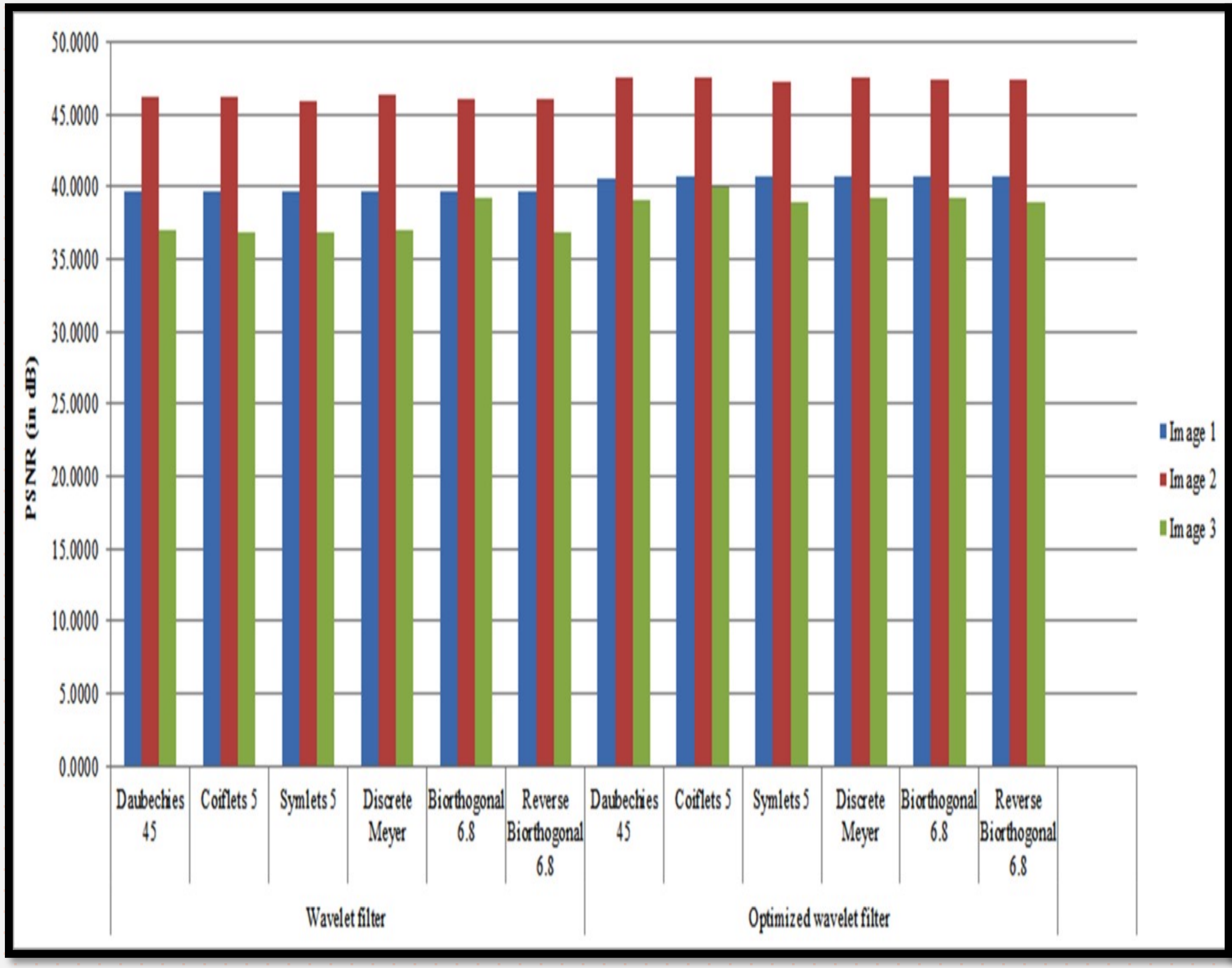
Objective evaluation of MAE – training dataset

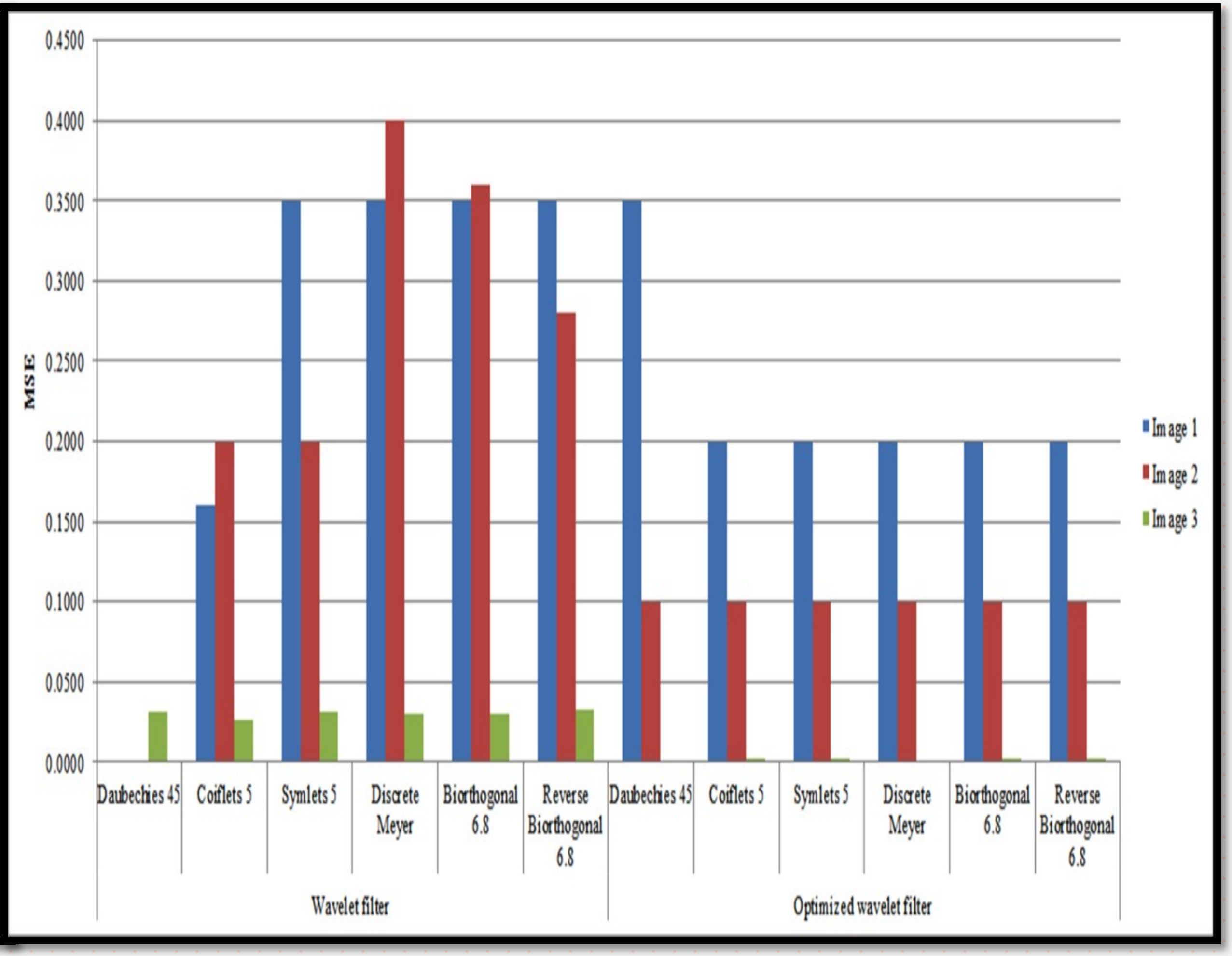


Objective evaluation of CORLN – training dataset

Testing Dataset

contd....

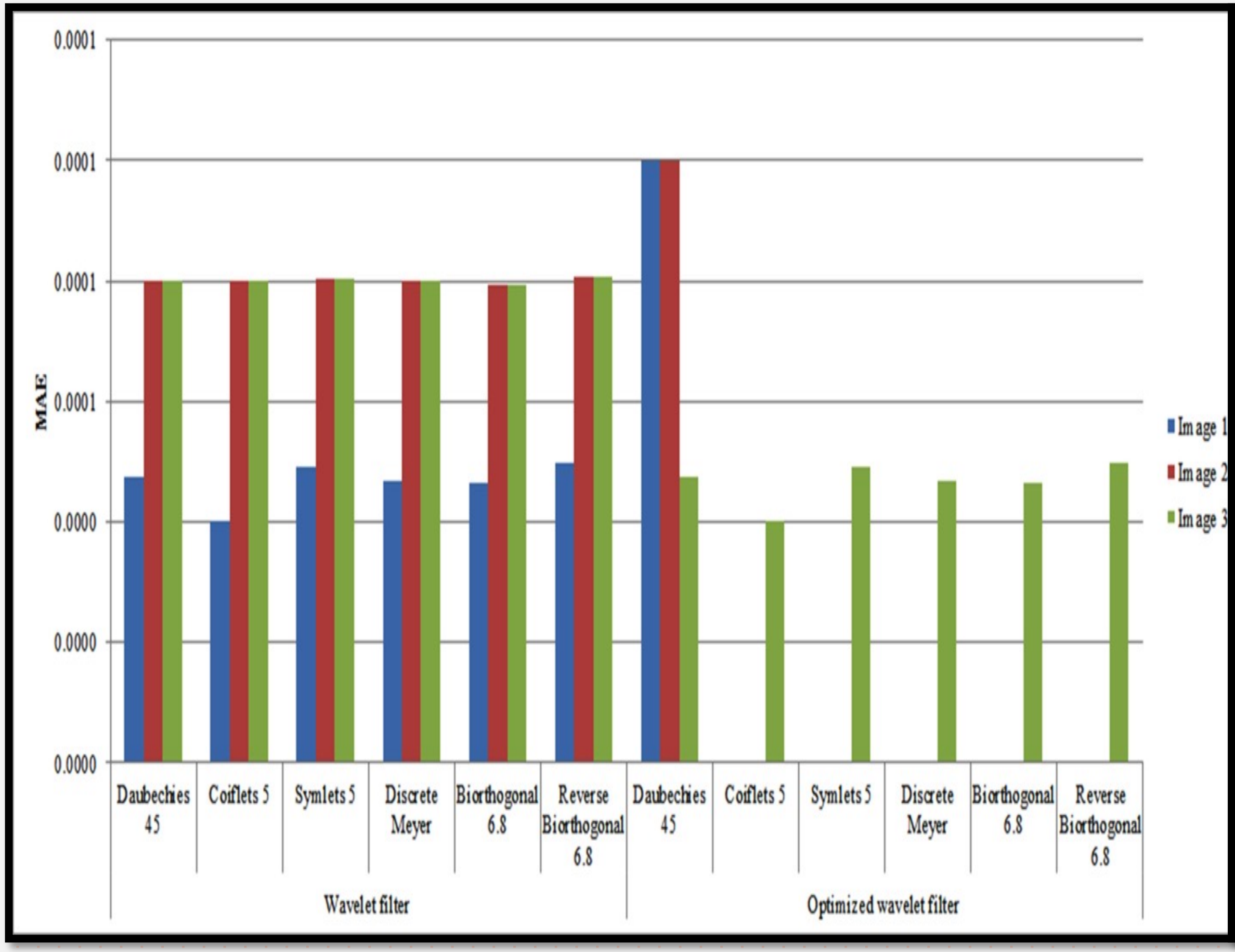




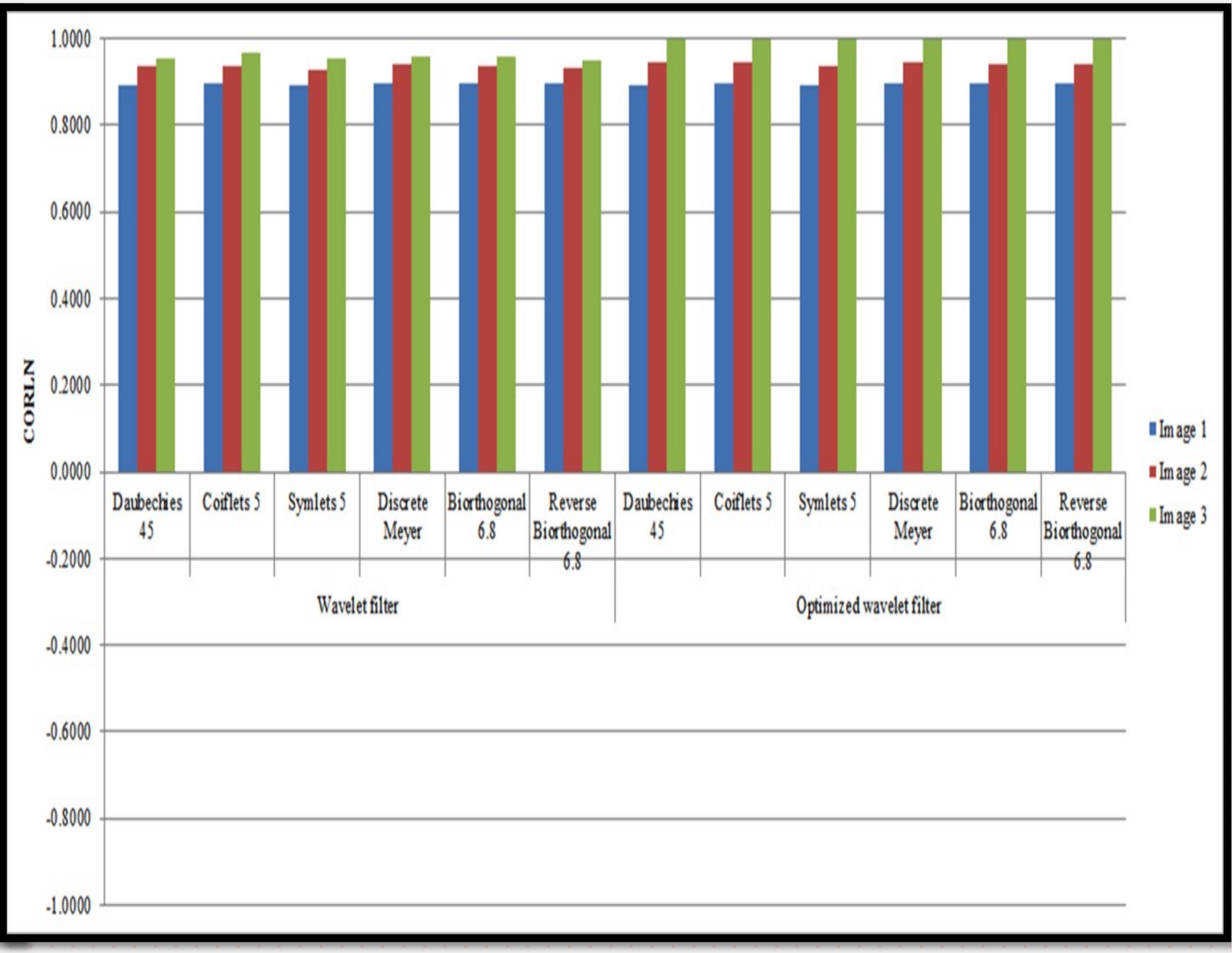
Objective evaluation of PSNR – testing dataset

Objective evaluation of MSE – testing dataset

Testing Dataset



Objective evaluation of MAE – testing dataset



Objective evaluation of CORLN – testing dataset

PHASE 2 : OPTIMAL WAKE DETECTION

Two reasons are more important to detect the wake patterns in SAR images namely,

1. Wake pattern is larger and more distinct than the ship signature, and it can yield a better estimate of the ship's true location.

2. The ship wake pattern can yield information about the ship's heading and speed.

But, the internal waves on the surface may be detectable in SAR image and not all the wake components are visible in every image due to characteristics such as different orientations of the SAR sensor, variation in ship size and speed as well as varying ocean and wind conditions.

Thus, the project challenges to develop an approach to locate, identify ship wakes under critical characteristics of SAR image especially under rough sea conditions.

TASK 1: IMPLEMENTATION OF RADON TRANSFORM

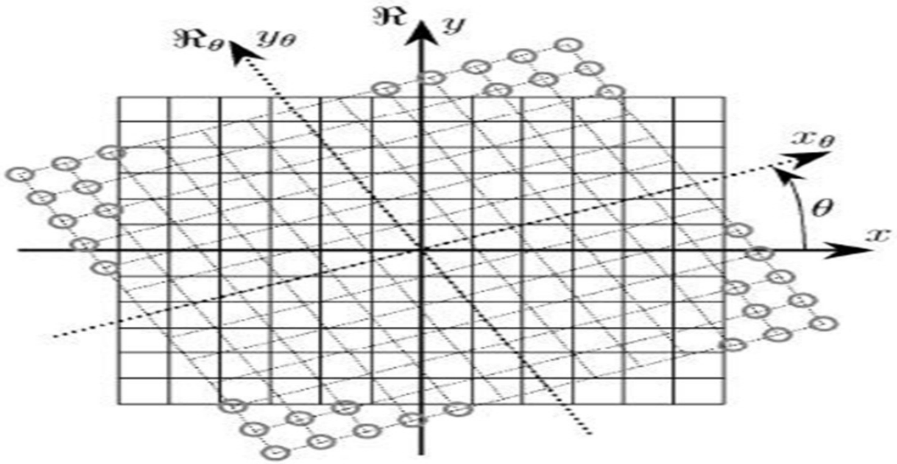
The Radon Transform calculates the angle that a straight line perpendicular to the track makes

with the x-axis in the center of the image

The Radon transform $\hat{I}$ is given in equation below

$$\hat{I}(x_\theta,\theta) = \sum_{y\theta=-M/2}^{M/2} I(x_\theta\cos\theta - y_\theta\sin\theta, x_\theta\sin\theta + y_\theta\cos\theta) - \ldots\ldots (1)$$

where $((x_\theta, y_\theta) \in Z$ and $\theta \in [0;\pi]$



Discrete Radon Transform (DRT) is a two dimensional function f(x, y) that represents the data points projected at an angles θ, 0 ≤ θ<π. DRT is an efficient mathematical transform for the detection of line in the entire image domain. Here, DRT equation (2) is applied to the detection of ship wakes in Synthetic Aperture Radar (SAR) images.

The equation of line is y = sx + t. (|s| <= 1)

$$Radon(\{y = sx + t\}, I) = \sum_{u=-n/2}^{\frac{n}{2}-1} \widetilde{I^1}(u, su + t) \quad \text{...(2)}$$

where

$$\tilde{I}^1(u, y) = \sum_{v=-n/2}^{\frac{n}{2}-1} I(u, v) D_m(y - v)$$

$D_m(t) = \frac{\sin(\pi t)}{m \sin(\frac{\pi t}{m})}$, the Dirichlet kernel with m = 2n+1.

Where n is the mean value of pixels in the image. -n<t<n

The drawbacks of RT are

The intensity integration is performed over the entire length of the image and has no capability of providing information about the positions of the endpoints of these shorter line segments, or on line length which may not produce suitable peaks or that leads to misidentification of linear signatures in SAR images.

TASK 2: IMPLEMENTATION OF OPTIMIZED RADON TRANSFORM

The mathematical expression of radon transform (ρ_0, θ_0) *is equivalent to the integral of the input denoised SAR image over the line equation* $\rho 0 = x.\cos\theta_0 + y.\sin\theta_0$ *is written as follows.*

$$RI(\theta,\rho,\sigma) = R_{Loc}\{RI\} = f\int_{xmin}^{xmax}\int_{ymin}^{ymax} f(x,y)\,\delta(\rho - x\cos\theta - y\sin\theta)\,dydx \quad (1)$$

Where $xmin = \min(\rho\cos\theta - \sigma\sin\theta, \rho\sin\theta - (\sigma+\lambda)\sin\theta)$, $xmax = \max(\rho\cos\theta - \sigma\sin\theta, \rho\sin\theta - (\sigma+\lambda)\sin\theta)$

$ymin = \rho\sin\theta + \sigma\cos\theta$, $ymax = \rho\sin\theta + (\sigma+\lambda)\cos\theta$

σ *= shift parameter ,* λ *= length of the line segment of integration (LSOI)*

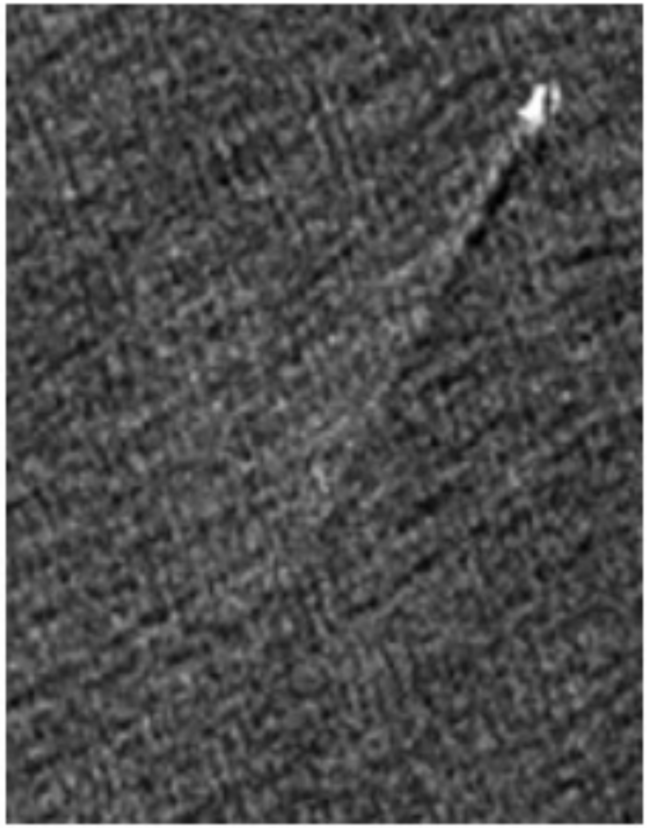
The shift parameter is utilized to construct sinusoidal wave by using angle and offset value from the range of discrete set of known data points. The value of shift parameter falls within range of 0.0 to 10.0 within the interval of 0.25.

The shift parameter value is applied to construct a curve that has the best bit over a series of data points. The novel Synergistic Fibroblast Optimization (SFO) algorithm is utilized to choose shift parameter.

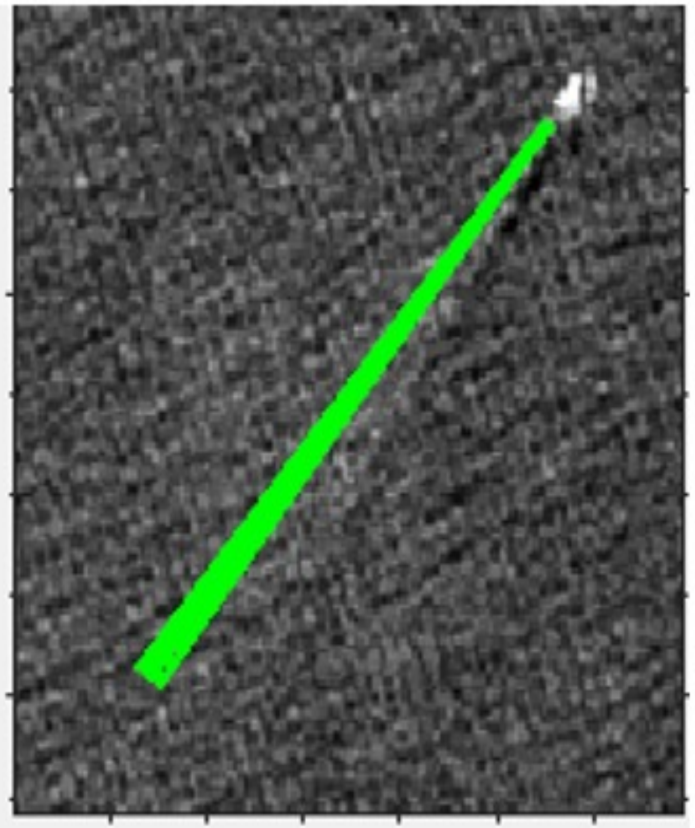
VISUAL ASSESMENT FOR WAKE DETECTION METHOD

Sample Dataset –Single Target

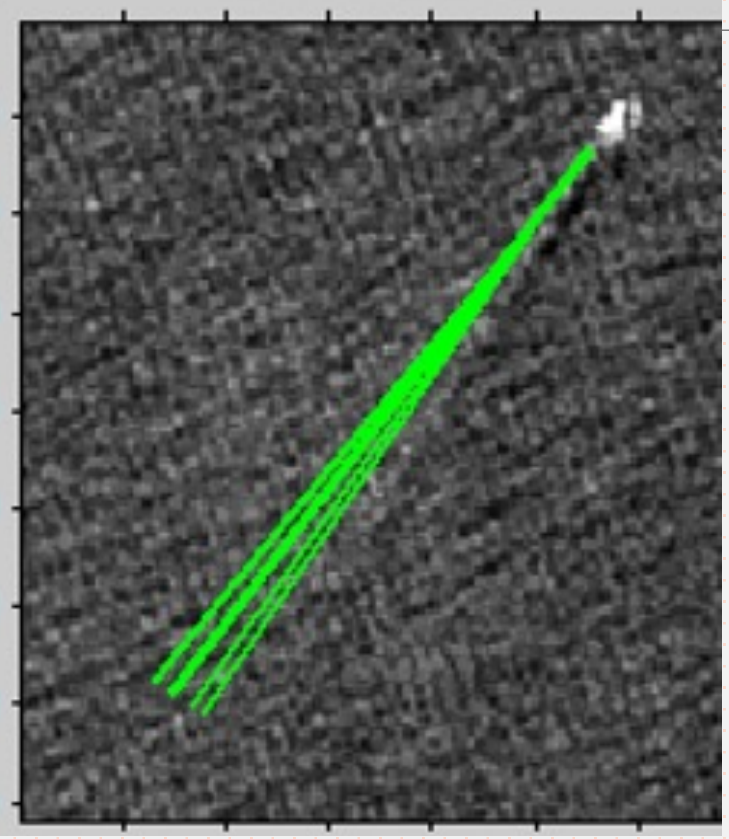
Original Image



Wake Detection

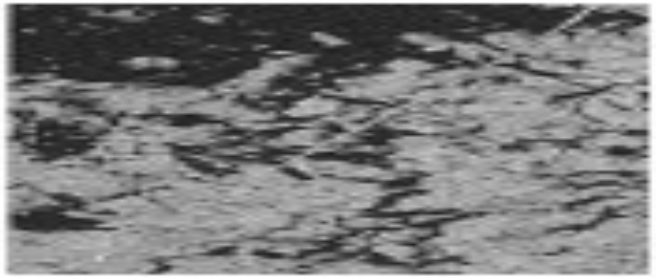
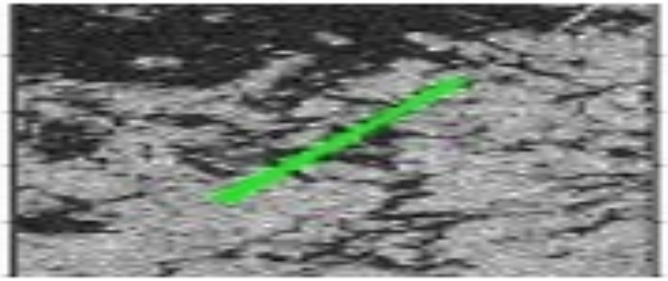
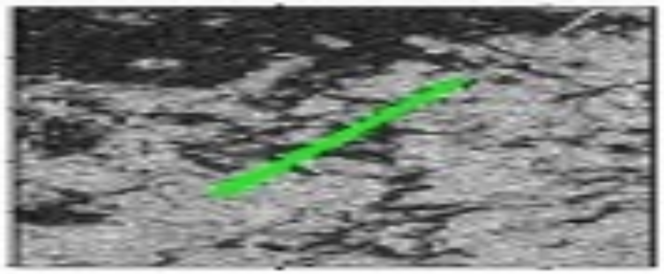
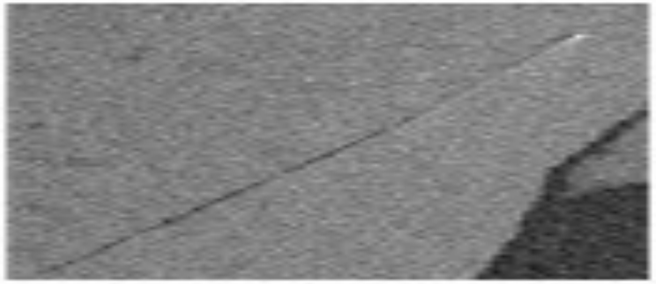
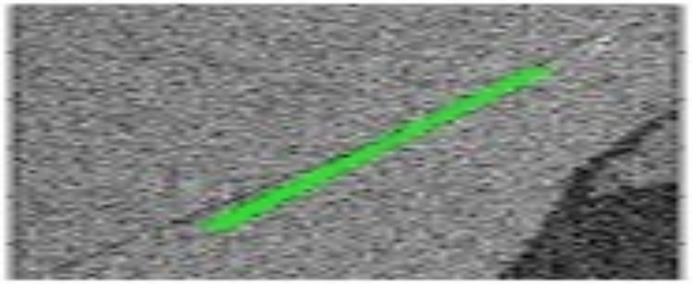
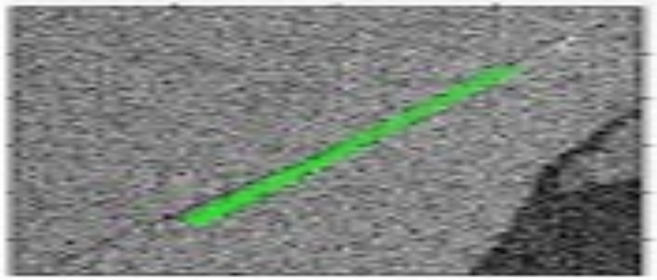
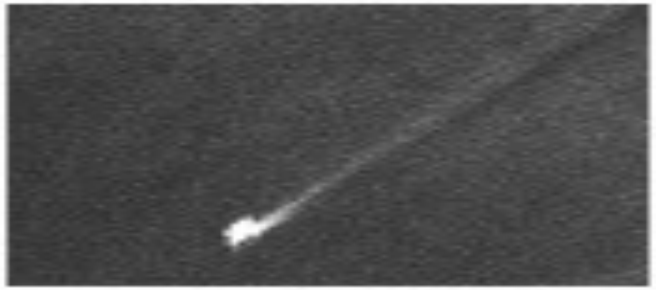
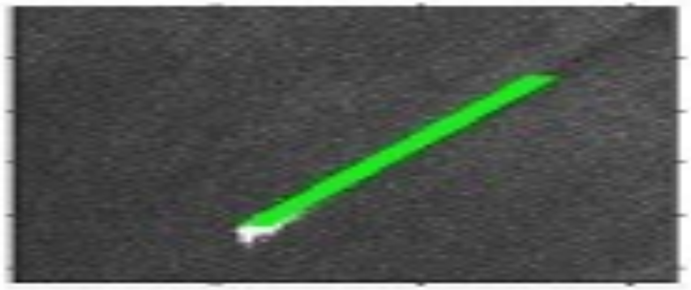
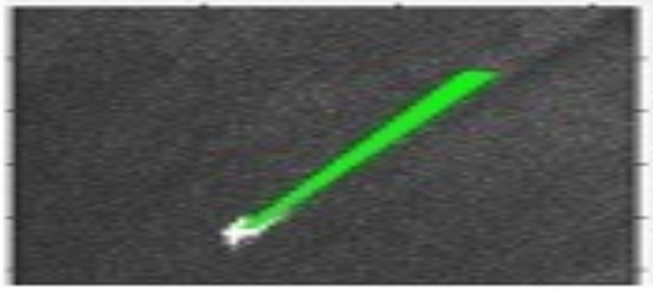


Optimal Wake Detection



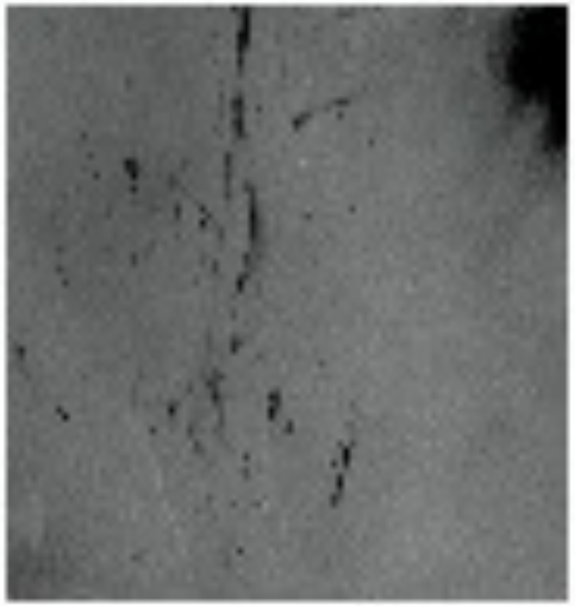
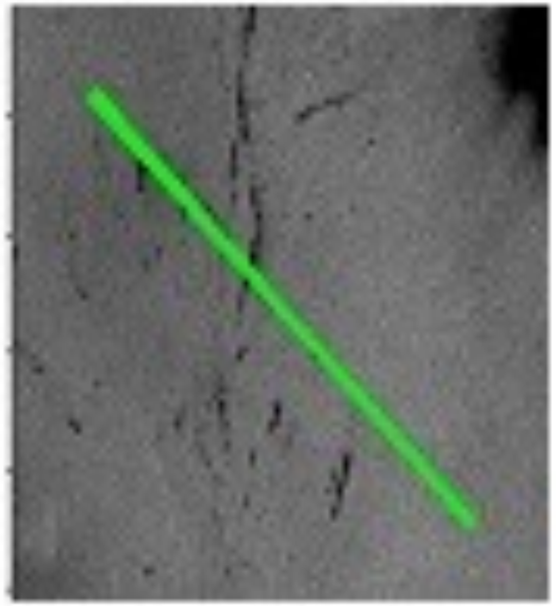
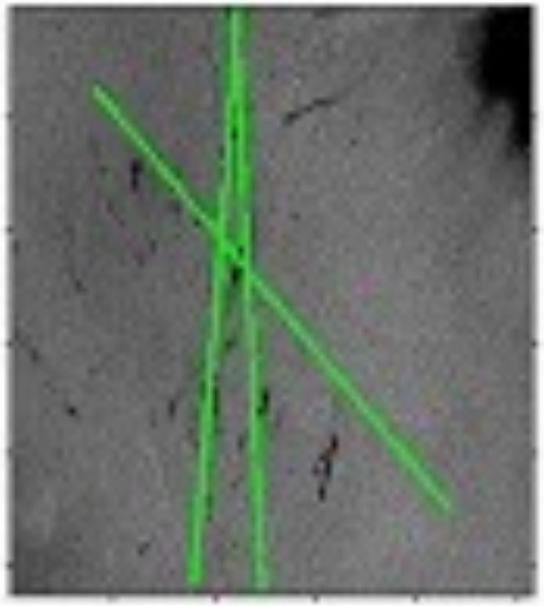
VISUAL ASSESMENT FOR WAKE DETECTION METHOD

Training Dataset –Single Target

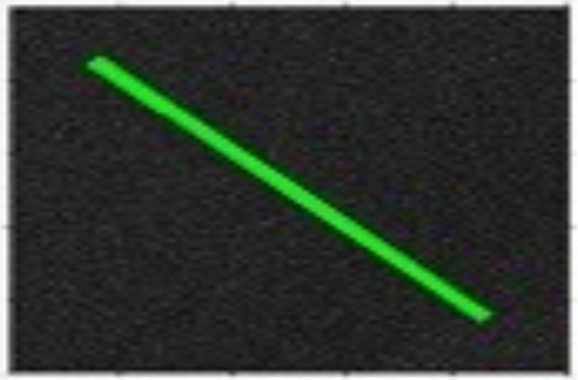
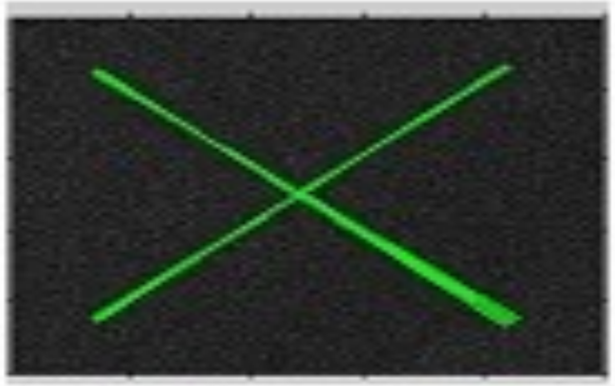
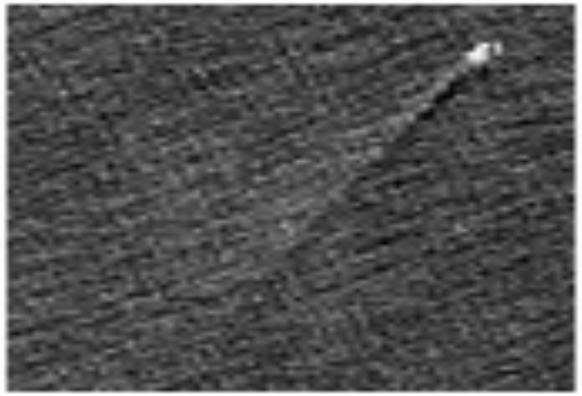
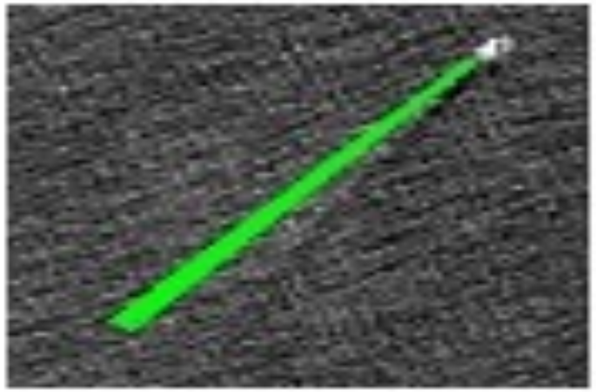
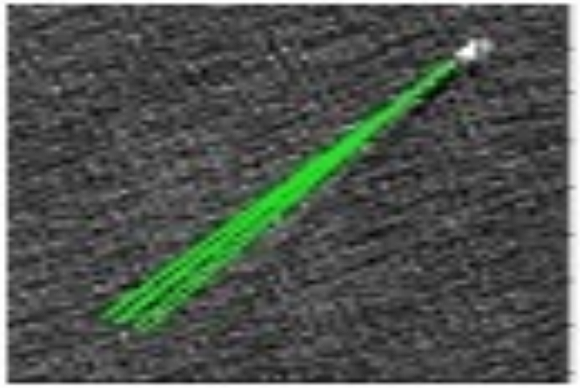
Image to Detect Wake	Detected Wake – Conventional Radon Transform	Detected Wake – Optimized Radon Transform
		
		
		

VISUAL ASSESMENT FOR WAKE DETECTION METHOD

Training Dataset –Multiple Target

Image to Detect Wake	Detected Wake – Conventional Radon Transform	Detected Wake – Optimized Radon Transform
		

Testing Dataset-Single target

Image to Detect Wake	Detected Wake – Conventional Radon Transform	Detected Wake – Optimized Radon Transform
		
		

VISUAL ASSESMENT FOR WAKE DETECTION METHOD

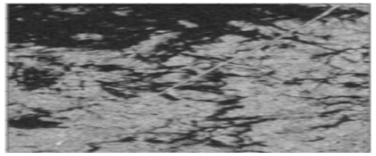
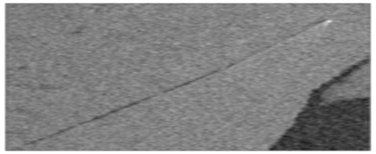
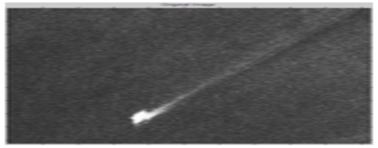
Testing Dataset-Multiple target

Image to Detect Wake	Detected Wake – Conventional Radon Transform	Detected Wake – Optimized Radon Transform
		

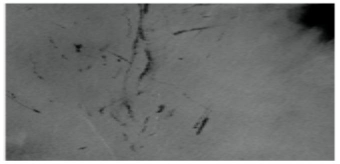
SUBJECTIVE ASSESSMENT

contd....

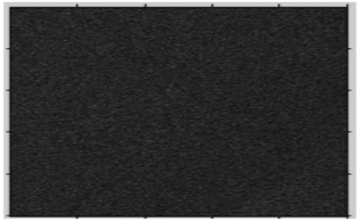
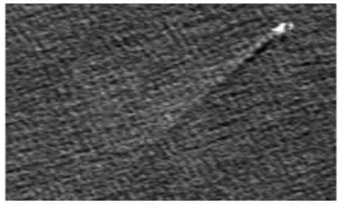
Assessment of wake detection algorithms (0°-179°) – Training dataset (single target)

Input image	Visual observation	Linear feature identified		Misidentified linear feature		False alarm rate	
		Conventional Radon Transform (RT)	Optimized Radon Transform (ORT)	Conventional Radon Transform (RT)	Optimized Radon Transform (ORT)	Conventional Radon Transform (RT)	Optimized Radon Transform (ORT)
	1	1	1	0	0	0	0
	1	1	1	0	0	0	0
	1	1	1	0	0	0	0

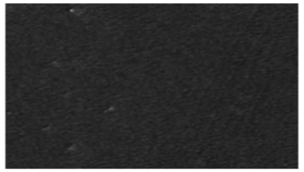
Assessment of wake detection algorithms (0°-179°) – Training dataset (multiple targets)

Input image	Visual observation	Linear feature identified		Misidentified linear feature		False alarm rate	
		Conventional Radon Transform (RT)	Optimized Radon Transform (ORT)	Conventional Radon Transform (RT)	Optimized Radon Transform (ORT)	Conventional Radon Transform (RT)	Optimized Radon Transform (ORT)
	14	1	5	13	9	0	0

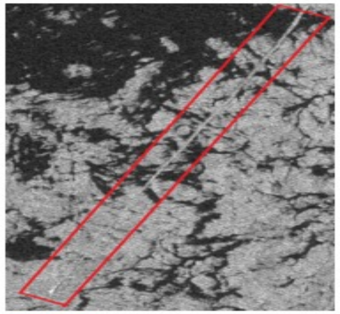
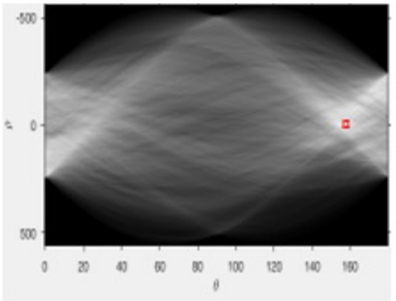
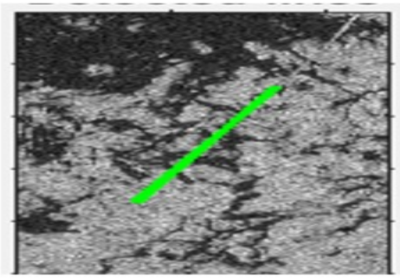
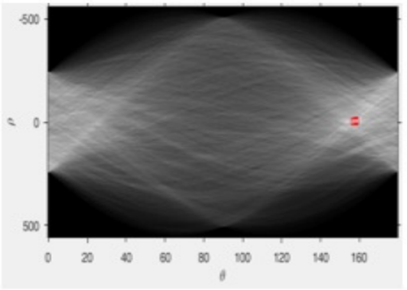
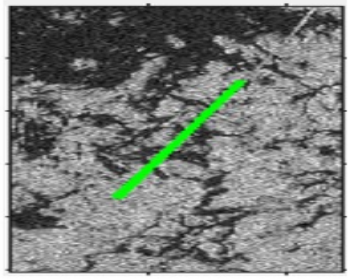
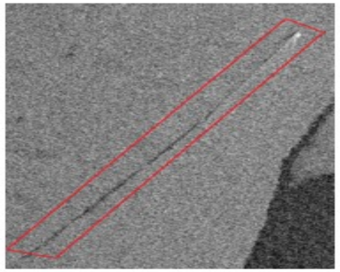
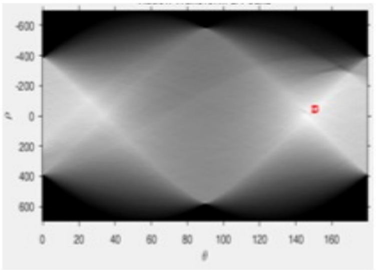
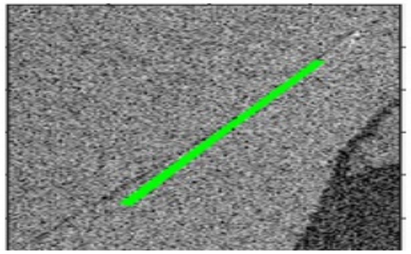
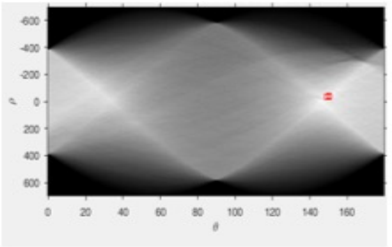
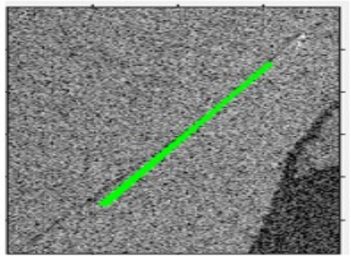
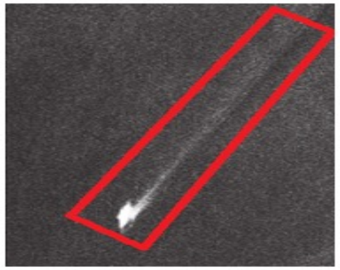
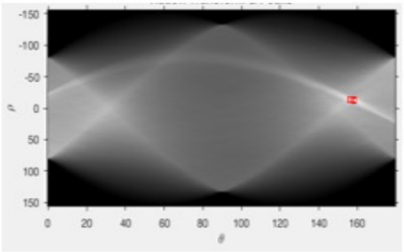
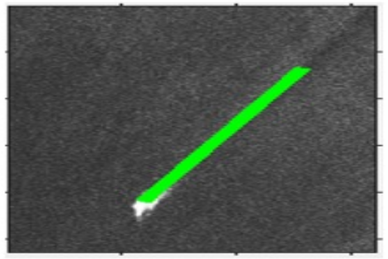
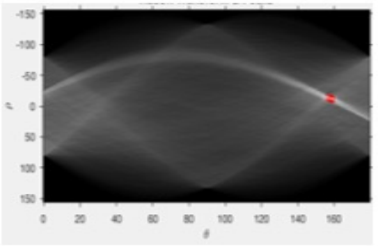
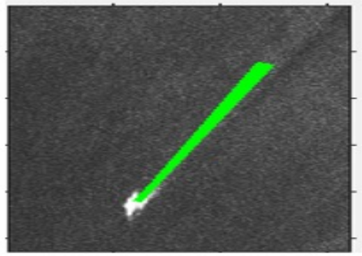
Assessment of wake detection algorithms (0°-179°) – Testing dataset (single target)

Input image	Visual observation	Linear feature identified		Misidentified linear feature		False alarm rate	
		Conventional Radon Transform (RT)	Optimized Radon Transform (ORT)	Conventional Radon Transform (RT)	Optimized Radon Transform (ORT)	Conventional Radon Transform (RT)	Optimized Radon Transform (ORT)
	2 (1 wake + 1 oil slick)	1	2	1	0	0	0
	1	1	1	0	0	0	0

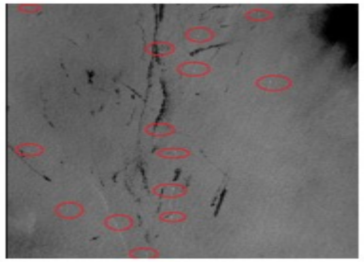
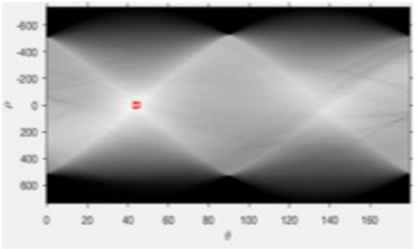
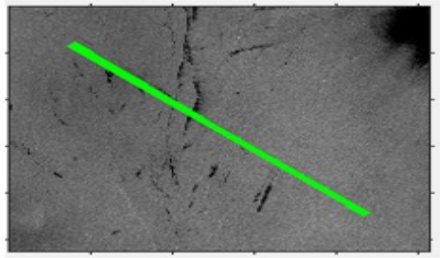
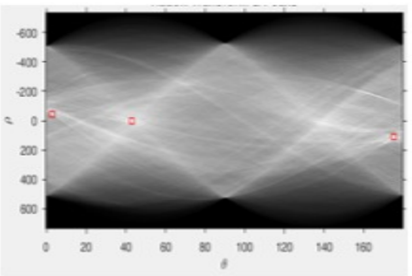
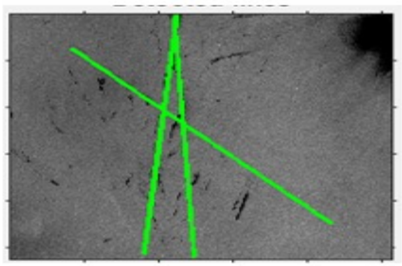
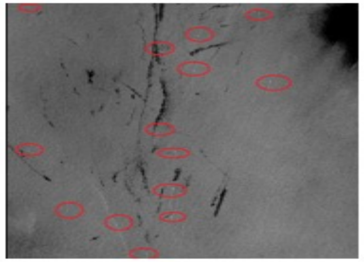
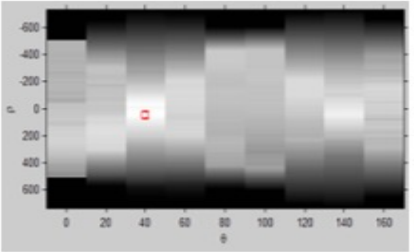
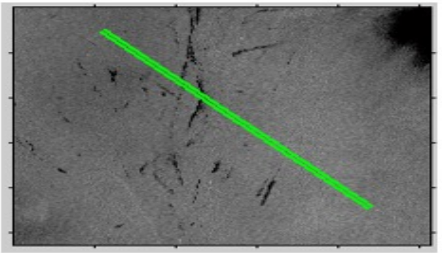
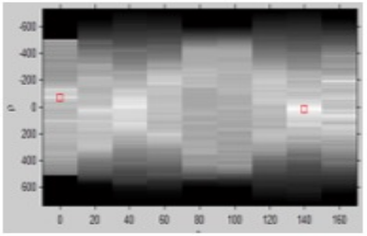
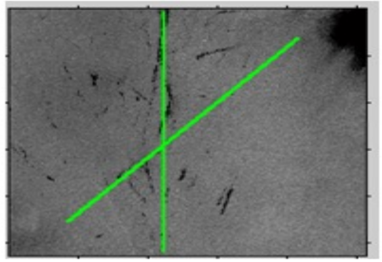
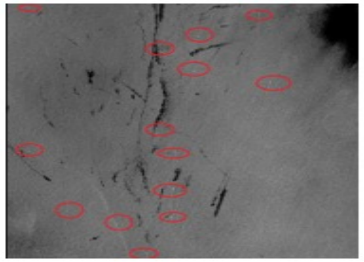
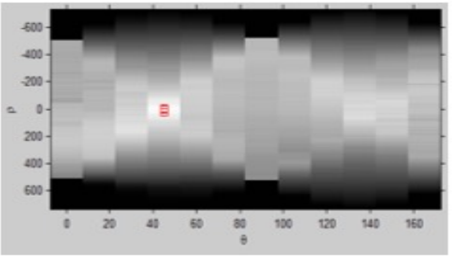
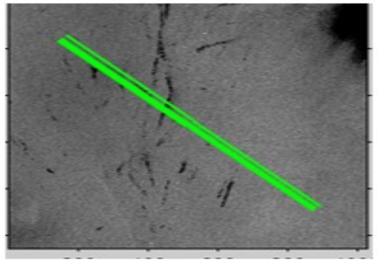
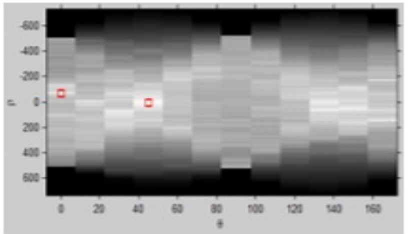
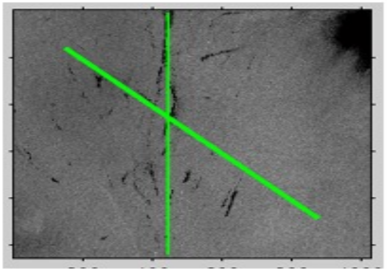
Assessment of wake detection algorithms (0°-179°) – Testing dataset (multiple target)

Input image	Visual observation	Linear feature identified		Misidentified linear feature		False alarm rate	
		Conventional Radon Transform (RT)	Optimized Radon Transform (ORT)	Conventional Radon Transform (RT)	Optimized Radon Transform (ORT)	Conventional Radon Transform (RT)	Optimized Radon Transform (ORT)
	6 (3 wakes + 3 oil clutter)	1	3	5	3	0	0

INVESTIGATION ON TRAINING DATASET WITH SINGLE TARGET

Image to Detect Wake	Conventional Radon Transform	Detected Wake – Conventional Radon Transform	Optimized Radon Transform	Detected Wake – Optimized Radon Transform
				
				
				

INVESTIGATION ON TRAINING DATASET WITH MULTIPLE TARGETS

Image to Detect Wake	Conventional Radon Transform	Detected Wake – Conventional Radon Transform	Optimized Radon Transform	Detected Wake – Optimized Radon Transform
				
				
				

INFERENCES FROM THE RESULTS –TRAINING DATASET

From the observation of experimental results, it is inferred that, linear signature is identified by both conventional RT and optimized RT methods for single target.

A visual assessment of SAR image with multiple target training dataset , it is identified that, there are large number of ships visible as bright spots followed by wakes. Moreover, it shows the numerous dark patches which results from oil discharged from ships.

Optimized RT is able to detect number of linear features with respect to different coordinates or offset value given in the projection angle.

INVESTIGATION ON TESTING DATASET WITH SINGLE /MULTIPLE TARGETS

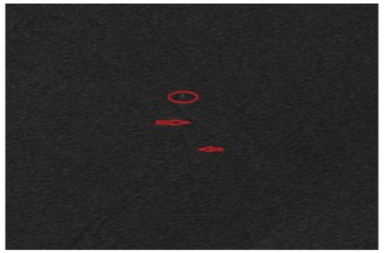
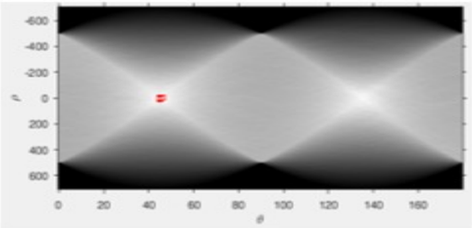
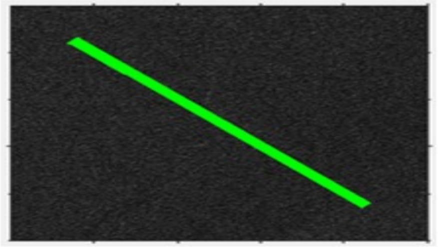
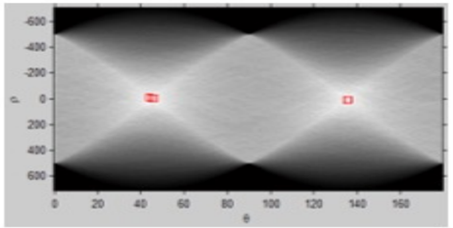
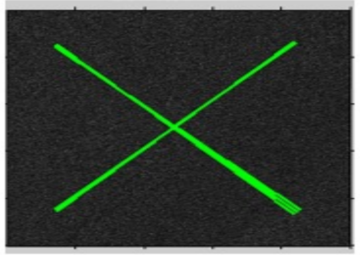
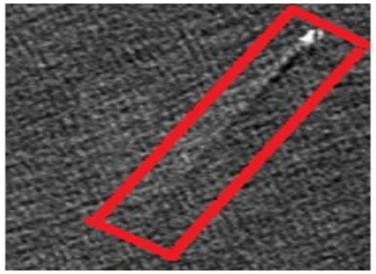
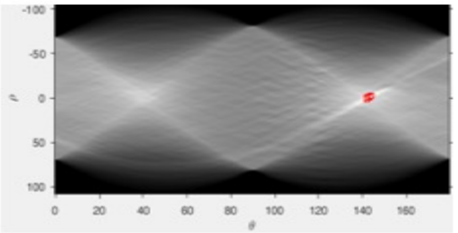
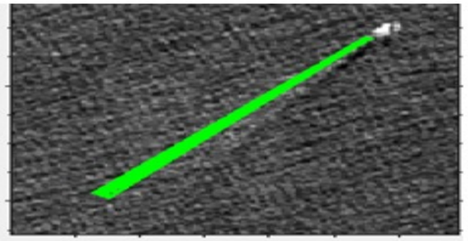
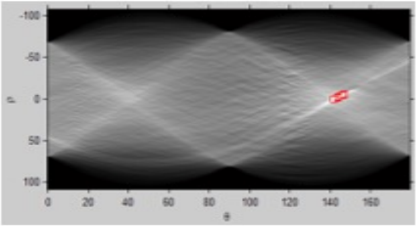
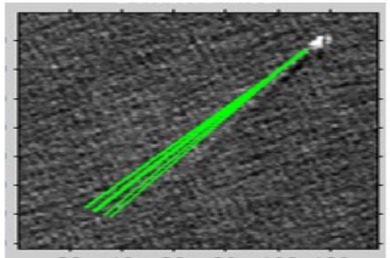
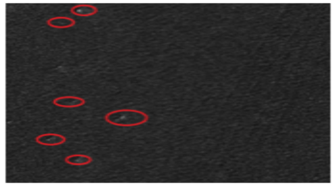
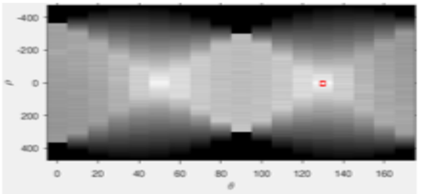
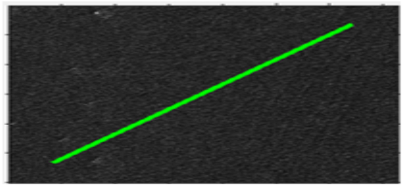
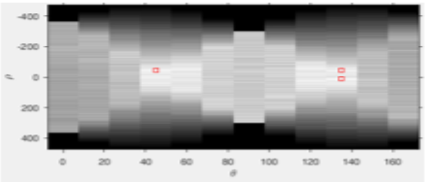
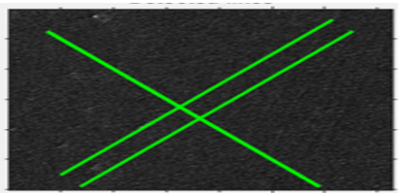
Image to Detect Wake	Conventional Radon Transform	Detected Wake – Conventional Radon Transform	Optimized Radon Transform	Detected Wake – Optimized Radon Transform
				
				

Image to Detect Wake	Conventional Radon Transform	Detected Wake – Conventional Radon Transform	Optimized Radon Transform	Detected Wake – Optimized Radon Transform
				

INFERENCES FROM THE RESULTS –TESTING DATASET

1. Based on the visual inception of first image of the testing dataset with single target, it is assumed that, SAR image shows a single ship wake and oil clutter or oil slick discharged by ship present in it.

- From the observation of experimental results, it is inferred that, wake is identified by both conventional RT and optimized RT methods, whereas Optimized RT is able to detect extra linear features present in SAR images and it gives better results than conventional RT method.

2. A visual analysis on the second image of the testing dataset with single target, it is assumed that, SAR image shows a kelvin wake present in it.

- It is indicated that, a linear signature or single streak is identified by conventional RT method whereas optimized RT method is able to detect two wake lines in form of kelvin pattern with the source of the wake at the vertex of the V.

3. From the visual insight information third image of the testing dataset with multiple targets, it is assumed that, SAR image shows three wakes and three oil clutter present in it.

- Conventional RT method is able to detect single linear signature whereas three linear features are identified by Optimized RT method.

CONCLUSION

- An optimized denoising algorithm is developed to substantiate the preprocessing phase
- An optimized wake detection algorithm is developed for SAR images under rough sea condition
- The efficiency of the proposed algorithm is validated with the ground truth SAR imagery taken from ESA sentinel Copernicus database and the improvement of the algorithm is measured using standard performance metrics.
- An important property of the proposed method is its reliability, simplicity and low computational cost

THANK YOU