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A NOVEL NAVIGATION BASED DECISION ALGORITHM TO GENERATE TSUNAMI ALERTS USING SENSOR NODES

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Abstract: This research paper deals with a decision-based prediction system for generating tsunami alerts by analyzing real-time data that tags the sea turtle movement along the interiors of the Indian Ocean. In this paper Navigation based Decision Algorithm: NBDA which uses the Haversine Equations to detect the difference between the angle of the direction of Loggerhead Turtles at different durations of years from 2004 till 2012 is proposed. The dataset used here is provided by the OBIS Seamap-an official organization that maps the distribution of living species in Ocean present on their web portal having Latitude and Longitude values for turtle movement in the interiors of Indian Ocean obtained from underwater sensors. Using NBDA, The historic Tsunami year of 2004 is marked as the alert year on the basis of change in navigation directions of sea turtles in the Indian Ocean from the subsequent year of 2008. Proposed NBDA is validated with available real data which highlights 2004 as Tsunami Year. This Algorithm can further be used to design a prediction system to generate Tsunami Alert well in advance in real time by analyzing abnormal aquatic animal behavior.

Keywords: NBDA, Tsunami, navigation, Haversine, Bearing angle, Decision, Prediction.

I. INTRODUCTION

Aquatic animals use different sets of cues to maintain orientation and navigation pattern even in variable underwater conditions. These underwater conditions are characterized as certain parameters i.e. induced electric field or changing electromagnetic force across a given column of water which vary with respect to oceanic water movement across earth's geomagnetic field [1].
These underwater condition parameters do vary in presence of any unfortunate naturally induced process termed as natural hazards such as Tsunami, Cyclones, and Floods etc. One of the deadliest histories recorded till date is the Tsunami of 2004 that had hit the shores and interiors of Indian Ocean. This has created an urge in researchers to formulate such techniques that can be used to detect these upcoming natural hazards eg: Tsunami well in advance and therefore design a sorted well before time Alert system.

Authors in [2] have deduced a similar observation using statistical models to present the underwater induced voltage and magnetic field values in presence of Tsunami Seismic Waves. Using an underwater network of deployed sensor nodes which can detect above mentioned abnormal conditions, a Tsunami warning system can be designed where these conditions have a direct impact on migration, navigation breeding patterns of various classes of aquatic

animals specifically sea turtles [3], We therefore present prediction system which generates a series of alerts wherever a deflected navigation pattern is observed in presence of mentioned abnormal conditions.
In this paper, a Prediction system for Tsunami detection is used in Decision Making based on Navigation. The proposed NBDA analyze the navigation patterns of loggerhead sea turtles in terms of latitude, longitude pair, plotted near Indian Ocean by under-water sensor nodes, using Haversine navigation equations [4] formulated in a spherical coordinate earth system. The deflection patterns studied by the deployed underwater senor nodes are thus used to further train another network of sensor-nodes and thus generate a Tsunami alert for future.

The paper is divided as follows: Section II highlights the current state of art for various parameters considered for natural hazard Detection. Section III describes the proposed Navigation Based Decision Algorithm: NBDA. Subsequent Section IV presents the description of Data set with Implementation and Performance analysis of the proposed NBDA in the next Section. Section VI highlights the Results and discussion followed by the conclusion in the last (VII) section.

II. LITERATURE REVIEW

Studying navigation direction of underwater animals plays a key role in characterizing the abnormal underwater conditions. Authors in [5] have presented a profound framework for Tsunami alert system. The framework identifies navigation direction, migration and breeding patterns of aquatic animals as an indicator for generating Tsunami alert in presence of unusual underwater conditions. In [6] the proposed framework is validated for classification in alert and non-alert situations.

Studying and linking animal behaviour to seismic activity has been actively demonstrated by some researchers. Authors in [7] clearly identify animal sensory reception and their consequent abnormal behaviour as a precursor for seismic hazard detection. As tsunami is related to underwater abnormal conditions in terms of induced Electromagnetic field intensity as discussed in[1][8] ,it becomes evident to study aquatic animal behaviour using sensors to identify change in breeding, navigation and nesting patterns which if used to train underwater sensor nodes can help in designing a well time alert system.

Further, Sea turtle behavior analyzed in presence of induced Electromagnetic field intensity is discussed by authors in [9], a basis for the proposed NBDA.

III. PROPOSED NAVIGATION BASED DECISION ALGORITHM: NBDA

In this paper, a decision based algorithm (NBDA) which particularly decides or selects the base year and the alert year from the given dataset values is proposed. Figure 1 presents the Pseudo code of the proposed NBDA algorithm. In order to select the alert year, the proposed algorithm finds the bearing angle difference between all pairs of year present in the dataset.

Clearly, the decision taken here based on bearing angle calculation is further used to train the sensors, here given a set of latitude and longitude values, the sensors will issue an alert as in when the abnormal navigation direction is observed for loggerhead sea turtles over a given period of time. As discussed above the proposed algorithm selects the Alert Year as 2004 i.e. the year Tsunami had occurred along the Indian Ocean based on the deviation patterns it observes from the year 2008 which is normal adaptive condition year for sea turtles. We further validate our decision algorithm in terms of deflection it has from the ideal situation of 180 degree as the opposite direction deflection.

Figure 2 presents a snapshot of the C# implementation for the proposed decision algorithm. Implementation and Evaluation of the proposed algorithm is presented in the next section.

Pseudo code

```
#region Load Year_Data

DataTabletable = ReadCsvFile();
#Load Year_Data for 2004….2012

for(i=FirstYear till LastYear)
        {for j = i+1 till last year)
                {for(j = LatLon_TableCell0 to 500)
                #BruteForce  every top 500 Navigation markers
                {  if (Mean(AngleDiff(Table[i],Table[j])  is
                        between 170 and 180))
                            Set BaseYear = i and
                        AlertYear=j  #where i<j
                else Continue

                }}}

IntAngleDiff(CellValueYear1,CellValueYear2)

{
#Calculate BearingAngle as per Equation 1 to 3 Above
Return BearingAngle
}
```

Fig. 1: Decision Algorithm Pseudo code

```
dX = cRadius * Math.Cos(dInputLatInRadians) * Math.Cos
  (dInputLonInRadians);
dY = cRadius * Math.Cos(dInputLatInRadians) * Math.Sin
  (dInputLonInRadians);
dZ = cRadius * Math.Sin(dInputLatInRadians);

dXDash = dX * Math.Cos(dRotationAngleInRadians) - dY * Math.Sin
  (dRotationAngleInRadians);
dYDash = dX * Math.Sin(dRotationAngleInRadians) + dY * Math.Cos
  (dRotationAngleInRadians);
dZDash = dZ;

dOutputLatInRadians = Math.Asin(dZDash / cRadius);
dOutputLatInDegrees = ConvertToDegrees(dOutputLatInRadians);

dOutputLonInRadians = Math.Atan2(dYDash, dXDash);
dOutputLonInDegrees = ConvertToDegrees(dOutputLonInRadians);

table.Rows[i][3] = dOutputLatInDegrees;
table.Rows[i][4] = dOutputLonInDegrees;
```

Fig. 2: C# Implementation Snapshot

IV. DESCRIPTION OF DATASET

Navigation direction is one of the key parameters to be considered by the Decision algorithm furnished in consequent sections.

To study the navigation direction of loggerhead turtles, we have used a publically available data set having plotted latitude and longitude values for loggerhead sea turtles (Scientific name : Carettacaretta) in Indian-Ocean from [10] which is a web based access point to information about the distribution and abundance of living species in the ocean [11]. Figure 3 presents the metadata (attribute description) of the selected dataset. Here Latitude and longitude is plotted and presented in Degrees for various years explored in the subsequent sections. A snapshot of dataset is presented in Figure 4 where a pair of longitude and latitude has been tagged along with required date and time.

V. NBDA: IMPLEMENTATION AND PERFORMANCE EVALUATION

The proposed decision algorithm is based on prediction algorithm presented in [5] which examines the given set of latitude, longitude values in terms of bearing between them Bearing Theta(θ) as defined by Haversine formula is an important parameter in terms of navigation in ellipsoid or sphere coordinate system. Using these equations, circle distance followed by bearing angle between two points on a sphere from their latitude and longitude can be calculated. Bearing i.e the angle subtended between two directions of navigation having set of latitude and longitude points as ((Lat1, Lon1); (Lat2, Lon2)) is given by this formula as:

Theta(θ) = atan2(X,Y) ....(1)

X = sin (ΔLon)*cos(Lat2) ....(2)

Y = cos(Lat1)*sin(Lat2)-(sin(Lat1)*cos(Lat2)*cos(ΔLon)...........(3)

Here: ΔLon= Lon1- Lon2

As per the current data set obtained from [9], Loggerhead sea turtle movement has been captured where (Lat1, Lon1) present the logged values in the existing dataset for any of the years: 2004….2008…2012 selected as the base year. In order to study the difference between navigation directions of the base year as selected above and Alert Year to be selected below, in terms of angle as required by the decision Algorithm presented in the subsequent section, the formulated Haversine equations require a Spherical to Cartesian Coordinate Conversion.

Figure 5 presents the spherical coordinate system[12] where polar angle measured from fixed zenith direction is termed as Latitude (Taken as Lat1) and azimuth angle measured from azimuth reference direction to the orthogonal projection is termed as Longitude (Taken as Lon1). Here Radius is the Euclidean Distance taken as 6371 kms.

Attribute	**Description**
Tag_ID	Unique ID provided by Owner of Dataset
Lat	Latitude (In Decimal Degrees)
Lon	Longitude (In Decimal Degrees)
Sp_code	Specie code of the observed Species
Obs_Count	Number of Animals Sighted
Obs_ Date_Time	Date and time of Observation in UTC

Fig. 3: Metadata of the dataset

	A	B	C	D	E	F	G	H
1	Tag_id	Latitude	Longitude	sp_code	count	obs_date	date_time	Age_Class
2	1014_20138	-34.3149	43.32803	Caretta caretta	1	30-11-2009	30-11-2009 01:16	Juvenile
3	1014_20137	-34.3169	43.3216	Caretta caretta	3	29-11-2009	29-11-2009 23:19	Juvenile
4	1014_20136	-34.2662	43.32394	Caretta caretta	2	29-11-2009	29-11-2009 18:18	Juvenile
5	1014_20135	-34.264	43.32138	Caretta caretta	1	29-11-2009	29-11-2009 17:44	Juvenile
6	1014_20134	-34.2561	43.31562	Caretta caretta	1	29-11-2009	29-11-2009 16:38	Juvenile
7	1014_20133	-34.2465	43.31781	Caretta caretta	1	29-11-2009	29-11-2009 15:37	Juvenile
8	1014_20132	-34.2403	43.31174	Caretta caretta	1	29-11-2009	29-11-2009 15:17	Juvenile
9	1014_20131	-34.2254	43.30511	Caretta caretta	1	29-11-2009	29-11-2009 13:58	Juvenile
10	1014_20130	-34.2218	43.30553	Caretta caretta	2	29-11-2009	29-11-2009 13:35	Juvenile
11	1014_20129	-34.2059	43.29821	Caretta caretta	1	29-11-2009	29-11-2009 12:17	Juvenile
12	1014_20128	-34.1189	43.28561	Caretta caretta	3	29-11-2009	29-11-2009 06:57	Juvenile
13	1014_20127	-34.0716	43.27153	Caretta caretta	5	29-11-2009	29-11-2009 01:13	Juvenile
14	1014_20126	-34.0871	43.24997	Caretta caretta	1	28-11-2009	28-11-2009 22:40	Juvenile
15	1014_20125	-34.0474	43.23165	Caretta caretta	1	28-11-2009	28-11-2009 21:08	Juvenile
16	1014_20124	-34.0843	43.21653	Caretta caretta	1	28-11-2009	28-11-2009 20:42	Juvenile
17	1014_20123	-34.0328	43.18746	Caretta caretta	1	28-11-2009	28-11-2009 18:39	Juvenile

Fig. 4: A snapshot of Dataset in Year 2009

Theta(θ) for every Year: On the basis of above given equations i.e. (1 to 3), Theta(θ) is calculated using brute force approach between every pair of year i.e. 2004-2008, 2008-2009 for all Latitude and longitude values present in our dataset .The Bearing angle (Theta(θ)) clearly, falls ~170.18 degrees for the 2004-2008 pair.

The following Equations(4 to 11) are used to verify the above stated result by creating a temporary set of Latitude and Longitude as (Converted_Latitude,Converted_Longitude) where 180 degree(converted to radians), as mentioned in [5] signifies an opposite direction deflection in presence of abnormal Tsunami conditions.

The range of these set of temporary converted pair values thereby coincide with the range of Latitude and longitude values of Year 2004- termed as the Alert year and thus the subsequent Decision Algorithm is designed where Lat2, Lon2 are the values for Year 2004

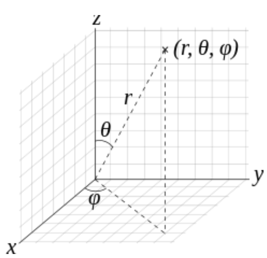

Fig. 5: Spherical coordinates (r, θ, φ) as radius, Latitude and Longitude

Spherical to Cartesian Coordinate Equations

XCoordinate = Radius *sin(Lat1) *cos(Lon1)…………….(4)

YCoordinate=Radius *sin(Lat1) *sin(Lon2).…………….(5)

ZCoordinate=Radius *cos(Lat1).…………….(6)

Here: ***Radius = 6371 km*****[11]**

Rotated Coordinates about Z axis Rotation

X``= XCoordinate.……………..(7)

Y``= YCoordinate*cos(Δd)–ZCoordinate*sin(Δd)……………(8)

Z``= YCoordinate*sin(Δd)+ZCoordinate*cos(Δd)……………(9)

Here Δd is referred to be the ideal change in navigationn direction referred to as 180 degrees obtained from [5]

A. Converted Latitude and Longitude from above Cartesian Rotated Coordinates:

Converted_Latitude (Or ±Lat2) = Asin(Z``/Radius) ..………(10)

Converted_Longitude(Or ±Lon2) = Atan2(Y``, X``)……………..…(11)

B. Decision Algorithm Verification

As discussed in [5], Authors have projected the ideal change in navigation direction in a high electromagnetic force conditions characterised as a tsunami alert situation, is observed to be opposite to the ideal navigation direction. The ideal direction of navigation is termed as the adaptive direction taken by the loggerhead turtles under defined range of EMF's that persist around the earth's magnetic poles.
In reference to the prediction algorithm discussed [5] , We therefore predict the approximate closeness of Δd to the mean Theta, calculated by the decision algorithm above, thus verifying the correctness of the decision algorithm in generating a Tsunami Alert.

Mean **(Theta of([(Lat1,Lon1)_BaseYear],[(Lat2,Lon2)_AlertYear])) ………(12)**

The above Equation approximates to 169.9618 degrees. Here mean is calculated over first 1000 dataset values for both years.

Deviation (±€) = Δd–Mean(Theta(θ)) /Δdequals 0.0613 or 6.1%.

VI. RESULTS AND DISCUSSION

Figure 6 and 7 presents the box plots for latitude and longitude respectively for all years present in our dataset.

The plots provide a clear snapshot for comparing the distributions of latitude and longitude for every year. Clearly, there is a significant gap or no marginal overlap between the notch values for year 2004 as compared with other years, thus we conclude with 95%confidence that the medians do differ. The median difference signifies no correlation of navigation direction of year 2004 with other years, which if would have been sensed by the underwater sensors would have generated an alert in that year.

Using the above mentioned Equation (12): Mean (Theta of([(Lat1,Lon1)_2008],[(Lat2,Lon2)_2004])) ~= 169.9618 Degrees. Therefore, the mean bearing angle lies closer to 180 degrees signifying a reversal in navigation direction along. Thus with 95% confidence, it can concluded that NBDA can predict Tsunami and generate Alert messages in realtime. Table-1 depicts the same, where the marked position for loggerhead turtles in both 2004 and 2008 as selected by our algorithm is used to calculate the bearing angle difference.

A closer to 180 degree value justify our claim of a direction reversal in presence of Tsunami, where the EMF effects produced by the Tsunami short waves misguide the loggerhead turtles and push them opposite to their adaptive natural direction of navigation.
Figure 8 presents the scatter plot of the above selected values from the dataset depicting the direction of navigation. As shown in the figure, the direction of

navigation shows an opposite direction reversal in the year 2004 with respect to year 2008 thus validating our results.

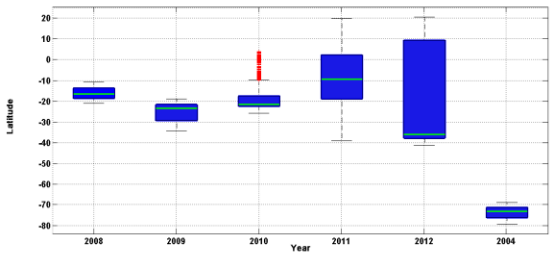

Fig. 6: Box plot representing median Latitude for all years.

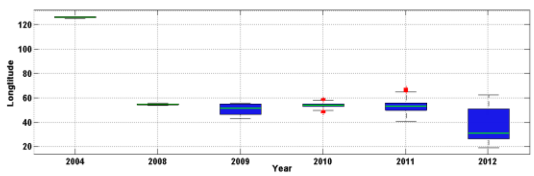

Fig. 7: Box plot representing median Latitude for all years

Table 1: Bearing Angle and Δd for year 2004(Alert Year) and 2008

Position on days much after Tsunami day 2004		Position on days just before Tsunami day 2004		Angle of Deviation (θ)
Latitude(Lat1)	Longitude(Lon1)	Latitude(Lat2)	Longitude(Lon2)	
-13.82421	55.28547	-76.17579	124.71453	170.374
-13.85602	55.30534	-76.14398	124.69466	169.342
-14.16267	55.47008	-75.83733	124.52992	170.032
-14.17639	55.47253	-75.82361	124.52747	169.018
-15.79131	54.57994	-74.20869	125.42006	169.087
-15.87084	54.61234	-74.12916	125.38766	169.001
-18.28956	54.24111	-71.71044	125.75889	170.12
-18.29386	54.22864	-71.70614	125.77136	169.113
-18.29735	54.22866	-71.70265	125.77134	169.109

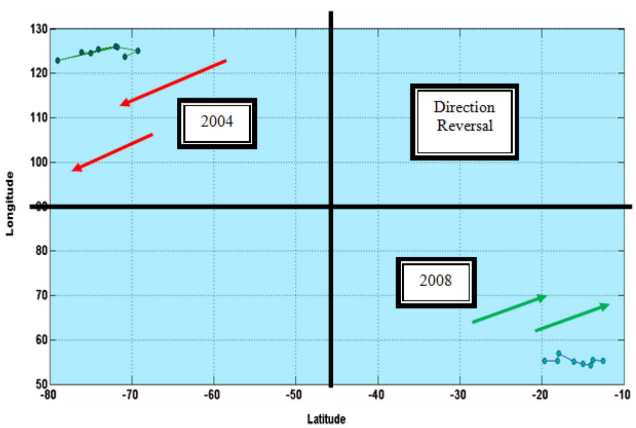

Fig. 8: Scatter plot showing direction of navigation in 2004 and 2008 by sea turtles

VII. CONCLUSION

Tsunami Prediction has become a vital area of research in recent years. This paper proposes a navigation based decision Algorithm to predict tsunami taking sea turtle behaviour in terms of navigation patterns into account. The results of the NBDA represent 2004 as the alert year on the basis of data analysis available from subsequent years. Clearly, if the proposed decision prediction system deployed underwater can easily identify the abnormal conditions and generate alert well in advance. The correctness and accuracy of our algorithm are justified on the ground that validates 2004 as the alert which is deadliest year of Tsunami in the Indian history. Therefore, NBDA as proposed comes out to be the self-validated algorithm, consequently the proposed algorithm implementation results in a close to 180 degree bearing angle thereby validating its prediction with a confidence of 85%. Such system can be deployed underwater and near shores to detect such hazards thus preventing major loss to life and property.

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