ICTC 2025

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WAVE DIRECTION ESTIMATION FROM OPTICAL SATELLITE IMAGERY USING MULTI-STAGE GABOR FILTER

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presented by Surasak Boonkla

ASEAN IVO · NECTEC · BUU IF · Burapha University · CADT · itenas · Universiti Teknologi Malaysia · Thammasat University · SIIT SINCE 1992

INTRODUCTION

The impacts of coastal erosion

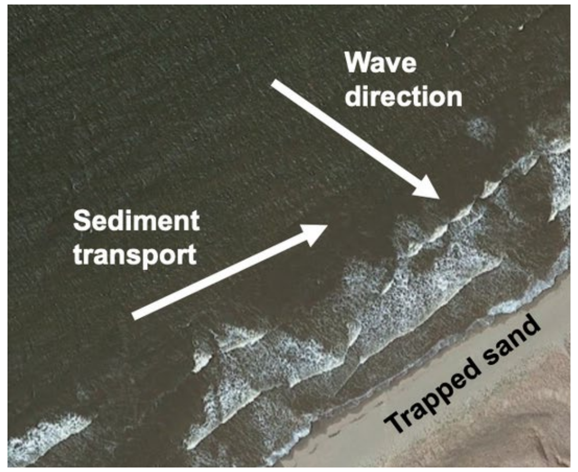
- Local Economics
- Communication
- Infrastructure
- Tourism industries
- Coastal agriculture
- Public safety

groin

breakwater

Key factors influencing coastal erosion include

- Wave height
- Wave velocity
- Wave direction
- Coastal geomorphology
- Wind patterns and sediment supply.



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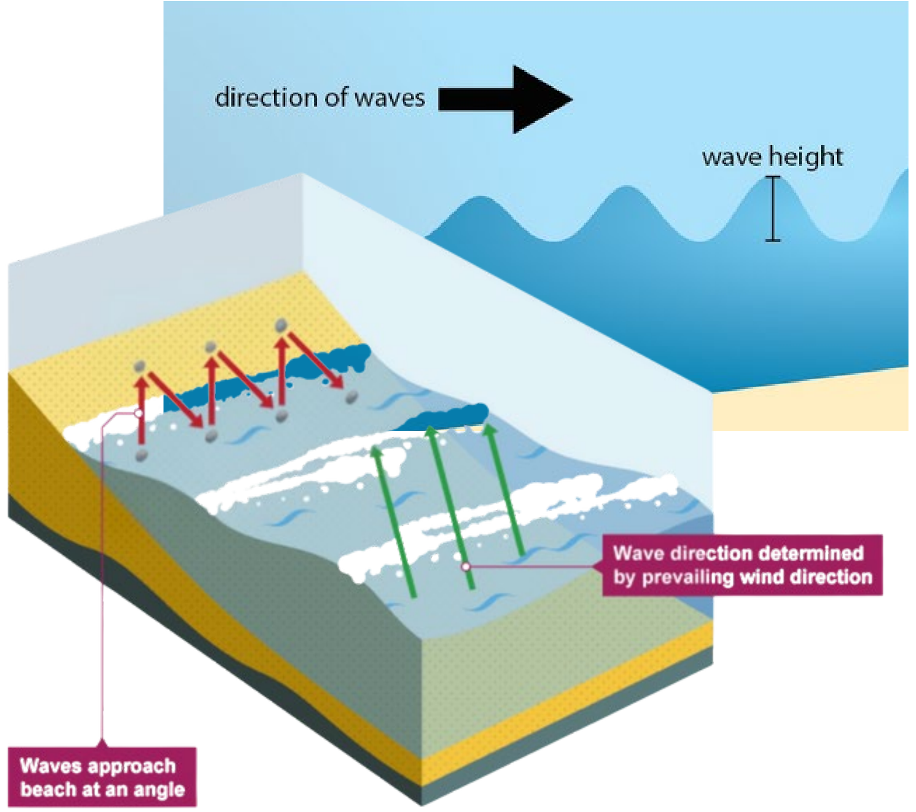
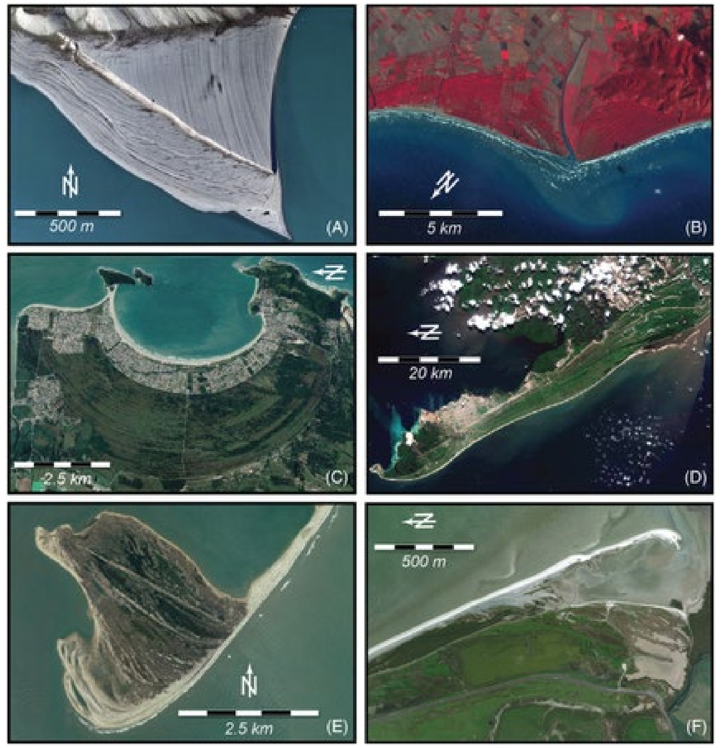




INTRODUCTION

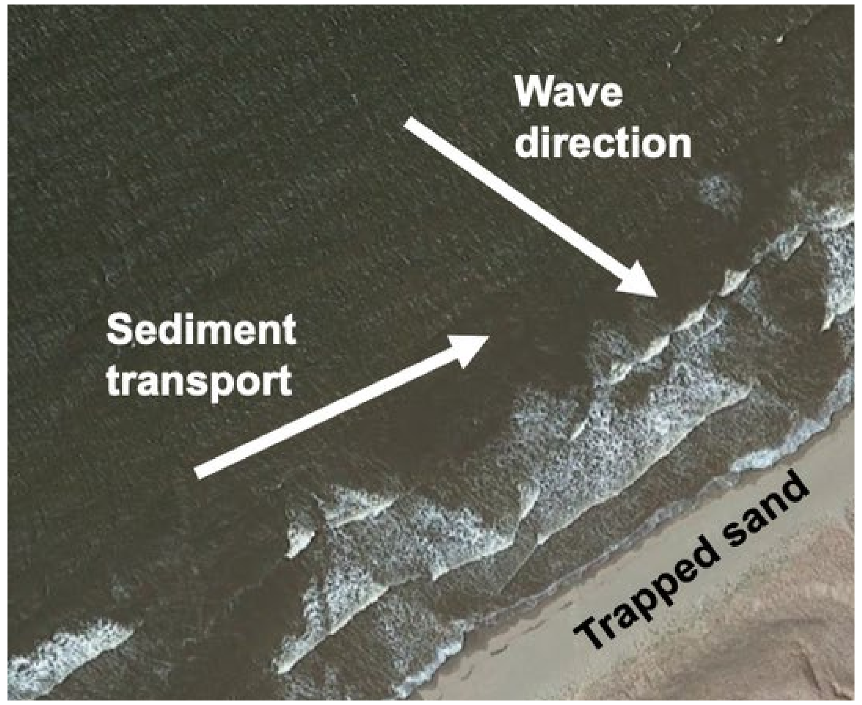
Why is wave direction a key factor?

Wave direction is a primary drivers of sediment transport and shoreline changes.

Wave direction → Shoreline sediment transport patterns —Serve as→

Mechanism for
- coastal , beach , shoreline morphological
- shoreline distribute patterns and stability

longshore current and longshore drift



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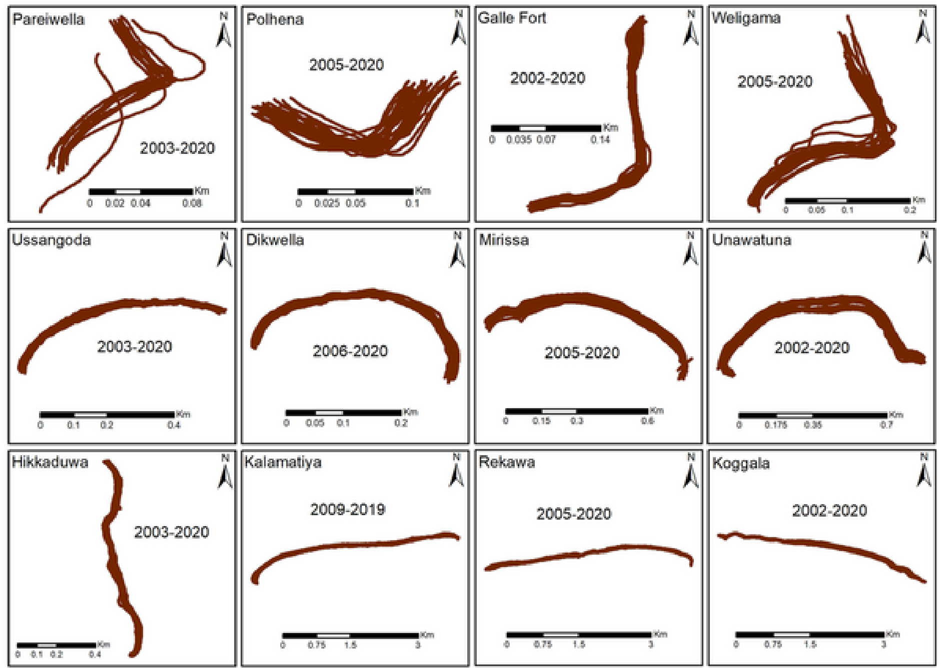

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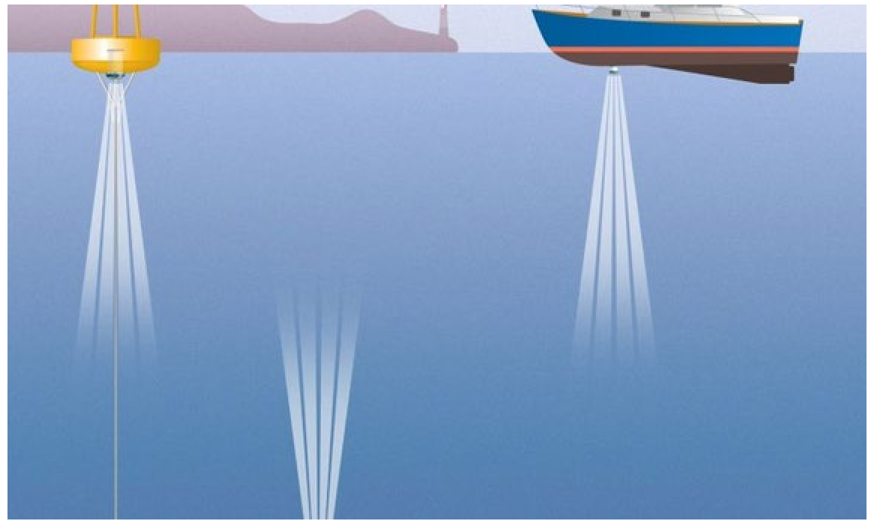
INTRODUCTION

How estimate wave direction?

Direct

Mooring
buoy



Acoustic Doppler
Current Profilers
(ADCPs)

Limitations :

- High cost
- Limited Coverage

Indirect

Radar or Drones

Satellite imagery

Advantage :

- Large - Scale Coverage : allows for the analysis of large coastal areas, overcoming the spatial limitations of direct measurement

INTRODUCTION

Satellite imagery has been used in Thailand to analyze coastal changes and morphology.

Paper	study field
Shoreline Changes from Erosion and Sea Level Rise with Coastal Management in Phuket, Thailand	Analyze shoreline position from satellite images
Coastal dynamism in Southern Thailand: An application of the CoastSat toolkit	Extract coastline locations from satellite images
Application of Sentinel-2 Imageries for Study Seagrass Beds	Use satellite imagery to classify and map seagrass distribution

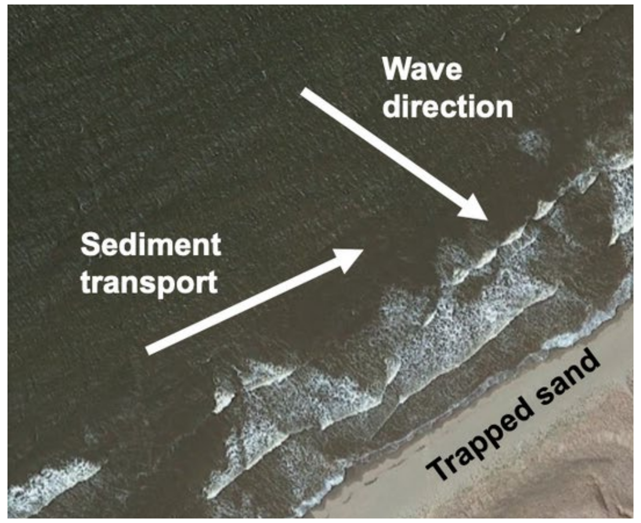
None of those studies can estimate wave direction directly from satellite images.

Therefore, our research proposes a methodology to directly estimate wave direction from satellite imagery, thereby filling a critical gap in current Thai coastal erosion studies.

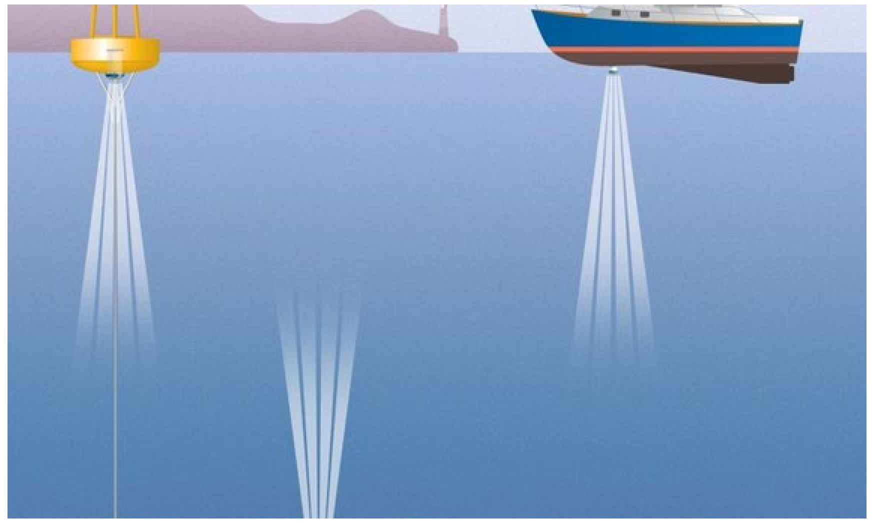
PROBLEM STATEMENT & OBJECTIVE

Severe coastal erosion

Wave direction is a key factor



Limitations of direct measure

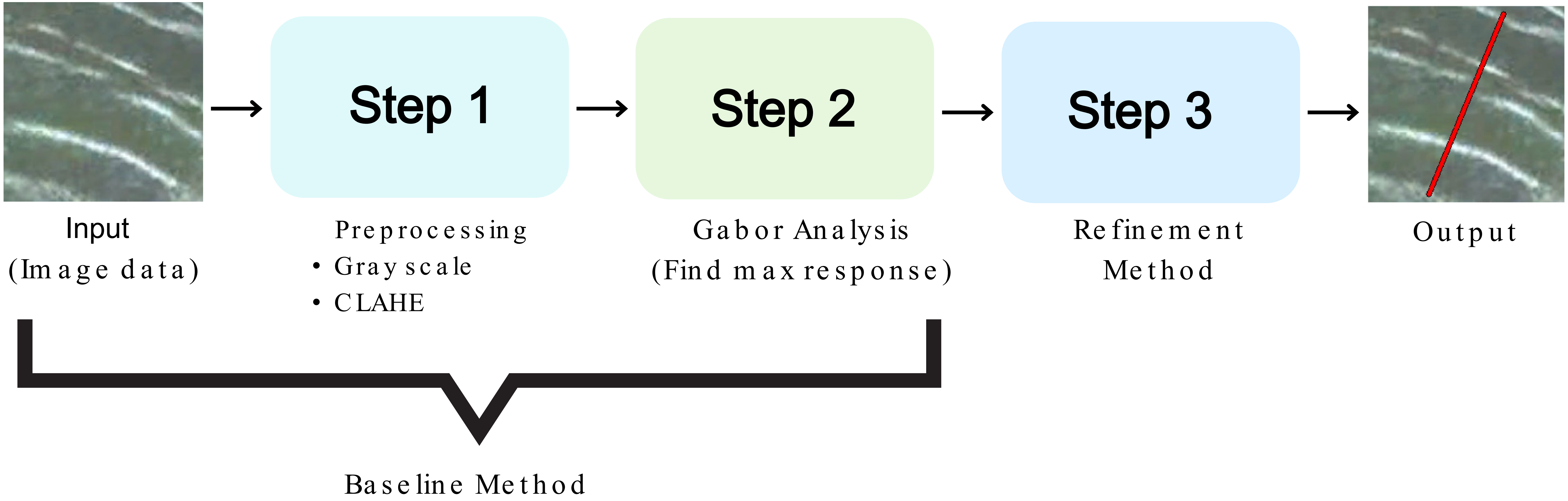


A gap in current research

Objectives

- To propose a method for estimating wave direction from satellite images using Gabor filter analysis.
- To investigate and compare three refinement strategies: baseline, two-stage refinement, and Interpolation refinement, to find the best balance practical performance.
- To assess the potential of the method as a cost-effective and scalable approach for contributing data to support coastal management efforts.

PROPOSED METHOD



CLAHE (Contrast Limited Adaptive Histogram Equalization)

PROPOSED METHOD

Input
(Image data)

→ **Step 1**

Preprocessing
- Gray scale
- CLAHE

→ **Step 2**

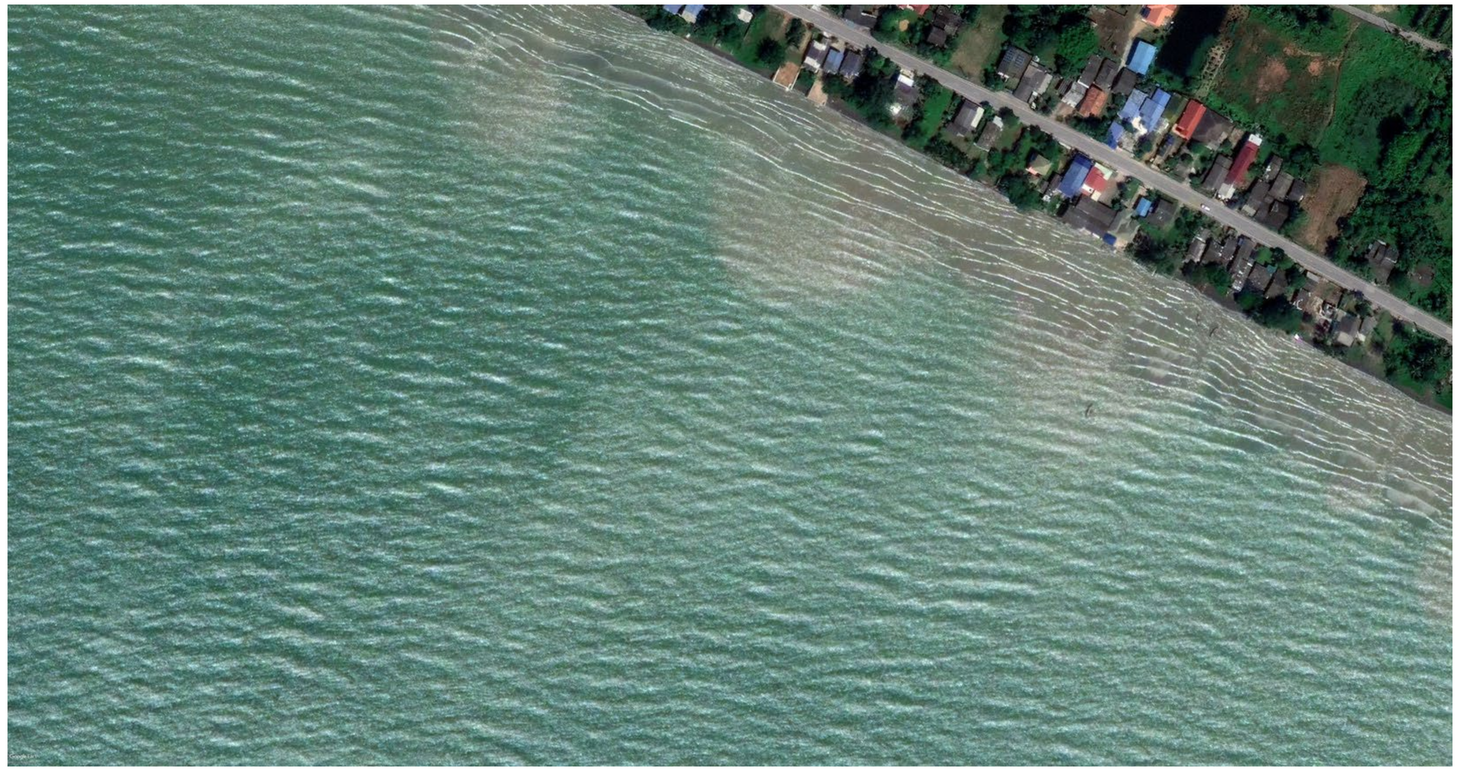
Gabor Analysis
(Find max response)

→ **Step 3**

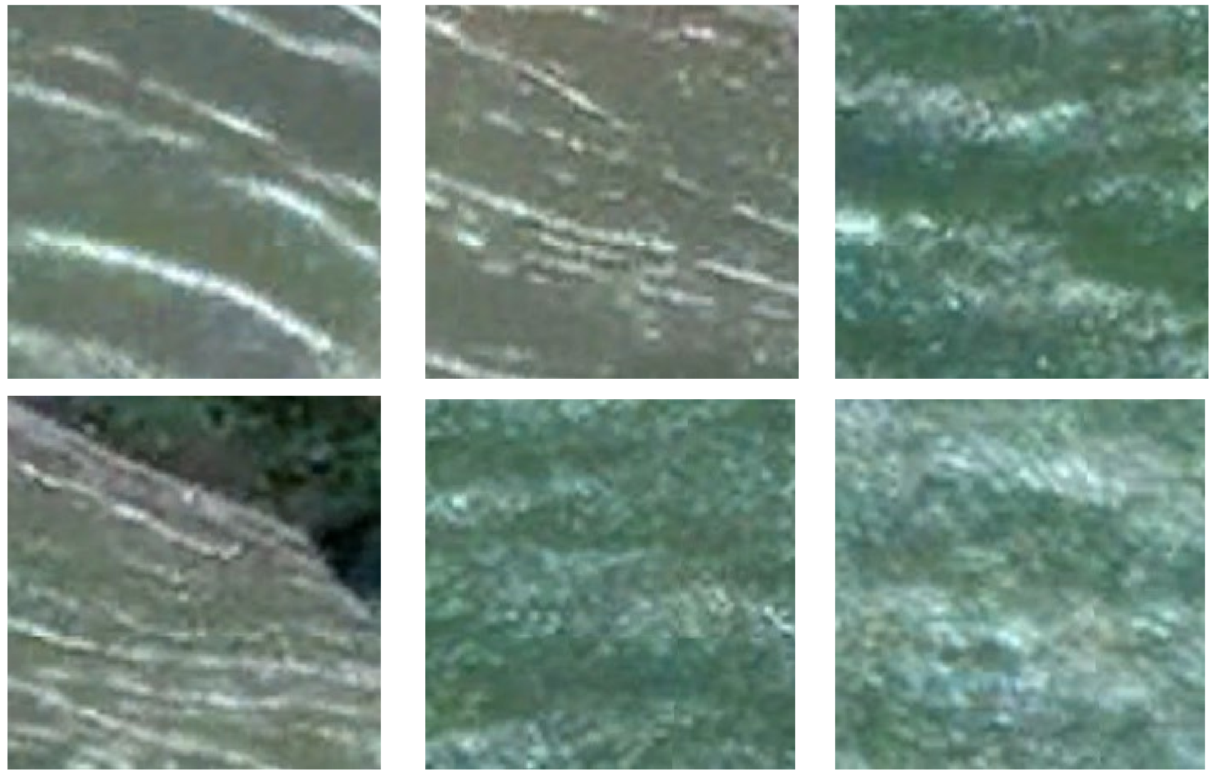
Refinement
Method

→ 

Output

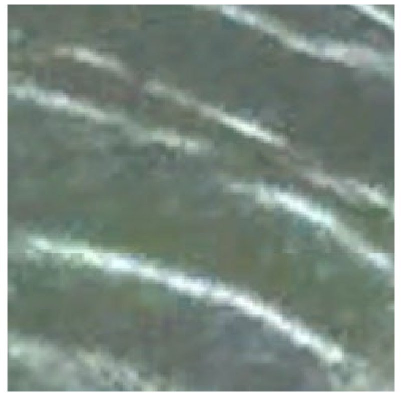


Segment →



Input
(Image data)

PROPOSED METHOD



Input
(Image data)

→ **Step 1** →

Preprocessing
- Gray scale
- CLAHE

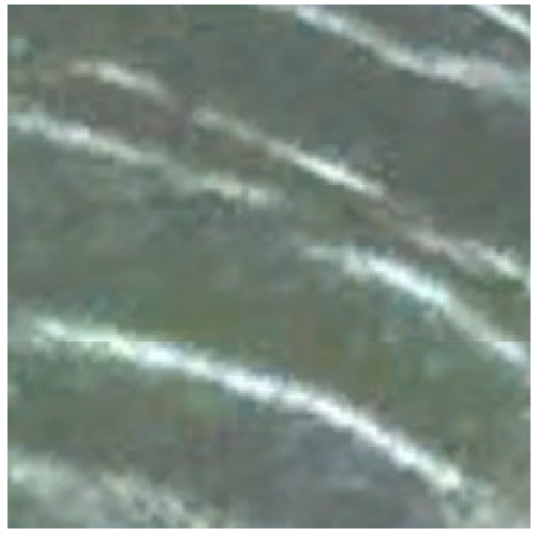
Step 2 →

Gabor Analysis
(Find max
response)

Step 3 →

Refinemen
t
Method

Output

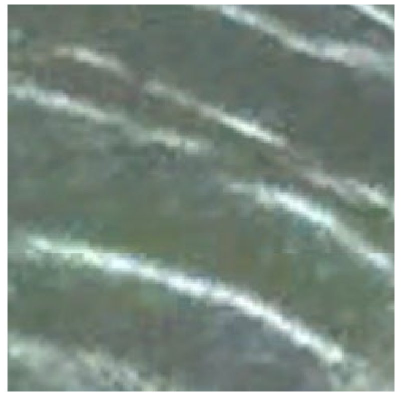


Input
(image data)

\+ **Step 1** =

Gray scale +
CLAHE

PROPOSED METHOD



Input
(Image data)

→ **Step 1** →

Preprocessing
- Gray scale
- CLAHE

Step 2 →

Gabor Analysis
(Find max response)

Step 3 →

Refinement
method

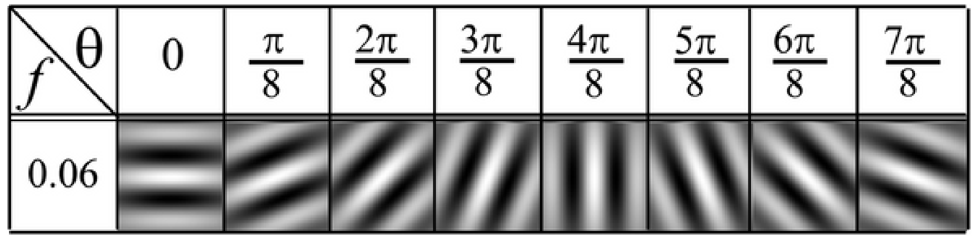
Output

$I(x,y)$

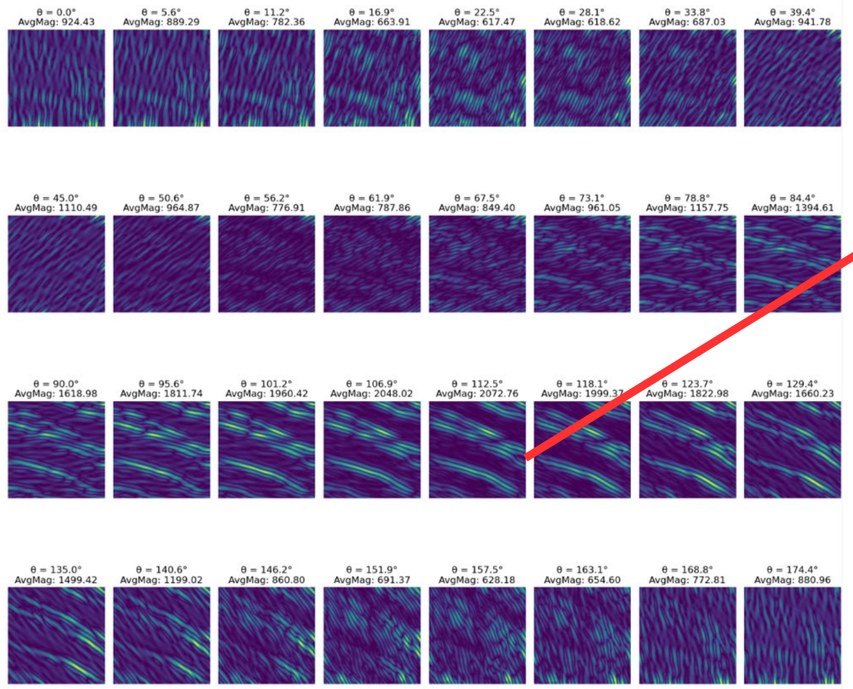
Gray scale +
CLAHE

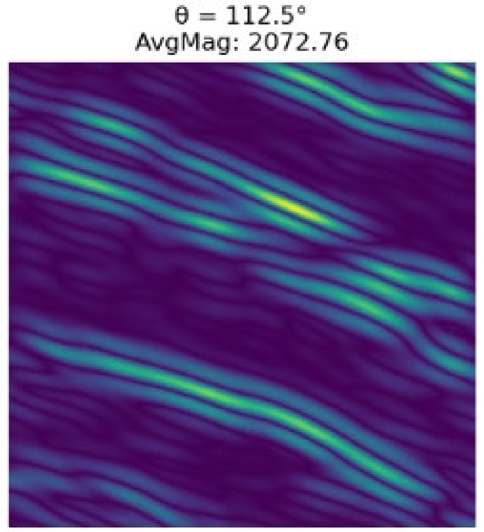
→ **Gabor filter** →

32 angles,
0 – 180 °



$g_k(x,y)$





$\hat{k} = \arg\max_k \bar{M}_k$

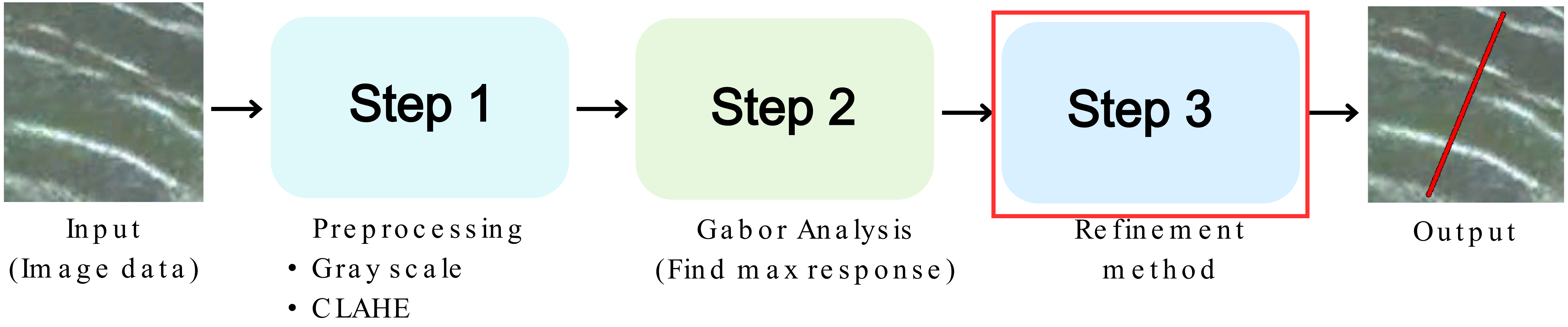
$$\bar{M}_k = \frac{1}{N}\sum_{x,y} |I(x,y) * g_k(x,y)|$$

mean response magnitude

Result of
baseline
method

$\theta_{\hat{k}}$, θ = 22.5

PROPOSED METHOD



Refinement methods:

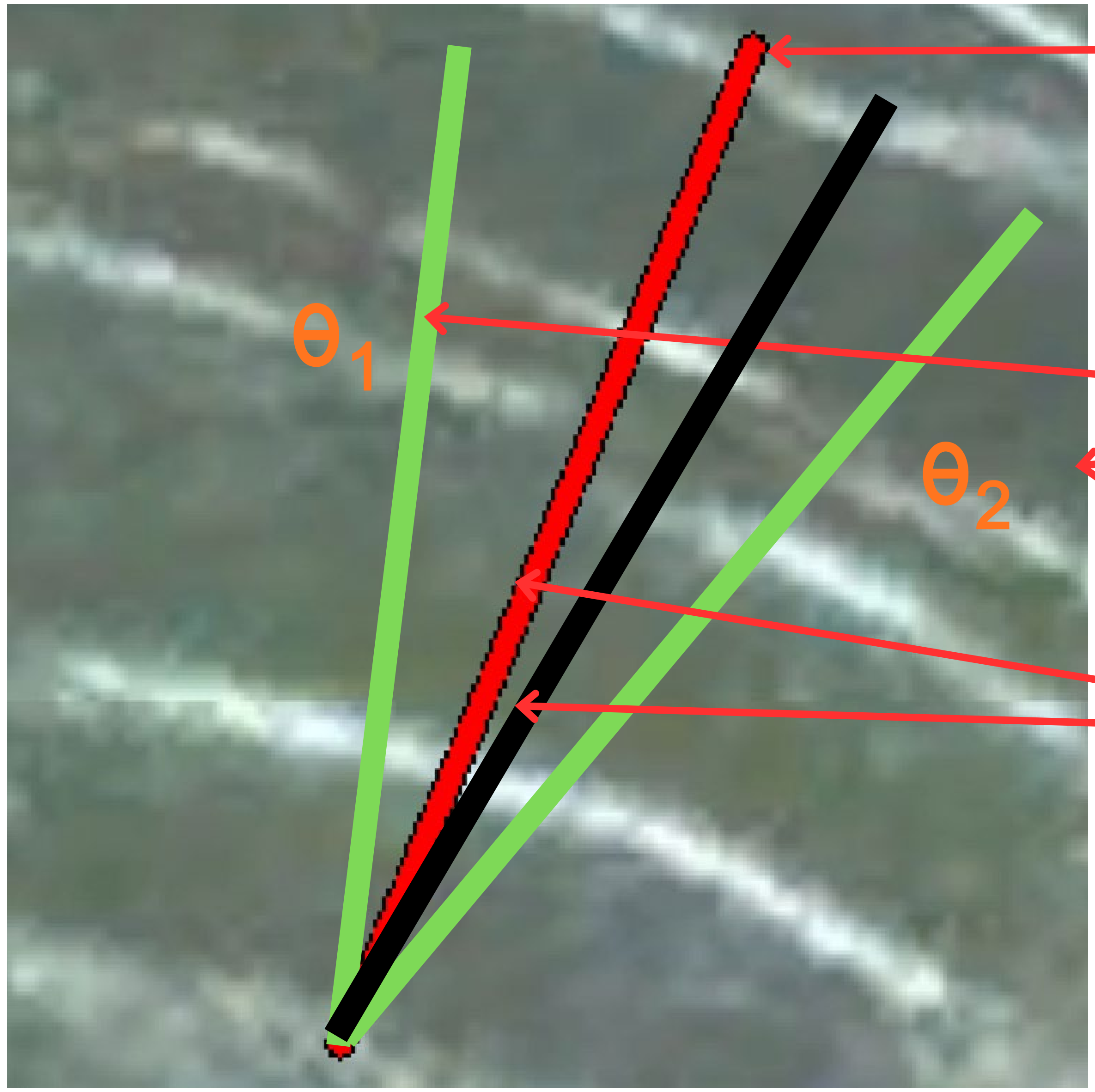
Two-Stage refinement: Uses a hierarchical "coarse-to-fine" search to improve precision.

Interpolation refinement: Uses mathematical estimation to find a more precise angle without running a second search.

PROPOSED METHOD

Step 3

Two - Stage Refinement



Baseline

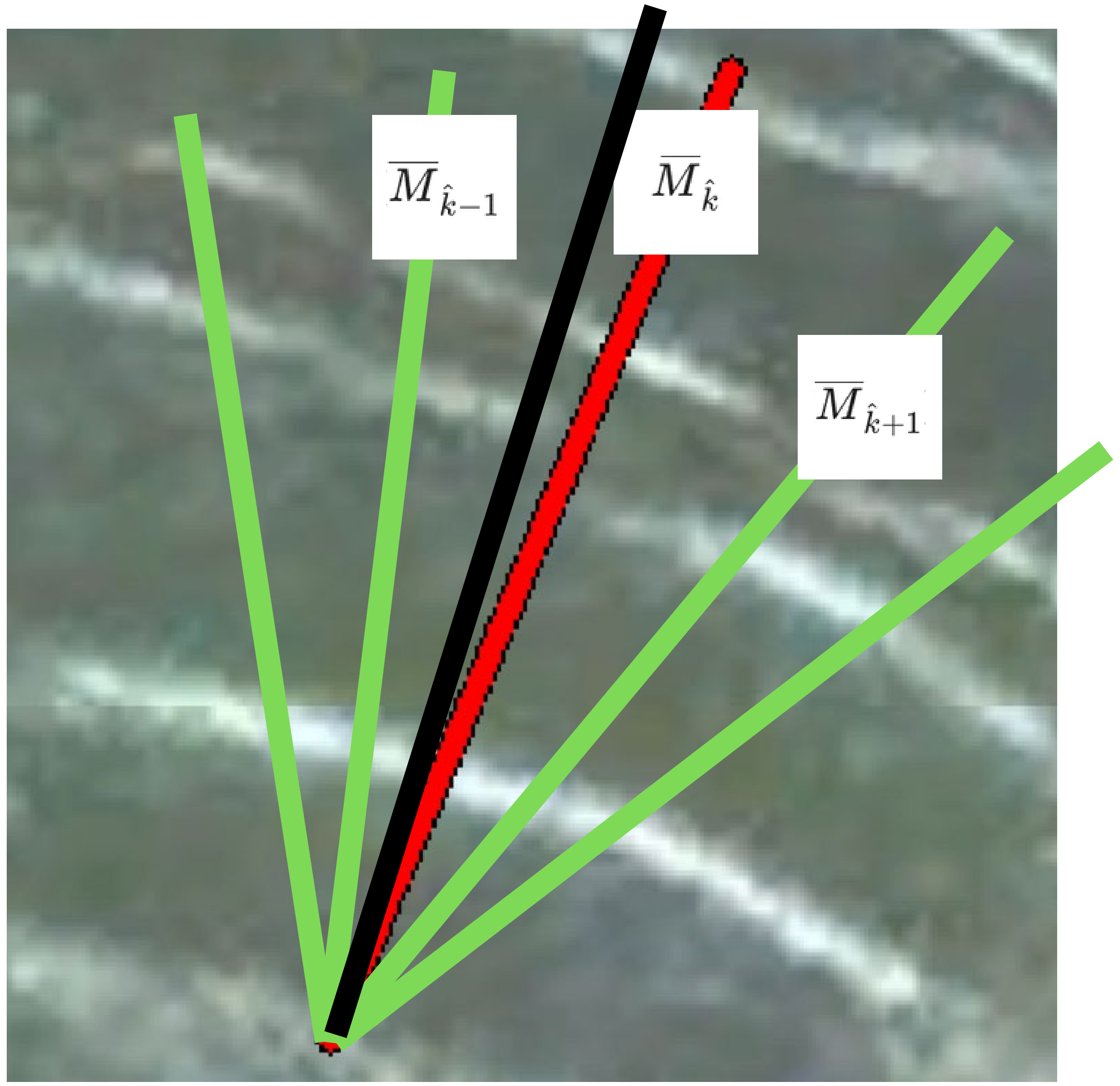
0 - 180 -> θ_1 - θ_2. Repeat the steps.

Compare result from baseline (red line) and after refinement **(black line)**

PROPOSED METHOD

Step 3

Interpolation Refinement

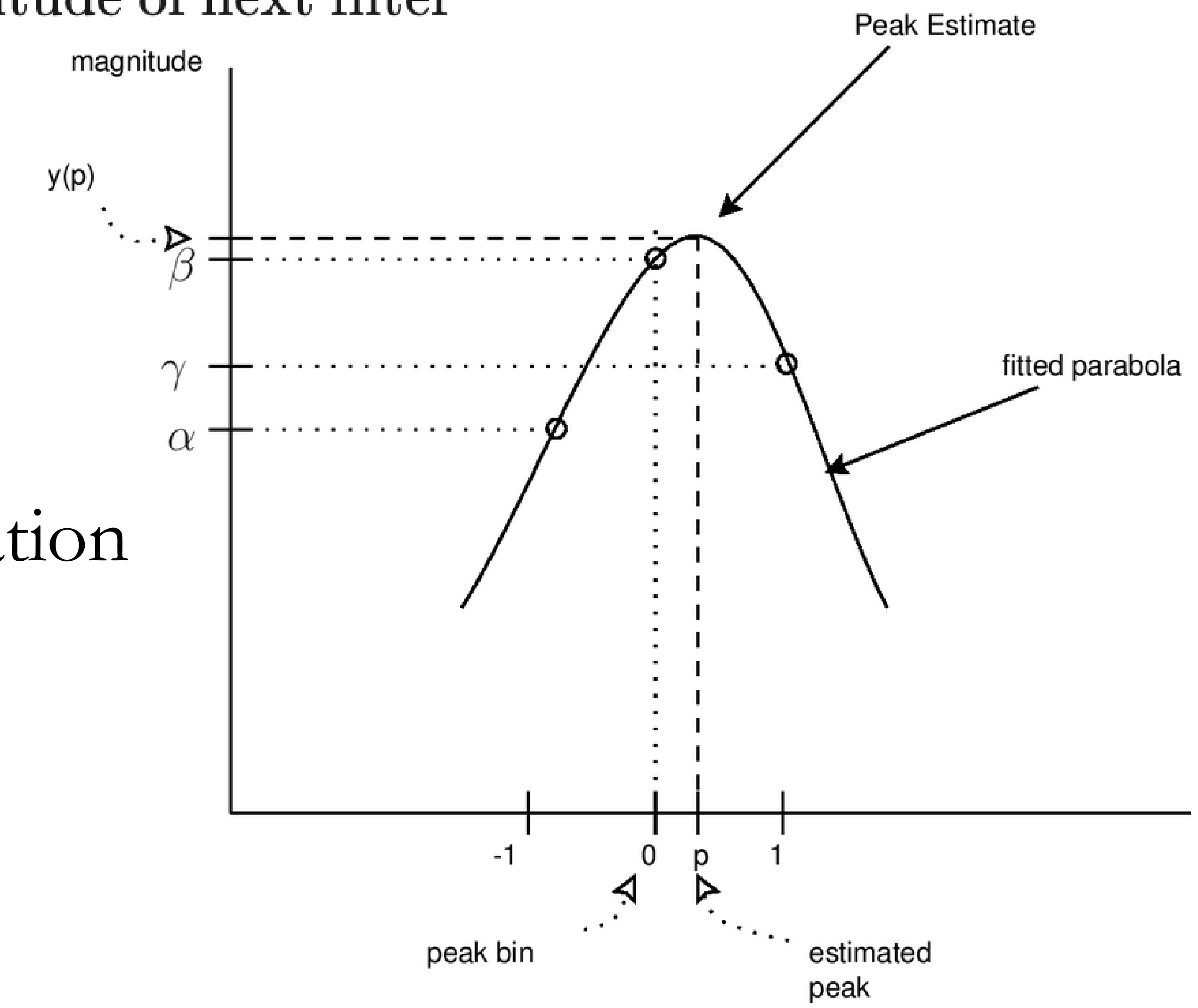


$\overline{M}_{\hat{k}}$ = max Average Response Magnitude → result from baseline method

$\overline{M}_{\hat{k}-1}$ = Average Response Magnitude of previous filter

$\overline{M}_{\hat{k}+1}$ = Average Response Magnitude of next filter

Parabolic interpolation



PROPOSED METHOD

Baseline
22.5°

Two-stage refinement
27.0°

Interpolation refinement
21.4°

DATASET PREPARATION

Method	Source	Image & Partitioning Details
Synthetic Grid Benchmark	Programmatically generated to simulate ideal wave patterns	• 1952x1952 px image • Partitioned into an 8x8 grid • Each cell is 244x244 px
Real-world Imagery	High-resolution satellite imagery from Google Earth Pro.	• Partitioned into 403 non-overlapping patches • Each patch is 244x244 px

DATASET PREPARATION

Ground truth : Real-world Imagery

GIMP

403 images

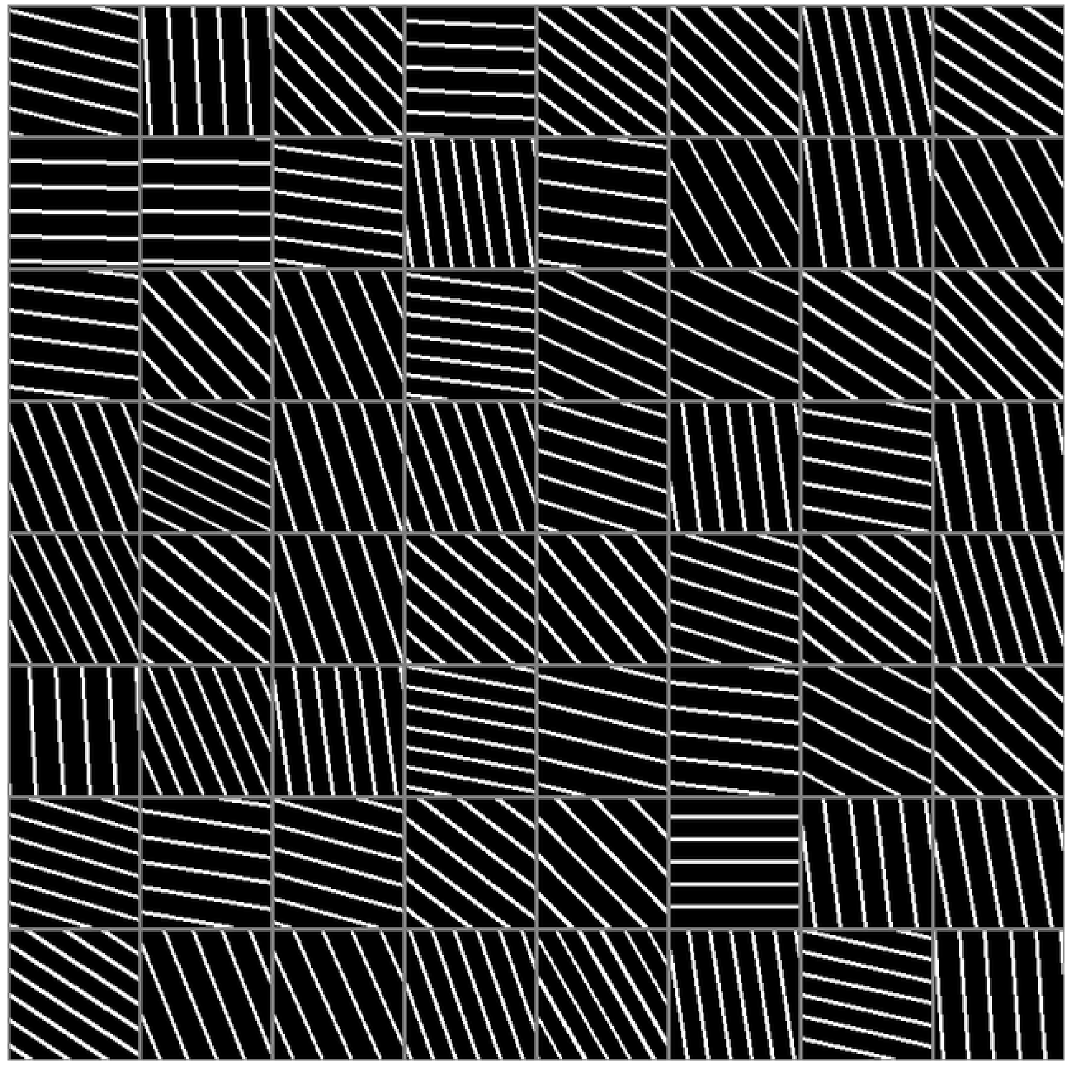
Angle compared with the vertical (y-axis)

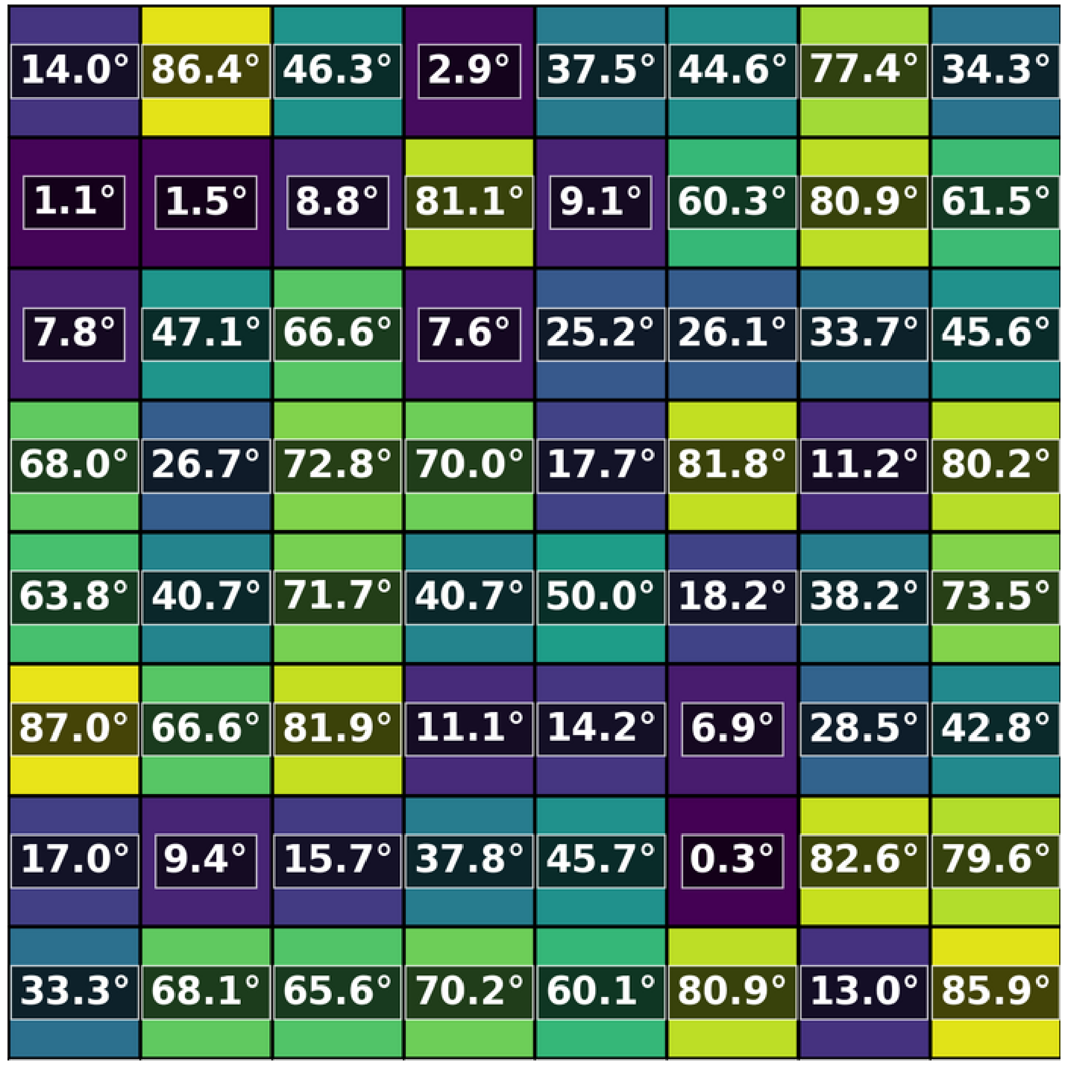
The ground truth was created by five volunteers, each measuring the angle twice and averaging the two results.

DATASET PREPARATION

Ground truth : Synthetic grid benchmark

Generate by code
total size of 1952 ×1952 pixels,
with each cell
sized 244 ×244 pixels.



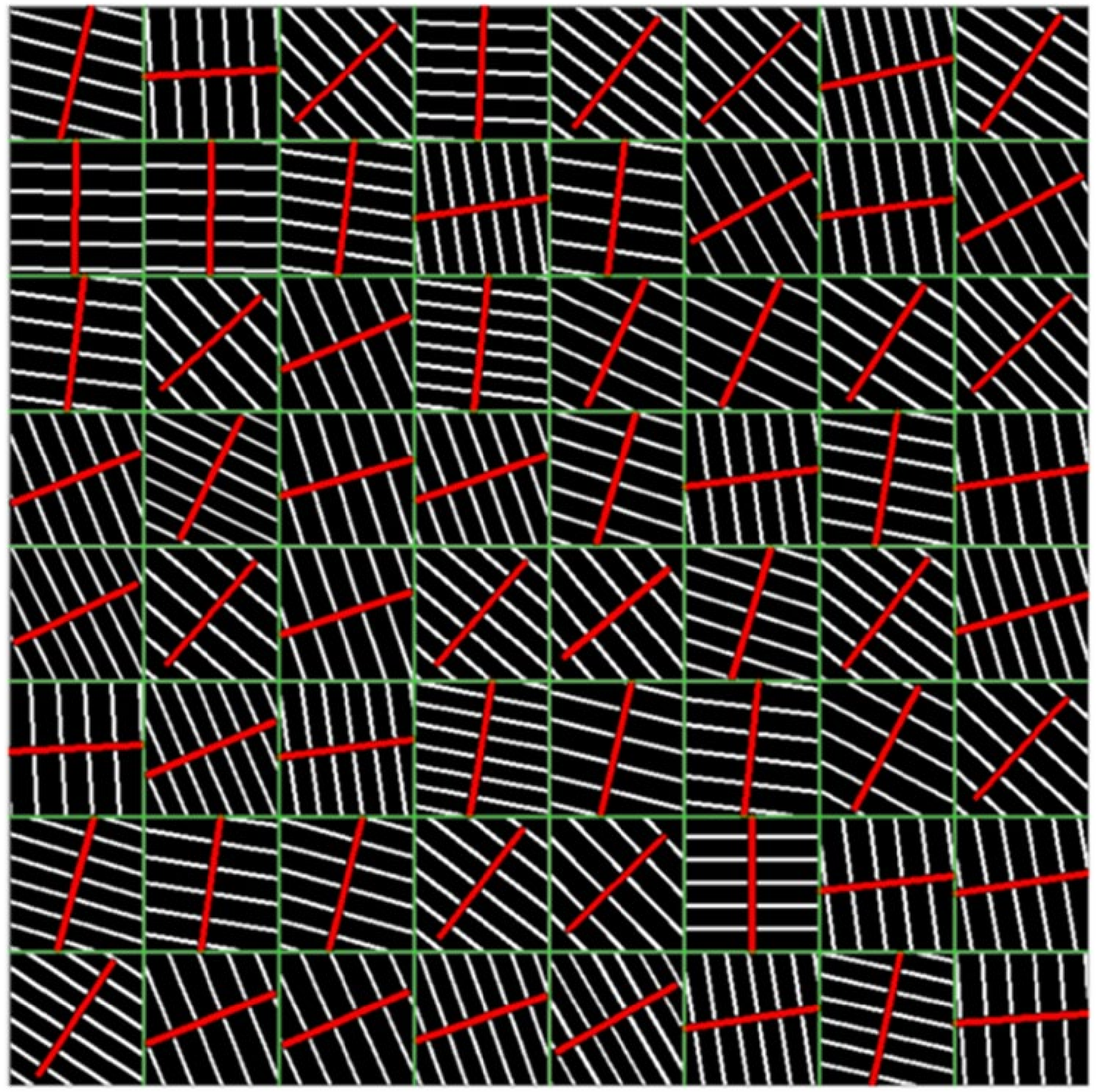


EVALUATION

EXCEPTIONAL PERFORMANCE IN IDEAL CONDITIONS.

Metrics MAE : Mean absolute error

$$\mathrm{MAE} = \frac{1}{N}\sum_{i=1}^{N} |y_i - \hat{y}_i|$$

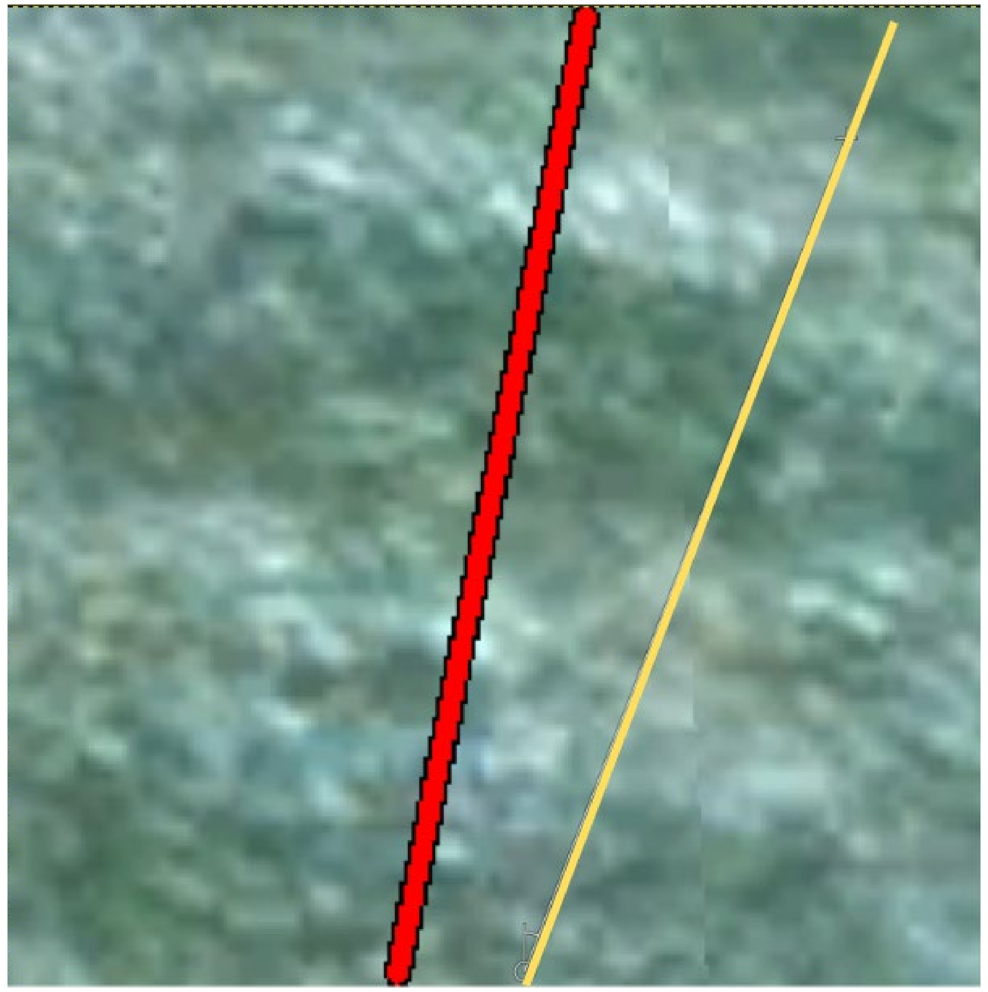


Method	MAE (°)
Baseline (no refinement)	1.453
Two -stage refinement	**0.234**
Interpolation refinement	0.432

EVALUATION

EXCEPTIONAL PERFORMANCE IN REAL -WORLD IMAGERY.

Metrics MAE : Mean absolute error, Within ±20 ° (%)



Method	MAE (°)	Within ±20 ° (%)
Baseline (no refinement)	13.23	79.65
Two-stage refinement	12.96	81.39
Interpolation refinement	**12.95**	**81.14**

The Interpolation refinement offer the best balance of accuracy and efficiently for practical use. (yellow line = ground truth , red line = predicted)

DISCUSSION

Practical Implications

This work enables automatic nearshore wave direction estimate from widely available satellite images. It provides a crucial, previously missing data layer, especially in this era of IoT and AI.

It is important for
- validating and calibrating sediment transport models,
- explaining observed patterns of erosion and accretion, and
- informing the design and placement of coastal protection structures.

Limitations

- Fixed Gabor filter parameters may not be optimal for all imagery.
- Performance can be affected by non-wave features (sun glint, ship wakes).

CONCLUSION

- This study presents an approach for estimating wave direction from satellite imagery using Gabor filters, with results indicating its potential for this application.

- The findings suggest that the Two-Stage refinement achieves the lowest error under synthetic conditions (MAE of 0.234°), while the Interpolation method offers an effective balance for practical, real-world applications (MAE of 12.95°).

- It is hoped that this work can contribute a practical and scalable method, providing valuable data to support future coastal erosion management and planning efforts.

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