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Visualization of Wave Energy Density Hotspots from EEZ Satellite Images

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***Abstract*—**The energy that may be obtained from the motion of ocean waves is referred to as wave energy in oceans. The collected energy is subsequently put to use for a variety of beneficial tasks, such as the production of electricity, water desalination, and pumping of water. SAR imagery provides information about what is on the ground, but distortions and speckle make these images very different from optical images. Identifying the wave energy density hotspots gives us an advantage of producing more energy with minimum number of wave energy harvesting plants. But nonetheless, it continues to be challenging to capture wave energy for both industrial and commercial usage because of the variability of its geographical and temporal changes. In this paper, SAR images of EEZ region wave data in Pacific Ocean region are taken and processed to visualize the wave power density hotspots. Image processing techniques like canny edge detection is used for edge detection, Fuzzy c means is used for segmentation, K-means clustering is used for clustering the density hotspots, layer masking are used in the process of find the locations of wave energy density hotspots. Then the images are resized into smaller images and the average wave energy density and the coordinates are found for each image. The proposed system is evaluated using performance metrics such as PSNR and MSE are calculated as 10.73 dB and 74.06 dB respectively which proved that the method is accurate and suitable for identifying the density hotspots from the satellite images.

Keywords*—Wave energy density, satellite images, EEZ region, Segmentation, Sentinel-1, Empirical algorithms*

I. INTRODUCTION

Currently, researchers from all over the world are looking at novel strategies for producing energy from renewable resources. This is due to the fact that producing energy using conventional methods—such as those found in thermal and nuclear power plants—has resulted in significant pollution and hazardous waste creation that has harmed the

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environment since the dawn of the industrial period. It is crucial that humanity uses renewable energy sources, such as wind, wave, and solar power, in order to prevent additional environmental harm.

One of the main challenges of using renewable energy sources is the high cost of constructing the power plants necessary to generate the energy. Additionally, these power plants must be constructed in specific locations in order to produce the highest possible output. For instance, to increase energy output from waves, power stations should be situated in locations with regular water movement.

Ocean surface waves carry and absorb energy, which produces wave energy, which is a form of renewable energy. This energy can be used for a variety of applications, which mainly includes generation of electricity. It's crucial to locate the ocean's wave energy density hotspots in order to exploit wave energy to its greatest capacity.. This information can be obtained from satellite images, which provide valuable insights into the spatial and temporal variations of wave energy density in different regions of the ocean.

However, the construction of power plants that use these renewable resources can be expensive. In order to have high output and make these power plants financially viable, they must be constructed in suitable locations. For example, to maximize generation wave energy, power plants should be located in areas where water movement is frequent in order to maximize energy production.

Scientists have created a system for identifying the waves in satellite photos in order to find these appropriate places for wave energy generation. It is feasible to find the regions where energy output can be maximized by locating wave energy density hotspots in the ocean. The hotspot localization technique groups the image's points into clusters to identify the wave's epicenter, which can be used to build wave energy collecting systems.

The use of satellite imagery to identify wave energy density hotspots has revolutionized the process of selecting locations for wave energy harvesting plants. The images offer important details regarding the temporal and geographical changes of wave energy density in various oceanic regions. This make it possible to identify the most promising locations for wave energy production, which can lead to significant improvements in the efficiency and profitability of renewable energy production.

Another benefit of using renewable energy sources like wave power is that they are sustainable. Unlike traditional energy sources like fossil fuels, which are finite and will eventually run out, renewable energy sources like wave power are virtually inexhaustible. This means that they can provide a long-term source of energy for future generations.

Solar, wind, and other renewable energy sources are essential for minimizing the damaging effects of conventional energy generation methods on the environment. The construction of

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power plants that use these renewable resources can be expensive, but the use of satellite imagery to identify wave energy density hotspots can help to pinpoint suitable locations for wave energy harvesting plants. This might totally change the renewable energy industry and boost the efficiency and profitability of wave energy production. Economically speaking, the development of renewable energy sources like wave power is crucial since it may increase employment possibilities and lessen reliance on imported energy.

1.1 Remote Sensing:

Remote sensing is a technique that involves examining the physical features of a region from afar by studying the radiation that is reflected or emitted, usually from aircraft or satellites. Remote sensing imagery, captured with specific cameras, is used by researchers to obtain a tactile understanding of the planet. This method is often used to recognize and classify objects on the planet using sensing systems that rely on aircraft or satellites.

1.2 K-Means Clustering:

K-Means The data clustering method known as clustering divides a data collection into N groups, with each data point in the dataset being somewhat related to each cluster. For example, a data point close to the cluster's centre will have a high degree of membership there, while a data point far from the cluster's centre would have a low degree of membership.

1.3 Synthetic Aperture Radar:

SAR, a radar technology, is capable of capturing objects in either two dimensions or rebuilding them in three dimensions, particularly landscapes. SAR offers higher spatial resolution compared to beam-scanning radars by moving the radar antenna across the target area. An imaging radar transmits an electromagnetic signal towards the surface to determine the amount of backscattering, bouncing, or echoing back, as well as the delay. The radar imaging is produced based on the intensity and time delay of the returned signal, which mainly depend on the roughness, electrical conductivity, and separation of the viewed surface from the orbiting radar.

1.4 GeoTIFF:

A GeoTIFF is a file format that ends with a three letter extension (tif). It is a type of TIFF file which contains spatial referencing information of geo-referenced raster imagery in the form of GeoTIFF Tags. GeoTIFF format is known as raster format of data.

1.5 Sentinel-2:

The European Space Agency's Copernicus Program operates the Sentinel-2 satellite mission, which includes two identical satellites, Sentinel-2A and Sentinel-2B, launched in 2015 and 2017, respectively. The purpose of this mission is to provide high-resolution images of the

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Earth's surface to aid in environmental monitoring and land management. The Multispectral Instrument (MSI) on the satellites can capture images in 13 spectral bands, ranging from visible to short-wave infrared wavelengths. The spatial resolution of the imaging varies from 10 to 60 meters, depending on the spectral band.

1.6 Radar Backscatter:

Backscattering is the term used in physics to describe the reflection of waves, particles, or signals back in the direction they originally came from. While diffuse reflection from scattering occurs more frequently than specular reflection from a mirror, specular backscattering can still occur at normal incidence with a surface. Backscattering is important in astronomy, photography, and medical ultra-sonography. On the other side, forward scatter happens when a transparent substance, such a cloud, softens and diffuses sunlight.

1.7 MOTIVATION:

Energy production using natural resources like coal is becoming hazard to environment. There are alternative eco-friendly energy production systems such as windmills, water turbines, and solar power plants. However, it is very important to identify the locations where the system can obtain maximized output. One such natural energy production system is floating turbine platforms or buoys. This energy production system is most popular system because of its energy delivering ability. Using this system, we can produce high energy continuously. These systems occupy less space. It is very important to know the locations where we can obtain maximum output from these systems.

1.8 PROBLEM STATEMENT:

For human activities, water bodies have high potential to generate electricity. However due to climate changes the wave energy generation became uncertain and complex. Because of the construction costs, identification of locations where the power production can be maximized is vital. Therefore, this proposed system we focuses on analyzing the SAR images of waves and detecting wave energy density hotspots which has more potential to generate wave energy.

1.9 SCOPE:

The proposed system focuses on visualizing density hotspots from the satellite images bound to the EEZ Ocean region area of India from Sentinel-1A WV acquisitions.

1.10 OBJECTIVES:

The following is a list of the project's main objectives:

- To design a technology that can locate significant wave height locations in a given satellite image.

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- To estimate the wave energy density for every SAR image in the dataset.
- Using the dataset's metadata, locate each image's coordinates.

1.11 ADVANTAGES:

- Automated the process of detection wave energy density hotspot location in any region.
- Locations of each density hotspot can be found out.
- Wave energy break down regions are obtained at the end of the process in a given region.

1.12 APPLICATIONS:

- Real time wave energy plants can be implemented using the locations obtained from the project.

1.13 ORGANIZATION

This paper will be organized as follows: After introducing the problem of change detection in Section 1, Section 2 describes a survey of the existing literature on the topic. Section 3 then elaborates on the methodology and architecture being proposed. The findings and final thoughts are presented in section 4.

II.RELATED WORKS

This section lists the different literature reviews that are used as references. The authors of [3] created a numerical model to simulate standing waves in a closed channel and analyze the wave energy density and power collection capability of a wave energy converter (WEC) device positioned in the channel. The Navier-Stokes equations serve as the model's foundation, and it provides solutions for the channel's wave propagation, turbulence, and energy dissipation. The WEC gadget is envisioned as a heaving plate that captures wave energy. The effect of WEC characteristics, such as heave amplitude and resonant frequency, on the efficiency of power capture was investigated by the authors using a parametric analysis.

Advantages: The study provides a comprehensive analysis of the wave energy density and power capture potential in standing waves, which are an important source of wave energy in many coastal regions.

Disadvantages: The study is based on numerical simulations and does not include experimental validation.

In [4] In order to calculate the wave power density in the Gulf of Mexico, wave data from the Wavewatch III model is used. The scientists identified hotspot regions with significant potential for wave energy conversion by examining the spatial distribution of wave power

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density. Investigations are made on the connections between wave power density, wind speed, fetch, and ocean depth.
Advantages: The study estimates wave power density using an established model, which increases the dependability of the results.
Disadvantages: The study does not use field measurements to confirm the estimated wave power density. The study solely takes into account wave power density and ignores other aspects that may impact wave energy conversions, such as device performance and economic viability.

The process in [5] outlines the investigation of wind wave energy density while taking into account both theoretical and empirical methods. The theoretical analysis takes into account the impact of wave period, wave height, and wind speed on the total wave energy and is based on the linear wave theory. The wave energy density is statistically analyzed using long-term wave data from several sources. To calculate the wave energy density distribution and extreme wave circumstances, they used a variety of statistical techniques, such as probability distributions and extreme value analysis.
Advantages: The study includes a large dataset from different sources and regions, which enhances the generalizability of the results. The statistical analysis provides estimates of extreme wave conditions, which are important for the design of offshore structures and renewable energy devices.
Disadvantages: This may not be suitable for larger waves or extreme wave conditions.

Using computer animation and the concept of energy events, the authors of [6] looked at how wave energy behaved in the Gulf of Mexico. The authors used a three-dimensional representation to depict the wave energy field and detected energy events like breaking waves and energy dissipation based on their traits. Also, the scientists examined the spatial and temporal distribution of energy events and looked into the factors that may have contributed to them, such as wave characteristics and bathymetry.
Advantages: The work provides a unique perspective on behavior of wave energy in the Gulf of Mexico, which can expand our understanding of wave energy resource potential. In the study, the wave energy field is visualized using computer animation, which can help with the interpretation of complex data and enhance the dissemination of results.
Disadvantages: The study relies on a model for wave energy simulation, which may have limitations in accuracy due to uncertainties in input data and model assumptions.

Three empirical algorithms for oil slick detection are evaluated in [7] using Sentinel-1 SAR data. The algorithms tested were the threshold-based Lee Filter, the pixel-based Freeman-Durden Decomposition, and the feature-based Neural Network. The authors analyzed the

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algorithms' accuracy using both synthetic and real Sentinel-1 data and compared the results to ground truth data.

Advantages: The study tests the algorithms' performance using both synthetic and actual data, increasing the dependability of the results. The study compares the accuracy of the algorithms to ground truth data, providing a realistic assessment of performance. *Disadvantages:* The study focuses only on the detection of oil slicks and does not address other applications of SAR data.

In [8] authors conducted field measurements of wave parameters in a tidal channel using a high-resolution instrument. The instrument measures water level and wave height at a high sampling rate and provides accurate estimates of wave parameters such as wave period and wave energy density. The authors analyzed the wave data to investigate the wave energy density and spectral characteristics in the tidal channel, including the effects of tidal currents.

Advantage: The work offers high-resolution wave parameter measurements, enabling precise calculations of wave energy density and spectrum properties. Our understanding of wave behavior in tidal channels is improved by the study's examination of the impact of wind waves and tidal currents on wave energy density.

Disadvantage: The study may not be generalizable to other areas and tidal channels because it is based on field observations in a particular tidal channel. The study does not take into account other aspects of wave behavior, such as wave breaking or wave-induced currents, and instead concentrates on wave energy density and spectral features.

In order to explore the wave energy density in deep water, which is a crucial component in wave energy conversion, theoretical analysis is utilized in [9]. The wave energy density in deep water was calculated analytically, and the researchers compared their findings to those of earlier research and experimental evidence. The authors also considered how wave energy conversion technology might be affected by wave energy density. *Advantage:* For a better understanding of wave energy conversion technology, the paper offers a theoretical analysis of the density of wave energy in deep water. Analytical formulas for the wave energy density are provided by the study, and these expressions can be used to calculate the wave power and energy that is available for conversion.

Disadvantage: The study does not take into account other aspects of wave behavior, such as wave breaking or interactions with currents, and instead concentrates on the wave energy density in deep water.

Paper [10] comparative of different wavelet transform methods for estimating wave energy density. The study used synthetic and real wave data to compare the accuracy and computational efficiency of the different wavelet methods. The authors also compared the

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results with other methods commonly used for wave energy density estimation, such as the Fourier transform and the Hilbert transform..
Advantage: The study provides a comparative analysis of different wavelet transform methods for estimating wave energy density. The study highlights the advantages and limitations of each method, which can guide researchers in selecting the appropriate method for their specific application.

*Disadvantage:*The study relies on assumptions about the wave data, such as the stationarity and Gaussianity of the wave signal, which may not be accurate for all wave conditions.

In the work described in [11], the phase congruency model is promptly utilized on the logarithmic SAR image or the raw SAR image that has been affected by speckle noise. The authors propose an improved phase congruency model that integrates the SAR local energy model and a unique noise estimation technique that is customized for the six types of multiplicative speckle noise. The SAR-PC model is divided into three stages that mirror the phase congruency model, which includes the SAR local energy model, noise estimation, and extraction of edges and corners.

Advantages: In order to comprehend wave energy conversion technologies, the paper offers a theoretical analysis of the wave energy density in deep water. In order to calculate the wave power and energy that is available for conversion, the study offers mathematical equations for the wave energy density.

Disadvantages: The study does not take into account other aspects of wave behavior, such as wave breaking or interactions with currents, and instead concentrates on the wave energy density in deep water.

Work in [12] discusses the identification of seasonal fluctuations and energy profiles of various sites through statistical analysis of their specific characteristics, followed by direct comparison. The study sites are situated near the shoreline, and using reanalysis data from ECMWF, despite the loss of satellite measurements, is advantageous in terms of accuracy.

Advantages: The model still functions when the wind speed varies. Each parameter's threshold values are clearly described.

Disadvantages: It is crucial to note that prior comparisons of ECMWF wave data with observations have shown that these simulated values frequently underestimate peak values, particularly for the higher power class.

The aim of the work [13] is to evaluate the annual electricity output of a wind turbine and daily average values of ERA5 U10 by comparing them with the daily 7 mean values provided by AVISO. This evaluation provides insight into the distribution of wind energy across the Romanian coastline and inland regions. The IAV (inter-annual variability) index is used in

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climatologic analysis to measure the year-to-year variation of a particular parameter. The capacity factor is a standard measure for assessing the performance of a wind turbine.

Advantages: We can calculate the location of the wind turbine for maximum efficiency using this model.

Disadvantages: This method may provide significant uncertainty, making it not the most accurate.

The study in [14] discusses how segmentation models are constructed utilizing a base network-backed segmentation architecture. The backbone network employed in this study is the SEResNEXt50 segmentation architecture supported by LinkNet and Efficient Net. In 7 phases, segmentation accuracy is achieved. 512x512 pixels tiles were taken from photos in the first stage, and to prevent any segmentation issues, the predictions are averaged with overlays. In third step algorithm runs complete image in Z-shape generating around 32,000 forecast images. The following stage involves using the overlay to regenerate the prediction image, binarization, and vectorization of the binarized image to construct polygons over the recognized turbines and calculate the positives based on the retrieved geo-location.

Advantages: This approach exhibited decent accuracy in determining the turbine positions

.*Disadvantages:* The dataset is not of good quality. The collection contains item placement and location problems.

The technique presented in 15] to estimate the offshore wave energy entails summing the kinetic and potential energy densities per unit width through the formula Ewave=gH2/8, followed by computing the energy flux through a vertical segment of one unit width perpendicular to wave propagation. A vast number of uniform waves having distinct amplitudes and frequencies are combined to simulate the irregular wave behavior observed in the oceans.

Advantages: Calculations based on climatic characteristics can be made for energy production.

Disadvantages: It is impossible to analyze wave energy in the interior seas.

The methodology utilised by the authors in [16] includes an integrated strategy of primary wind speed assessment using Sentinel1 and reanalysis utilising Sentinel application platform software, as well as the usage of ENVI software to extract useful data and make judgements from satellite images. Initially GIS software is used to map wind potential with other factors in next phase user examines the potential of wind energy in specific area focusing on various hotspots. The ROI tool can be used to classify, mask, and extract data and statistics about a certain area.

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*Advantages:*This kind analysis will give clear idea about strengths, opportunities, weaknesses and threats in particular area for wind energy generation. It's economical compared with traditional analysis. *Disadvantages:*T here are high chances of information loss while analyzing data through this process.

The essential parameters required for assessing wind and wave energy are obtained from ECMWF data in [17]. By utilizing the wave and weather data obtained from buoys during an offshore renewable energy venture, the precision of the wave and wind field data furnished by ERA-Interim is verified. The collected wave field data from different buoys is compared in this study.

Advantages: Potentiality to generate wave and wind energy is determined.

Disadvantages: It requires a lot of data.

2.1 SOFTWARE REQUIREMENTS

The basic software requirements include**:**

- SNAP Desktop to view and segment the data
- Google Collab or Jupyter Notebook

2.2 HARDWARE REQUIREMENTS

The working platform requirements are

- Windows OS platform of version 8 or above / Mac OS X 10.0 or above
- 64-bit CPU
- 8 GB of RAM
- 4 GB of GPU

III METHODS

Below, we provide a thorough explanation of the suggested method. This proposed method uses synthetic aperture radar (SAR) images to identify hotspots of wave energy density. To improve the system's performance, we must reduce the noise in SAR images. After reducing the noise, we apply several image processing methods, including as segmentation, masking, edge detection, and clustering, to identify the hotspots of wave energy density. The wave energy density is then calculated for each image and set of coordinates once the image has been scaled. *Figure 1 displays the flow of the proposed system.*

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3.1 Methodology:

3.1.1 Read SAR images

We use Sentinel-2 satellite pictures to locate the wave energy density hotspot. They have a band-2 type with a resolution of 10 meters. Numpy arrays are used to read the photos and process them further.

3.1.2 Pre-Processing

Raw SAR images contains noise named speckle noise. This noise interferes when the images are being processed to remove this noise we use wiener filter. The Wiener filter returns the smallest mean-square error between the restored and original images. After applying the Weiner filter we segment the images into smaller images of size 512*512 for further processing. The Figure 2 presents the sample of dataset image after applying Weiner filter.

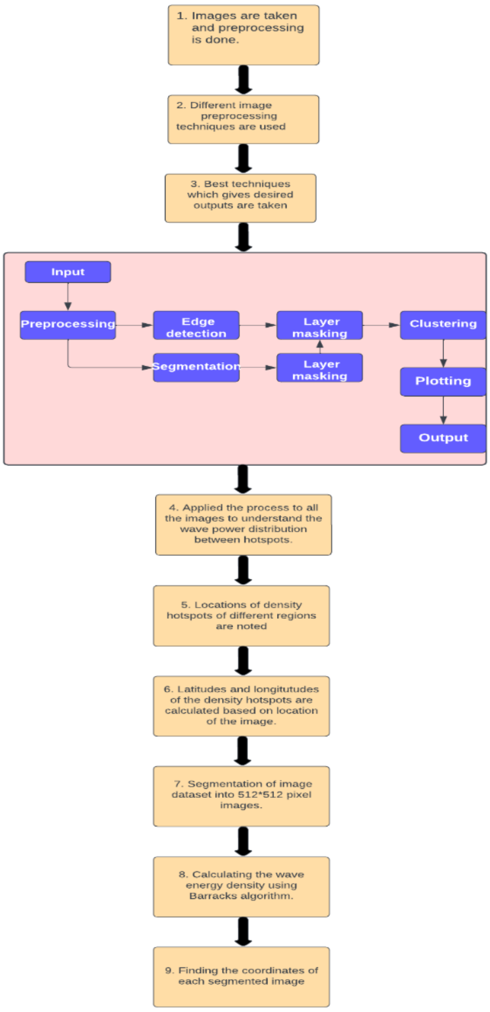

Figure 1: Proposed System

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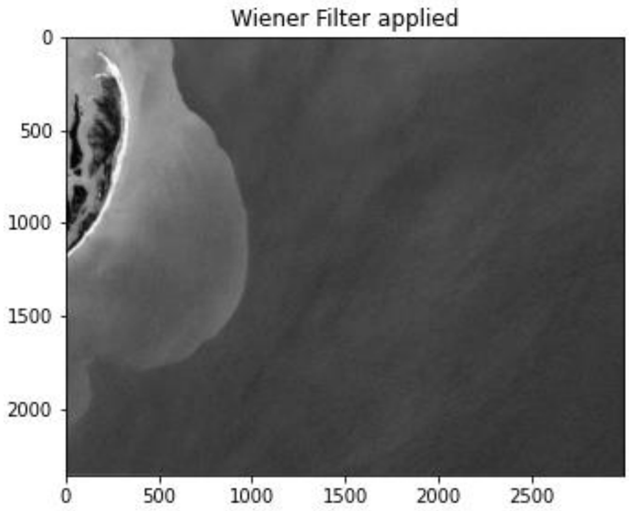

Figure 2: Pre Processed image

3.1.3Segmentation

When the images contain land areas, the land areas should be ignored by the process. In order to separate the land area from the wave region we use segmentation. The segment process will separate the land area from the water region so the process will not be disturbed by the land area. For segmentation we use fuzzy-c means segmentation. The *Figure 3 presents the sample of dataset image after segmentation of the image.*

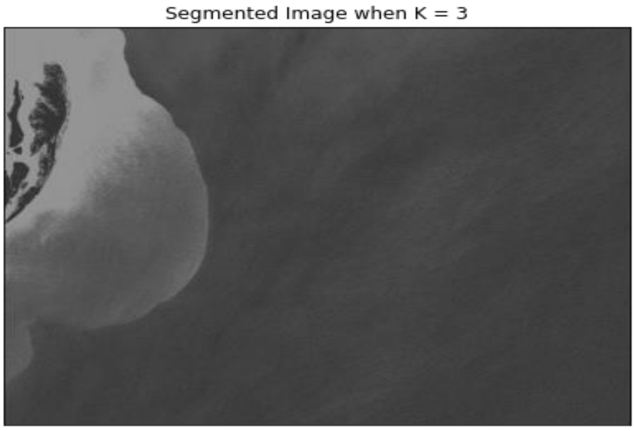

Figure 3: Segmented image

3.1.4Masking

After segmentation the land masses should be masked for the process to run smoothly. Masking is the process of hiding the unwanted information in the image. We use the layer masking to mask the entire land region in the image. *The Figure 4 presents the sample of dataset image after applying Masking technique.*

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3.1.5Edge detection

After removing all the information in the image which are unnecessary in detecting the waves in the image we use the edge detection process to detect all the waves in the image. Edge detection detects all the boundaries in the image which are waves. We use canny edge detection which is the best edge detection algorithm. *The Figure 5 presents canny edge detection applied image.*

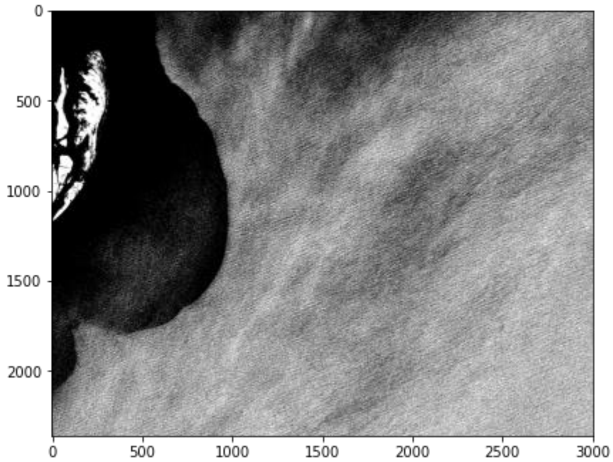

Figure 4: Masked image

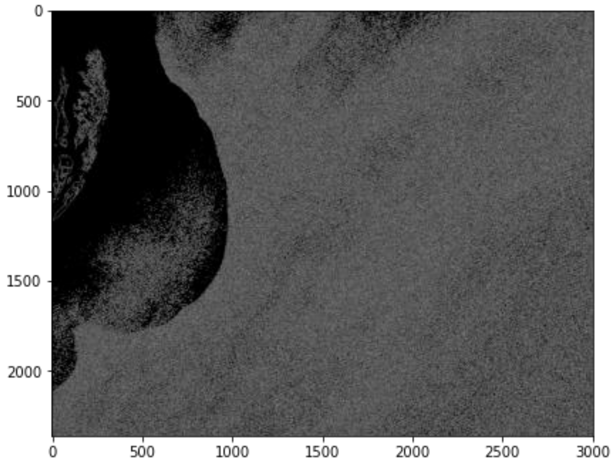

Figure 5: Segmented image

3.1.6 Clustering

After identifying waves using the edge detection technique, the wave energy density hotspots are found using the clustering algorithm. After edge detection, the coordinates of all the white pixels in the image are submitted to the clustering technique. We use k means clustering because it is centroid based clustering which is useful for the project. *Figure 6 presents the sample of dataset image after applying clustering algorithm.*

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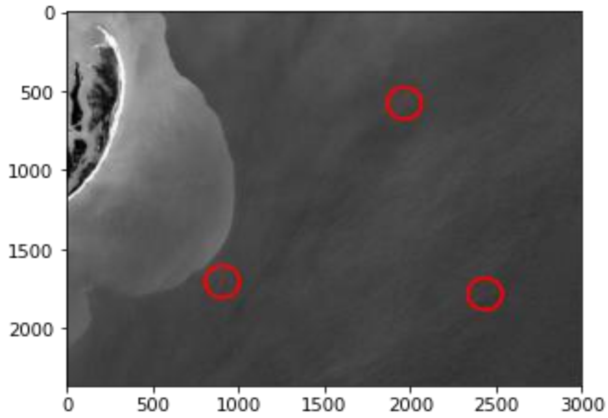

Figure 6: Clustered image

3.1.7Calculating wave energy density

The total energy that can be obtained from all the waves in the SAR image. To calculate the wave energy density using image processing we use empirical algorithms that relate the radar backscatter coefficient to wave energy. The algorithms include Barrack's algorithm, Maresca and George's algorithm, Heron et al algorithm[24]. Since it used a weighted second-order energy integral, the Barracks method outperformed the others as given in the research cited below.

3.1.8Finding the coordinates

The Meta data obtained with the SAR images is used to calculate the coordinates of each image.

3.2 Dataset Collection:

The European Space Agency (ESA) provides a site for viewing data from the Sentinel satellite missions of the Copernicus program, formerly known as the Sentinels Scientific Data Hub. A project run by the European Union called Copernicus aims to provide reliable, current information about the ecology and security of the planet. Data from Sentinel-1, Sentinel-2, Sentinel-3, Sentinel-4, and Sentinel-5P are made freely, completely, and openly accessible through the Copernicus Open Access Portal. These are images taken by the Synthetic Aperture Radar on board the Sentinel-1 mission (SAR). SAR shots are radar images that produce sharp images even in bad lighting or weather by using the motion of the satellite to simulate the impact of a much larger antenna. Researchers, academics, and organizations interested in using earth observation and remote sensing data can check out the Copernicus Open Access Hub. By providing free and open access to high-quality data, the Copernicus

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Open Access Hub encourages the development of new applications and services for the benefit of society. *The images from the Gulf of Mannar Dataset are shown in Figure 7.*

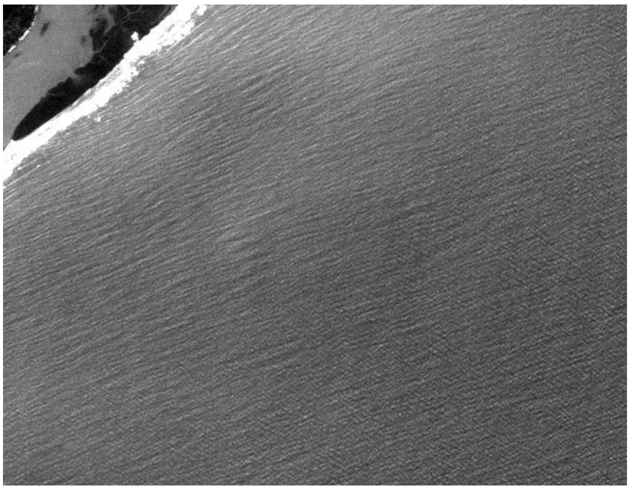

Figure 7: Dataset Specimen

3.3 Algorithm:

3.3.1 Data preprocessing:

The algorithm for the data preprocessing is Weiner filter described as follows:
Input: Dataset collection comprising of SAR images of water bodies.
Output: Preprocessed images
Process:
Step 1:Read the input image in form of numpy array.
Step 2:Resize the image from 1024*1024 to 512*512.
Step 3: Apply 2 dimensional convolution on the image.
Step 4:The pixels in the image are standardized and normalized
Step 5:The image is DE convolved using wiener filter as given in Eq(1).

$$G(u,v) = \frac{P_S(u,v)}{P_S(u,v)+\sigma_v^2} \quad (1)$$

3.3.2 Segmentation:

The algorithm for Segmentation is Fuzzy c means described as follows.
Input: Preprocessed Images of past images and current images.
Output: An image showing clearly defined boundaries
Process:
Step 1: Randomly divide the data points into the required number of clusters.
Step 2: Calculate cluster centers (centroid).
Step 3: Update Partition Matrix using Eq(2) and Eq(3).

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$$\mu_{ij} = 1 \Big/ \sum_{k=1}^{c} (d_{ij}/d_{ik})^{(2/m-1)} ----------- (2)$$

$$v_j = \left(\sum_{i=1}^{n} (\mu_{ij})^m x_i\right) \Big/ \left(\sum_{i=1}^{n} (\mu_{ij})^m\right), \forall j = 1,2 \cdots\cdots C ----(3)$$

3.3.3 Masking:

The algorithm for masking is layer masking described as follows.
Input: Preprocessed Images of past images and current images.
Output: An image showing only necessary areas in the image.
Process:
Step 1: create the binary mask form the original image with threshold 75.
Step 2: Applying the bitwise operator to every pixel in the image and binary image to get mask.

3.3.4 Edge detection:

The edge detection algorithm is canny edge described below.
Input: Preprocessed photos from the past and current images.
Output: An edge detected picture of the original image.
Process:
Step 1: Analyze the image input.
Step 2: After the image is made grayscale, a 5x5 Gaussian filter with a 1.4 value is applied.
Step 3: The intensity gradient of the previous image. The image's edges have been managed by reproducing.
Step 4: Apply non-maximum suppression to the preceding image.
Step 5: Applying double thresholding to the previous image. Weak pixels have gradient values between 0.1 and 0.3. A gradient value greater than 0.3 indicates a strong pixel.
Step 6: Apply hysteresis to the previous picture.

3.3.5 Clustering:

The algorithm for Clustering is K means clustering described as follows.
Input: Preprocessed Images of past images and current images.
Output: An image clustered areas in the image.
Process:
Step 1: The ideal value for K center points or centroids is determined iteratively.
Step 2: chooses the nearest k-center for every data point. Data points that are in close proximity to a certain k-center form clusters.

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3.3.6 Wave energy density calculation:

The algorithm for density calculation is Barrack's algorithm described as follows.
Input: Preprocessed Images of size 512*512.
Output: wave energy density value in terms of J/m^3.
Step 1: Choose a complex number z_0 in the domain of the function f (z).
Step 2: At z 0 and two neighboring points, z 1 = z 0 + h and z 2 = z 0 + ih, where I is the imaginary unit and h is a short step size, evaluate the function f (z).
Step 3: Create a complex polynomial P (z) that interpolates the function values at z 0, z 1, and z 2 using the three function evaluations.
Step 4: Calculate the complex derivative of P(z) at z_0, which provides an estimate of the gradient of the function f(z) at z_0.
Step 5: Use the estimated gradient to update the value of z_0 and repeat the process until convergence.

3.3.7Finding the coordinates for each input image:

Input: Meta data obtained from the dataset.
Output: Locations of each image in the dataset
Step 1: For top left coordinates, Eq(4) is used
topl=[la[0]+(i/4)*(la[1]-la[0]),lo[0]-(j/5)*(lo[0]-lo[1])] (4)

Step 2:For bottom right coordinates, Eq(5) is used botr=[la[0]+(((i+1)/4)*(la[1]-la[0])),lo[0]-(((j+1)/5)*(lo[0]-lo[1]))] (5)

IV RESULTS AND DISCUSSION

4.1 Elbow Method Graph

We determine the number of clusters at which the WCSS change levels out by plotting the relationship between the cluster number and the within-cluster sum of squares (WCSS) (elbow method).*Figure 8 represents the WCSS graph for the input data specimen.*

4.2Hotspot distribution analysis

Three clusters, cluster1, cluster2, and cluster3, were created from the total number of hotspots. *Figure 9 represents wave energy distributions to the top three clusters in the image of the dataset.*

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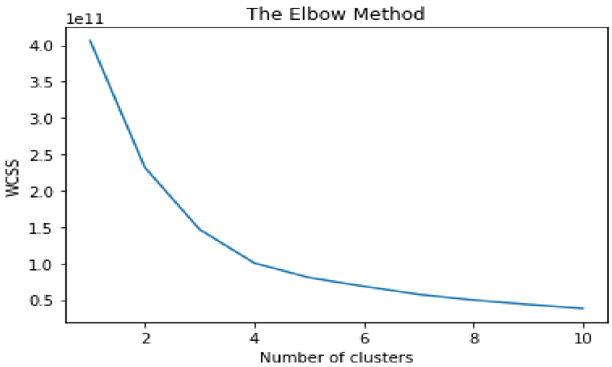

Figure 8: Wave power distribution in the give image

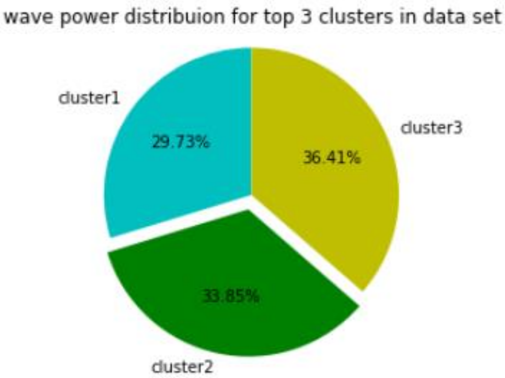

Figure 9: Wave power distribution for the top three clusters

The Figure 10 represents the density hotspot distribution over the entire area in the given image. The hotspots with high intensity levels are concentrated at the locations location 1: 8.1394, 79.81329; location 2: 8.1338,79.8882; location 3: 8.1364, 79.6547; location 4: 8.1383 79.3730 where we can detect bigger density hotspots and waves in the input image.

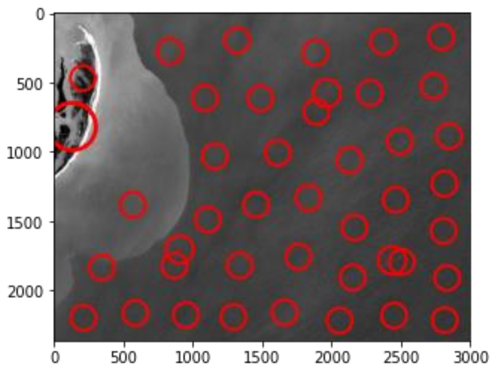

Figure 10: Wave power distribution in the give image

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There is no specific pattern visible of the distribution of wave energy density in the 2D and 3D visualization of density hotspots. The density hotspots with high intensity are located in coastal region and in middle of the ocean so the shape or pattern cannot be identified in the visualization. But majority of wave energy density hotspots are located far from land region. Figure 11 represents the 3D visualization of density hotspots.

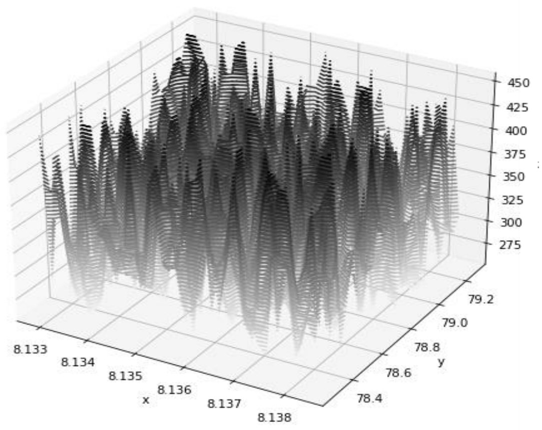

Figure 11:3D visualization of density hotspots

4.2 Wave energy density calculation:

Wave energy density and coordinates are calculated for each dataset specimen and they are displayed in descending order of wave energy densities. The percentage of wave energy density of each segmented image to the wave energy density of the input image is represented in figure 12. Figure 13 represents the presentation of each image after calculation of wave energy densities. *Figure 13 represents wave energy density and coordinates calculation.*

The Peak Signal-to-Noise Ratio (PSNR) value between original image and preprocessed image is calculated using Eq(6).

$$PSNR = 10\log_{10}\left(\frac{R^2}{MSE}\right) \qquad (6)$$

MSE is calculated using eq(7).

$$MSE = \frac{\sum_{M}^{N}[I_1(m,n)-I_2(m,n)]^2}{M*N} \qquad (7)$$

The calculated PSNR and MSE are calculated as 10.73 dB and 74.06 dB respectively. These values are optimal for any image noise removing techniques which concludes that the Weiner filter is suitable to remove speckle noise in SAR images

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Coordinates	Density	% of avg
TOP_LEFT [8.13,78.28] BOTTOM RIGHT [8.13,78.45]	1266.0J/M^2	116.296%
TOP_LEFT [8.13,78.45] BOTTOM RIGHT [8.13,78.62]	1353.0J/M^2	124.288%
TOP_LEFT [8.13,78.62] BOTTOM RIGHT [8.13,78.79]	1229.0J/M^2	112.897%
TOP_LEFT [8.13,78.79] BOTTOM RIGHT [8.13,78.96]	1175.0J/M^2	107.937%
TOP_LEFT [8.13,78.96] BOTTOM RIGHT [8.13,79.13]	924.0J/M^2	84.88%
TOP_LEFT [8.13,78.28] BOTTOM RIGHT [8.14,78.45]	1268.0J/M^2	116.48%
TOP_LEFT [8.13,78.45] BOTTOM RIGHT [8.14,78.62]	880.0J/M^2	80.838%
TOP_LEFT [8.13,78.62] BOTTOM RIGHT [8.14,78.79]	1321.0J/M^2	121.349%
TOP_LEFT [8.13,78.79] BOTTOM RIGHT [8.14,78.96]	1475.0J/M^2	135.495%
TOP_LEFT [8.13,78.96] BOTTOM RIGHT [8.14,79.13]	1181.0J/M^2	108.488%

Figure 12: Table with densities and percentage of wave energy of input image

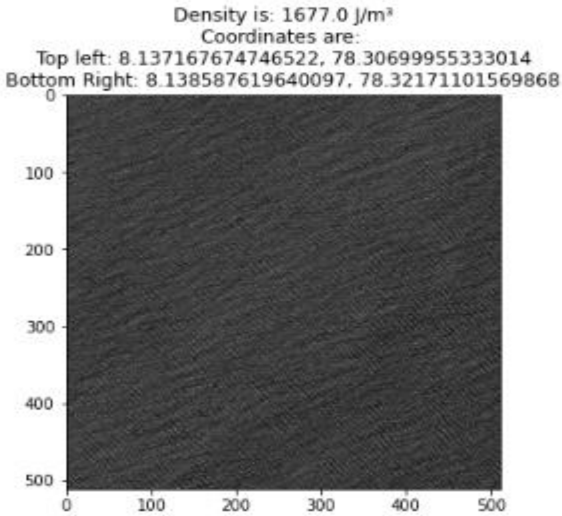

Figure 13: wave energy density and coordinates calculation.

V CONCLUSIONS AND FUTURE WORK

These findings are acquired using the suggested model. The density hotspots are identified using a linear process model. The design consists of running SAR pictures through a process of preprocessing, segmentation, edge detection, masking, and clustering. The clustering procedure is employed in the picture to find wave energy density hotspots. In the final output the density hotspots are marked by red circle. Then the dataset is segmented in to smaller images and the wave energy density hotspots and location of these images are found out using Meta data available with the dataset.

Future work is to use image smoothing techniques like Gaussian smoothing to reduce the noise created by land masses, dynamically update the threshold value for the creation of the binary image for the original image which increases accuracy, performance of this proposed system in EEZ regions.

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CONFLICTS OF INTEREST

The Authors declare no conflict of interest.

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