GSHHG Map based Sea Clutter Supression

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***Abstract*— In coastal surveillance radar systems, the radar signals can be reflected from objects (true targets) like buoys, boats, ships and also from clutters (false targets) such as sea, land, clouds, buildings etc. These clutter sources act as dominant scatters' and hence contribute to major part of the reflections. As a consequence, these predominant false alarms obstruct in detection of low RCS targets. These unwanted echoes give an annoyed situation when presented on the Plane Position Indicator (PPI). Hence, to minimize the clutter behavior, the current state of the art uses various clutter suppression techniques such as Sensitivity Time Control (STC), Fast Time Constant (FTC) etc. STC curve estimation technique attenuates strong signals from sea clutter and nearby range bins. STC Curve estimation technique tries to fit a curve with the available data points. But, this estimated 3rd order polynomial curve has a drawback that it is unable to represent the sudden transients at land-water interface, (coastal-boundary) as the curve estimation is initiated from the trailing edge of the sync rather than the actual coastline. Hence, the proposed clutter suppression method makes use of an open-source geospatial database referred to as the Global Self-consistent Hierarchical High Resolution Geographical (GSHHG) Map to identify coastal boundaries, islands and other land-water demarcations. The STC curve can be segmented dynamically or multiple curves can be estimated with the aid of GSHHG Maps for scenarios with islands or other intermediate structures within the same Azimuth Count Pulse (ACP). Also, maps can be used in masking unnecessary detections which leads to false alarms. The proposed method also uses user feed and interactions to adjust the map so as to cater to dynamic sea state changes or changes in land-water boundaries.**

***Keywords*—GSHHG, STC, Radar Video, ACP,Clutter,DSP**

I. INTRODUCTION

In coastal surveillance systems, major parts of the radar reflections are from sea and land regions. These radar signals may be reflected from objects (boats, vehicles), land, terrain, vegetation, man-made structures etc. Normally reflections from land, sea, weather etc. are considered as clutter (or unwanted echoes) as they mask echoes from desired targets such as boats and ships. Hence, the detection of true targets from predominant false targets (clutters) is a major challenge in radar signal processing. Also, these reflections degrade the quality of video representation on radar displays and consequently make it difficult to discriminate true targets on the display. Therefore, radar surveillance systems use various clutter suppression techniques such as Sensitivity Time Control (STC), Fast Time Constant (FTC) etc.

The power of the reflected signal usually varies as an inverse function of the target range. Hence, reflections from nearby clutter sources can be so strong and can saturate the radar receiver as shown in Fig1. Thereby, any small change in signal strength goes undetected and as a consequence, nearby point targets like ships and boats may be undetected. Hence, STC (or swept gain), which is a clutter suppression technique, is used to attenuate signals from nearby clutter regions or range bins.

Figure 1. Saturation of PPI display caused by sea clutter

Without this attenuation technique, the radar receiver would gradually saturate due to strong signals (Fig 2). In STC clutter suppression model, the STC curve with attenuation factor 'A' is an inverse function of range(R), $A \propto \frac{1}{R^n}$. The variation in attenuation with range might be of the order of R^2 for rain, R^3 for sea or surface clutter models. This arises because the radar cross section of sea clutter is a function of range. In traditional STC processing, the clutter model was isotropic i.e. the clutter is assumed to be uniform for all azimuths and therefore the STC curve may be fixed for all azimuth angles of the antennae. But, in real-time scenarios, to achieve remarkable clutter suppression results, a non-isotropic clutter model is used, as the clutter strength varies significantly with change in azimuth angles. Hence STC curve is estimated for all angles of the antennae.

STC curve estimation is usually initiated from the trailing edge of the range reference pulse called SYNC. Thus, the 3rd order STC curve for sea clutter suppression will be estimated starting from range bin one rather than the actual coastal point (or range offset). Hence, this estimated curve is unable to represent the sudden transients at land-water interface (i.e.

coastal boundary). As a result, STC processing of the radar input leaves signal residue around the coastal boundary resulting in degraded video representation and target detection. This anomaly can be resolved by using external geographical data sources such as Global Self-consistent Hierarchical High Resolution Geographical (GSHHG) maps.

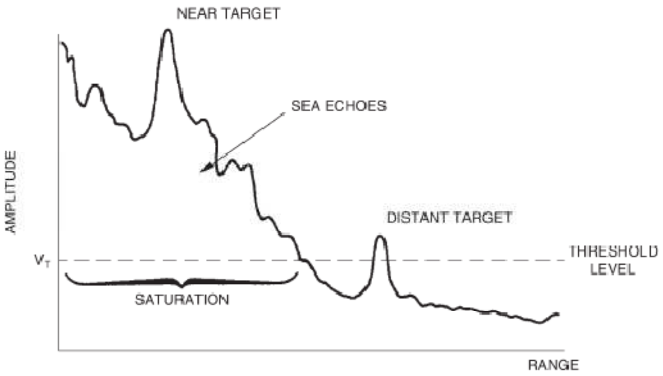

Figure 2. Without STC

GSHHG Maps [1], is a high resolution, open source, shoreline dataset amalgamated from two well known public domain databases World Data Bank II (WDB) and World Vector Shorelines (WVS). WDBII database contains coastlines, lakes, political boundaries and rivers.WVS contains shorelines along ocean/land interfaces (no land locked bodies). Shorelines (or land boundaries) are represented as a collection of closed, hierarchical set of polygons. Each vertex is geographically referenced with a latitude-longitude pair. The dataset is available in multiple resolutions. Hence GSHHG Maps helps in demarcating the coastal boundary and initiating STC curve estimation from coastal boundary points.

In Scenarios with intermediate islands or large RCS scatters', a single STC curve can be estimated or multiple STC curves can be estimated from every breakpoint (boundary points). The first technique results in an undesired STC performance whereas the later can be implemented using GSHHG Maps, as they help in segmenting STC curve estimation at coastal points.

For a non-isotropic sea clutter model, STC curve is estimated for all azimuth angles. The estimation for each angle should be initiated from its coastal boundary. This range offset differs for each angle with respect to its coastal boundary. Thus, GSHHG Map helps in determining these boundary points, thereby providing better curve estimation compared to a fixed range offset for all angles.

Lastly, with the help of maps, detections from land region can be masked completely [2]. Using land-water boundary points, detections from land region can be marked and can be discarded from being tracked by the radar data processing software. This reduces the density of detections and thereby enhances the tracker performance and reduces the number of false tracks.

Despite the high quality and resolution of the freely available data, the static coastline map may not align with the displayed radar video. These inaccuracies are expected as the radar video is just a temporal snapshot of the dynamic state of the sea/ocean. The sea state being dynamic keeps changing and hence the displayed coastal map may deviate slightly from the scan-converted radar video.

We have designed and implemented a novel approach for land and sea clutter suppression using GSHHG maps with user feed and interaction. The archived shoreline map is loaded and overlaid with radar video on the radar display. Non-overlapping coastline boundaries of the map can be matched with the video by dynamically adjusting the coastal map points. The land-water interface points are computed for every ACP and are used for STC curve estimation and land clutter suppression.

II. PROPOSED SCHEME

The proposed system has been implemented and integrated with the radar setup for coastal surveillance system. The setup consists of a

- Signal conditioning card with an embedded Digital Signal Processing (DSP) chip for STC and other signal processing techniques
- Radar display bundled with other software applications for scan-conversion and display of the radar video The operational steps in GSHHG map based clutter suppression system are described below (Fig 3):

A. *Initialize Radar Display*

The center of the Plan Position Indicator (PPI) display should be initialized with the radar position. The radar position is represented using Latitude-Longitude coordinate system and can be entered manually or obtained using Global Positioning System (GPS). The decompressed, scan converted radar video is displayed on the radar display.

B. *Load Map*

GSHHG database provides binary map files of five different resolutions. The vector map is loaded for a radius of maximum radar coverage. Map is represented using hierarchical set of polygons represented in latitude-longitude coordinate system. Each vertex of the polygon is converted from latitude-longitude to Cartesian coordinate system. Finally the map is overlaid on the radar video data and displayed on the PPI display.

C. *Overlay Map and Radar video*

The loaded coastline map is expected to overlay with the radar video contour pertaining to the shoreline. Any misalignment of the map with the video could be due to reasons such as dynamic sea state change, newly erected man-made structures, geographical changes due to catastrophe or other environmental changes, inaccuracies in map data representations, inaccuracies in radar beam width etc. To cater to this, radar display interface accepts user/operator feed/interaction to align the map with the video.

Landmass/Shorelines are represented as polygons. Existing shoreline can be adjusted by dragging the line segments. Apart from the existing coastal points, additional points can be inserted on the coastline map to provide advanced control, flexibility and geographical accuracy in coastline approximation.

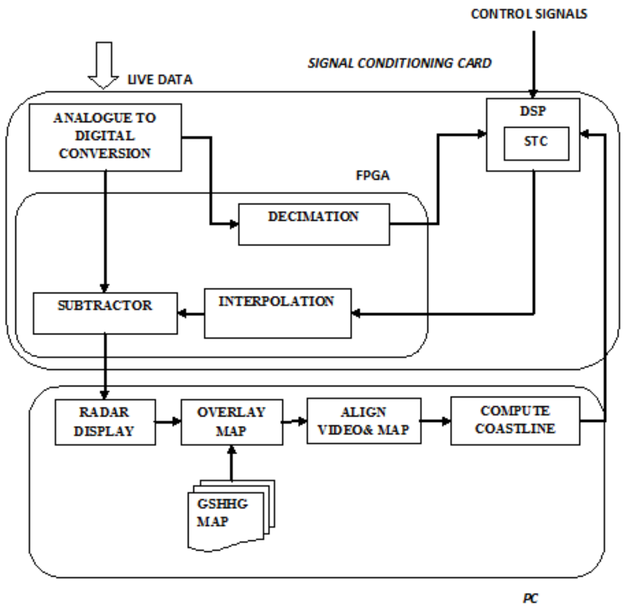

Figure 3 Block Diagram

Certain Islands or man-made structures may not be available in the GSHHG database. Such structures can be manually added to the existing map by drawing polygons. Certain islands/landmasses might have collapsed or washed out thereby disappearing completely or shrinking its size. Such islands/points can be deleted from the map to represent the present geographical condition. After modification, the newly formed map can be saved for future use.

D. Calculate Coastal Boundary Points per ACP

For the displayed map, the shoreline point for each ACP is calculated. Algorithm1 explains the steps in computing the coastal boundary points for each ACP.

E. Shoreline Points to DSP

These calculated intersection points are sorted in increasing order of range for each ACP and are send to the DSP module through serial interface based on a user predefined format. The format defines all possible coastline scenarios as shown in the figure. These shoreline boundary points are used as range offsets for STC curve estimation.

Algorithm 1

Input : {P} set of all loaded polygons
{V} set of all vertices of a polygon p, p ε P
{E} set of all edges of a polygon p, p ε P
ACPNo: Total no of ACPs
RP : (x,y) of Radar position
R : Max Radar Coverage Range
Output : {IP} List of Intersection Points for each ACP

for p ε P **do**
  for v1 ε {V},v2 ε{V} AND (v1,v2) ε{E} **do**
    $[\theta_x, R_x]$ ← latLonToRtheta(v1);
    $[\theta_y, R_y]$ ← latLonToRtheta(v2);
    for $\theta = \theta_x$ to θ_y **do**
      RR ← xyforRR(acp)
      [ipθ,ipr]←calculateIP(v1,v2,RP,RR)
      IP[ipθ].append← ipr
    endfor
  endfor
endfor

latLonToRtheta(x): function to convert x in (lat,lon) to (r, θ)
xyforRR(acp): function to determine the (x,y) of radar max range for ACP
calculateIP(v1,v2,RP,RR): function to calculate the point of intersection of two lines with end points (v1,v2) & (RP,RR)

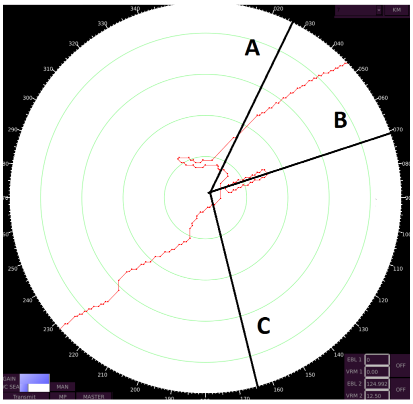

Figure 4. Different Cases of Coastal Boundary Points

F. STC Curve Estimation

STC curve estimation is a curve fitting technique for capturing the trend in the data by approximating a curve over the given 'n'data points [3]. Given n points (x_i, y_i), fitting it with a k^{th}degree polynomial requires the estimation of the (k+1) coefficients a_i.

$$y = a_0 + a_1 x + a_2 x^2 + \cdots + a_k x^k$$

In matrix notation Xa = Y, where X is a Vandermonde matrix as shown below, the solution vector 'a' can be computed using the equation $a = X^{-1}.Y$. In STC curve estimation, X matrix is the set of range values and Y matrix is the corresponding set of amplitudes for an ACP.

$$\begin{bmatrix} n & \sum_{i=1}^{n} x_i & \cdots & \sum_{i=1}^{n} x_i^k \\ \sum_{i=1}^{n} x_i & \sum_{i=1}^{n} x_i^2 & \cdots & \sum_{i=1}^{n} x_i^{k+1} \\ \vdots & \vdots & \ddots & \vdots \\ \sum_{i=1}^{n} x_i^k & \sum_{i=1}^{n} x_i^{k+1} & \cdots & \sum_{i=1}^{n} x_i^{2k} \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_k \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{n} y_i \\ \sum_{i=1}^{n} x_i y_i \\ \vdots \\ \sum_{i=1}^{n} x_i^k y_i \end{bmatrix}$$

STC Curve Estimation is done within the DSP module as shown in the block diagram. This STC Curve is an estimation of the sea clutter and hence is subtracted from the real time data for sea clutter suppression.

III. RESULTS

The proposed scheme is applied on the test data by fixing the radar lat-lon position for Vishakapattanam (17.6763,83.2926). The map is loaded for a radius of 192km. Fig.5 (a) shows the google map loaded for the radar lat-lon and (b) shows GSHHG Map. 'A','B'and 'C' points denotes the points of correlation.

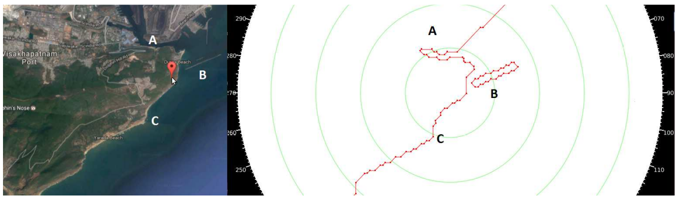

Figure5(a) Google Map (b)GSHHG Map, loaded for the same geographical region.'A','B' and 'C'shows the correlated points.

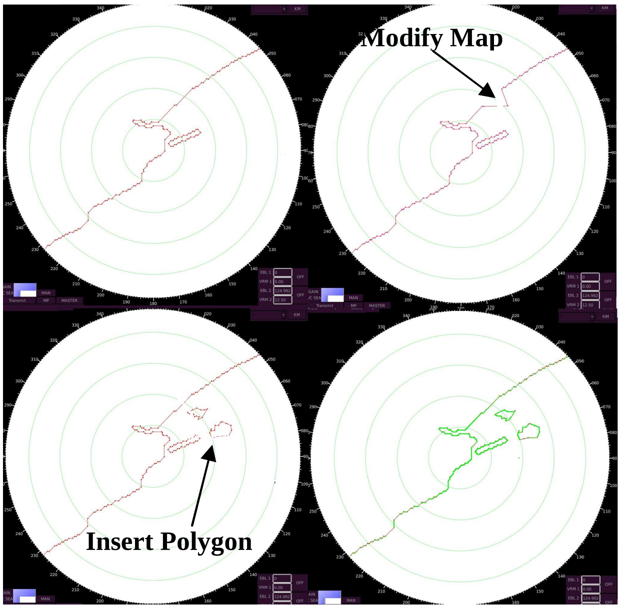

Figure.6 (a) GSHHG map loaded (b) Adjust map (c) Inserting Island (d) Compute Coastal boundary points

Fig.6(a) shows the GSHHG map loaded for a latitude 17.6767° and longitude of 83.2926°. The coastline can be adjusted by the user by dragging the coastline.Fig. 6(b) shows the adjusted coastline. Islands or other structures which are not available in the GSHHG database can be added by the user in insert mode (Fig.6(c)).Fig.6(d) shows the coastal boundary points for each azimuth angle.

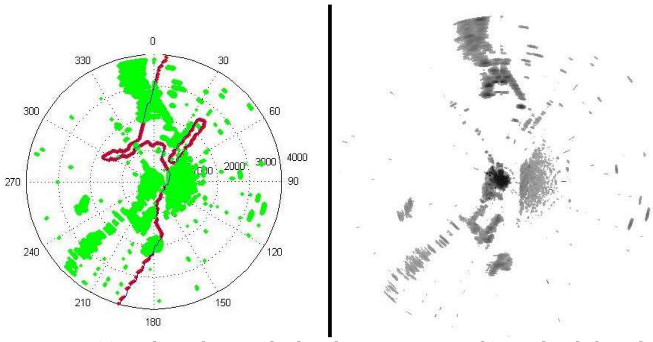

Figure 7 (a) Radar video overlaid with GSHHG Map (b)Amplitude based radar video representation

The input is scan converted and displayed on the display as shown in Fig 7(a). Blue plot shows the GSHHG map which is loaded for a radius of 4km from the center the display.The map indicates the coastal boundary from which the STC curve estimation should be initiated.The red plot shows the coastal points which are computed for each azimuth. These points are fed to the DSP module using serial interface for STC curve estimation. Fig 7(b) shows an intensity based representation of the radar video.

In Fig 8, the red curve shows the input signal for the ACP number 1024. Blue dashed line shows the estimated STC Curve. The curve is estimated from the trailing edge of the PRI in Fig 8(a) and hence results in a denser residue in the nearby range bin. Fig 8(b) shows the estimation of the curve based on the coastal boundary points. Black plot shows the residue obtained after subtracting the input signal with the estimated STC curve.

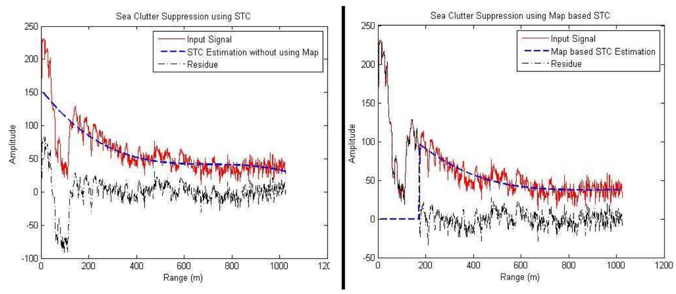

Figure 8 Sea clutter suppression using STC (a)without using Map (b) using GSHHG Map

If multiple coast line points are present in an ACP, separate curve is estimated for each of the segments (Fig 9). Blue dashed line shows a single STC curve estimated for the entire PRI irrespective of intermediate breakpoints. (Fig 9(a)). Fig 9(b) shows STC estimation with multiple STC curves estimation with the help of coastline boundaries.

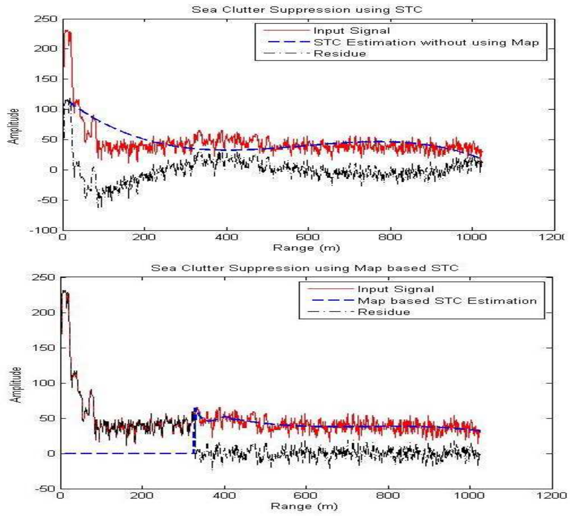

Figure 9 Sea clutter suppression using STC (a) without using Map (b) using GSHHG Map

IV. CONCLUSION

GSHHG map aided sea clutter suppression has been implemented. Map based STC provides better clutter suppression compared to the traditional STC technique. All reflections from the land region can also be masked completely using maps. Provision to insert and delete points and polygons on map enables the system to adapt to dynamic changes such as sea state, precipitation etc.

ACKNOWLEDGEMENT

Authors thank Sri. Mahesh V, Chief Scientist, and Shri.C.R Patil, Member Senior Research Staff, of Central Research Laboratory-Bangalore, Bharat Electronics Limited, India, for providing support for carrying out this research work in the organisation. We would like to thank all friends and colleagues who have contributed and supported us in the endeavour.

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