A Novel Trajectories Classification Approach for different types of ships using a Polynomial Function and ANFIS

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Abstract - In this paper, a Trajectories Classification Algorithm (TCA) is presented. The points of the tanker ship and fishing boat were collected in the same environment. Each trajectory of the tanker ship and fishing boat is partitioned to many segments to extract the features from each trajectory by using the polynomial function. The features extraction is used as input of the subtractive clustering to put the data in a group of clusters. Also, it is used as an input of the neural network in ANFIS.

The features extraction of each trajectory is represented with the membership functions and group of the Fuzzy If-then rules. The Initial Fuzzy Inference System (IFIS) is trained with artificial neural network to get the Final FIS. The performance of the TCA using a polynomial function and ANFIS is evaluated by different trajectories. The proposed TCA is tested using different trajectories obtaining a high classification accuracy 99.5%.

Keywords: Trajectories Classification; polynomial function; Subtractive clustering; ANFIS.

1 Introduction

Pattern recognition is a section of machine learning which aims to classify the trajectories of different kinds of objects. Trajectories’ classification is important research topic for predicting the type of moving objects (tanker ships and fishing boats) based on their trajectories and other features [1-3]. Trajectories’ classification is one of the hot topics that scientists are interested to work on. This study aims to discriminate between two different types of ships [4]: Tanker ship and fishing boat based on their trajectory data by using ANFIS. In the classification task, we work on predicting with the type of the object (fishing boat or tanker ship) that a trajectory belongs to. There are different features that are extracted from the tanker ship and fishing boat where the fishing boat moves in bending trajectories (no limitation of the movement of the fishing boat) and the tanker ship which moves in specified trajectories (simple trajectories) at sea. This presented innovative method that can be used widely in the future for detecting any abnormal ship movements through remote sensing, which can be an important assistance for security and coastal safety in general.

Adaptive Neuro-Fuzzy Inference System is used for the trajectories’ classification. ANFIS is not offered for all the Fuzzy Inference System options [5]. Fuzzy logic was proposed by Lotfi Zadeh [6]. Fuzzy logic concepts are contributed as an effective tool in automatic decision making systems such as pattern classification systems. In late 1980s, Neural Networks (NNs) and Fuzzy Logic (FL) technologies developed as an effective tool in many fields [7-11].

ANFIS is divided into two main groups: hybrid of neural network and fuzzy logic which combine to enhance the prediction capabilities so ANFIS merge both neural networks and fuzzy logic principles to take advantage of both of them in a single framework [5]. Artificial neural network performance depends on the size of training samples [12]. This means that the data must be prepared well before the training stage by artificial neural network. When the size of training data is small and doesn’t represent the possibility space, this preforms that the network results are poor [13].

For preparing the data before the classification stage, each trajectory is divided to many segments. A combination of polynomial function [14] and ANFIS are efficiently extract the features from each segment, and provide these features to ANFIS for the classification purpose for getting high classification accuracy and least average error.

This paper is organized as follows: Section 2 stated the trajectories characterization of the fishing boat and tanker ship. Section 3 stated the features extraction using the polynomial function, subtractive clustering and ANFIS. Section 4 stated training parameters using the ANFIS. The efficiency of the proposed method for classification of the ships trajectories in the proposed TCA through ANFIS is demonstrated in Section 4. In Section 5, the related work is discussed. In Section 6, conclusions are presented. Finally, references are presented in Section 7.
2 Trajectories

The Trajectories of both objects (tanker ship and fishing boat) are represented as a sequence of 2-dimensional points (vectors or trajectory elements) \([3, 4]\) \(<x_1; y_1; t_1>; \ldots; <x_n; y_n; t_n>\) where \(x_n\) and \(y_n\) represent the position of the object at time \(t_n\). In this paper, the temporal dimension is discarded, and each trajectory of both objects is presented as \(T = <x_1; y_1>; \ldots; <x_n; y_n>\). The sample rate of all trajectories is not constant where the temporal difference between the sequential samples is not always the same. Generally, the trajectories of both objects are different in temporal length, the number of data points and distance traveled. Each trajectory of both objects is partitioned to many line segments \([1, 2, 4, 15]\), and the used real trajectories database \([4]\) is represented two different types of ships in this study. This database is divided to two classes: Tanker ship class and fishing ship class. The total number of trajectories is 12 trajectories of both ships. The trajectories number of the tanker ship (points) is 6 (530), and the trajectories number of the fishing boat (points) is 6 (896).

3 Proposed Trajectories Classification Algorithm (TCA)

TCA consists of three parts that are: features extraction, subtractive clustering and ANFIS. The proposed algorithm is used to carry the goal of this research.

The proposed algorithm is illustrated in Fig.1.

The following subsections are clarified in the above system's block diagram.

3.1 Features Extraction

Polynomial function is used as a common base for extracting the coefficients (discriminating features) \([16]\) from each trajectory of both objects (tanker ship and fishing boat). The features extraction is the stage before the trajectories’ classification stage. For extracting the coefficients from each trajectory, the polyfit function is used “polyfit (x, y, n)” in MATLAB where ‘x’ and ‘y’ indicate the number of points of each trajectory of both objects which are represented as a Matrix and ‘n’ indicates the degree of the polynomial function \([14]\). This function is used to return the coefficients for a polynomial \(p(x)\) of degree \(n\) of each trajectory of both objects that is a best fit (in a least-squares sense) for the trajectory data in \(y\). A polynomial with a degree \(n\) is represented as in Eq. (1):

\[
p(x) = p_1 x^n + p_2 x^{n-1} + \cdots + p_n x + p_{n+1}
\]  

(1)
In simple and bending trajectories, when the coefficients number is increased by using the “polynomial function”, this will perform to “over-fitting problem” where the coefficients don’t represent the ships’ trajectories. For that, the increase of segments number helps in getting a very good representation of the sub-trajectories (all segments) of both objects, and overcomes on the “over-fitting problem”. There are a lot of experiments that are performed to specify the degree of the polynomial function (the degree of a polynomial is ‘4’).

The dataset contains all coefficients of all segments of all trajectories (both objects). The preparation of data is very important to get high classification accuracy and least average error so the coefficients extracted from all segments of all trajectories of both objects are partitioned to equal number of groups where the total number of groups is 22. The number of coefficients in each group depends on the length of the trajectories which include different number of points based on the type of object. The ‘standard deviation’, ‘variance’, max function’ and ‘bsxfun function’ in MATLAB [17, 18] are used for all coefficients of each group to reduce the size of dataset or to prepare the dataset well before the next stage (Subtractive Clustering) as shown in Fig. 6. This helped on reducing the number of rules which preformed to reduce the computational cost and training time [5]. In this study, 50 % of the dataset of each object is used for training by an artificial neural network, and 50 % of the dataset of each object is used for testing.
3.2 Subtractive Clustering

The training and checking data is uploaded to ANFIS EDITOR GUI of MATLAB. The training data is used in training the Sugeno based ANFIS in next phases. The purpose of the subtractive clustering is estimating the number of clusters and the cluster centers through the training data. Through the subtractive clustering, the training data is partitioned into clusters [19]. The procedure for grouping 22 data point clusters \( \{z_1, z_2, z_3, \ldots, z_{22}\} \) in the training set is described below [20].

1. Calculate the initial potential value for each data point \( (z_i) \) as in Eq. (2) [20].

\[
P_l = \sum_{j=1}^{n} e^{-\alpha(z_i - z_j)}
\]

\( \alpha = 4/\tau_a^2 \) where \( \tau_a^2 \) is a positive constant representing a normalized neighborhood data radius for each cluster. Any point will have a little effect if it drops outside this encircling region. The point is determined as a first cluster center if it has the highest potential value. This temporarily defines the first cluster center [20].

2. When potential value (\( p^{(1)} \)) is equal to the maximum of initial potential value (\( p^{(1)*} \)), the point is qualified as the first center as in Eq. (3) [15].

\[
p^{(1)*} = \max_i \left( p^{(1)}(z_i) \right)
\]

3. The threshold \( \delta \) is defined as the decision to continue or stop in search about the cluster center. The search about the cluster center will go on if the current maximum potential remains greater than \( \delta \) where \( \delta \) is defined as \( \delta = (\text{reject ratio}) \times (\text{potential value of the first cluster center}) \) where \( \eta \) is the rejection ratio and \( p^{(1)*} \) is the potential value of the first cluster center [20].

4. Remove the previous cluster center from further consideration [20].

5. Revise the potential value of the remaining points according to the Eq. (4) [20].

\[
p_l = p_l - p_k^* e^{-\beta(z_l - z_k^*)^2}
\]

Where \( p_k^* \) is its potential value, \( z_k^* \) is the point of the \( k_{th} \) cluster center, and \( \beta = 4/\tau_B^2 \) and \( \tau_B^2 > 0 \) indicates the radius of the neighborhood for which significant potential reduction will occur [21].

The work on generating the cluster centers is repeated until the maximum potential value in the current situation is equal to less than the threshold \( \delta \). We get different cluster center numbers from 22 training samples (patterns) after using the subtractive clustering (depending on the rejection ratio) [20]. The IFIS is generated with number of rules and membership functions at the end of clustering by using the subtractive clustering [19]. The training data is used to get the primary parameters of the membership functions [5]. The center of each cluster is projected to get the centers of the membership functions, and the widths of the membership functions are obtained on the basis of the radius [21].

There are multiple parameters that are used for clustering: Range Of Influence, Squash Factor, Accept Ratio and Reject Ratio. Range Of Influence indicates the radius of a cluster when the data space is considered as a unit hypercube [22]. The goal of the Squash Factor is that determines the neighborhood of a cluster center by multiplying the radii values in that factor [22]. The Accept Ratio contributes in determining the cluster center. When the value of Accept Ratio is high, this means that the data points have a very strong potential for being cluster centers [22]. The Reject Ratio contributes too in determining the condition to reject a data point to be a cluster center [20]. The criteria in determining the cluster center depends strongly on the Accept and Reject ratios [20]. Based on these parameters are mentioned before, the IFIS is constructed as shown in Fig.1.

The clustering parameters are used in this study are shown in Table I.
3.3 Adaptive Neuro-Fuzzy Inference System (ANFIS)

Adaptive Neuro- Fuzzy Inference System (ANFIS) is used in many applications [5, 23-25]. In this study, ANFIS is used for a classification purpose where it is used for predicting the type of object: Tanker ship or fishing boat through their trajectories. There are two kinds of fuzzy logic inference system: Mamdani fuzzy logic inference system and Takagi-Sugeno fuzzy logic inference system. The ANFIS has a good advantage where it merges artificial neural network and fuzzy logic system [24]. The Artificial Neural Network works on training the IFIS to access to least possible error between the desired output and FIS output through the dataset to obtain Final FIS as in Fig.1. The schematic of the architecture of ANFIS based on Sugeno fuzzy model is shown in Fig.7.

The ANFIS works on classifying the data based on the features extracted values [26] which represent the trajectories characteristics which apply as inputs of ANFIS. The structure of ANFIS [6] included input parameters, input membership functions, Fuzzy rules, output parameters which represent trajectories, output membership functions, and resultant prediction of trajectories. The hybrid-learning algorithm [27, 28] is employed here where it is used to fit the input and output membership parameters. The Hybrid learning rule is faster than the classical back-propagation method [29]. The Hybrid FIS is trained in 3 Epochs, and the Error tolerance is kept zero for the process. The Hybrid FIS is a combination of back-propagation algorithm and Least Squares [5]. The average error rate depends strongly on the number of membership functions. In addition, the average error rate and classification accuracy depend on the difference between the FIS output curve and checking data curve [5].

The ANFIS is evaluated with new input data (checking data) where an ANFIS simulates the checking data with the stored data [24]. After the training phase is successfully completed by using an artificial neural network, the Final FIS is tested with the checking data introduced where the training data is converted to Fuzzy data. The fuzzy data has value between '0 to 1' [23]. The ANFIS works on the basis of IF-Then rules [5] where the IF-Then rules change if any change (modify) happened in the membership functions. Based on the IF-Then rules, the checking data (input data) is compared with the trained data (output data). The ANFIS works on training the fuzzy logic system by changing the membership functions [24]. The membership functions represent the training and checking data which are uploaded from MATLAB workspace, and the input membership functions are shown in Fig. 8. The total number of IF-then rules is 4 rules where each IF-Then rule contains six coefficients where five coefficients are multiplied with five inputs in addition to the constant. IF-Then rules are the core of fuzzy logic, and are related varies stages with input parameters [5]. Each IF-Then rule explains some relationships between the input and output variables [25].

TABLE.I. The clustering parameters are used in this study

<table>
<thead>
<tr>
<th>Clustering Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range Of Influence</td>
<td>0.8</td>
</tr>
<tr>
<td>Squash Factor</td>
<td>1</td>
</tr>
<tr>
<td>Accept Ratio</td>
<td>0.5</td>
</tr>
<tr>
<td>Reject Ratio</td>
<td>0.15</td>
</tr>
</tbody>
</table>

The ANFIS is evaluated with new input data (checking data) where an ANFIS simulates the checking data with the stored data [24]. After the training phase is successfully completed by using an artificial neural network, the Final FIS is tested with the checking data introduced where the training data is converted to Fuzzy data. The fuzzy data has value between '0 to 1' [23]. The ANFIS works on the basis of IF-Then rules [5] where the IF-Then rules change if any change (modify) happened in the membership functions. Based on the IF-Then rules, the checking data (input data) is compared with the trained data (output data). The ANFIS works on training the fuzzy logic system by changing the membership functions [24]. The membership functions represent the training and checking data which are uploaded from MATLAB workspace, and the input membership functions are shown in Fig. 8. The total number of IF-then rules is 4 rules where each IF-Then rule contains six coefficients where five coefficients are multiplied with five inputs in addition to the constant. IF-Then rules are the core of fuzzy logic, and are related varies stages with input parameters [5]. Each IF-Then rule explains some relationships between the input and output variables [25].
4 Experiment Results

In this study, the training and checking of the proposed algorithm is done by using the ANFIS. There is 12 trajectories of both ships is applied to the proposed algorithm where six trajectories (three trajectories of both ships) is used as a training data and the other six trajectories (three trajectories of both ships) is used as a checking data for the proposed algorithm. The tanker and fishing trajectories are correctly classified by using the ANFIS. The ‘5’ input parameters are used for training and checking aims and work on getting high classification accuracy and least average error where the training and checking data is uploaded to the ANFIS Editor. The input and output parameters on FIS is shown in Fig.9. The Designer of Neuro-Fuzzy shows the checking data appears as plus signs (+), and the training data appears as circles (O) [19]. The Hybrid is specified as an ANFIS model parameter optimization. The number of training epochs is kept to the default value ‘3’, and the training error tolerance is kept to the default value ‘0’.

The Sugeno ANFIS is implemented in MATLAB R2011a. 50% of the dataset is used as a training data, and 50% of the dataset is used as a checking data. In other words, the Sugeno ANFIS is tested on 50 % of dataset. After IFIS is generated, it is trained with 4 membership functions by using the Artificial Neural Network. The input and output parameters are presented with group of membership functions. The IFIS is trained many times to get high classification accuracy and least average error. The average testing error is very small which is near to the tolerance limit. 99.5% correct classification is obtained at the ANFIS training with checking data, which indicates (reflects) a good discrimination of the trajectories of both ships. After the IFIS is trained, the trained FIS is tested against the training and checking data to notice the difference in average testing error between both of them.

The output of the FIS appears on the plot as asterisks * * * * * * * * * *. The plot indicates that there is very less contradiction (conflict) between the training and checking data output and the output of the FIS as shown in Fig 10, 11.
The average testing error is calculated by testing the training and checking data against the trained FIS as shown in Table. II.

<table>
<thead>
<tr>
<th>The average testing error</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testing the training data against the trained FIS</td>
<td>1.4426e-5</td>
</tr>
<tr>
<td>Testing the checking data against the trained FIS</td>
<td>0.0051065</td>
</tr>
</tbody>
</table>

5 Related Works

In the field of pattern recognition, the trajectories classification is used widely in many applications such as automatic recognition of handwritten postal codes on postal envelopes, signature, handwriting image and automatic speech recognition. In many of proposed methods, the Hidden Markov Model (HMM) classifier is used for the trajectories classification. G. Vries, W. Hage and M. Someren [3] worked on predicting with the type of the vessels through their trajectories by clustering the trajectories into groups of similar movement patterns and used the SVM for the classification purpose. The trajectories haven’t been partitioned to many segments before using the SVM classifier. They got classification accuracy 75.4%.

J. Lee, J. Han, X. Li and H. Gonzalez [4] worked on trajectories’ classification of two difference types of ships: Tanker ship and fishing boat by partition each trajectory of both ships to number of segments which helped on discriminating the parts of trajectories identifiable and explored two types of clustering: region-based and trajectory-based which worked on finding the features of the sub-trajectories and then used the SVM for the classification purpose. The cooperation between two types of clusters helped on discriminating the features of sub-trajectories of both ships and got high classification accuracy 98.2%.

R. Pelot and Y. Wu [1] worked on boats’ trajectories classification of 4 different types of the recreational boats to figure out the difference in the movements characteristics across boat types. The samples of the boats’ trajectories were accumulated in two environments. To discriminate between different types of boats, there are 7 variables helped in that: Mean Speed (MS), Max1/20 Speed, Mean Turning Angle (MTA), Total Distance traveled (TD), Aspect Ratio (AR), Coverage Index (CI) and furthest Distance from Shore (DFS), but MS, MTA and DFS are most active variables in discriminating the boat type. The statistical multivariate approach helped in specifying the group to which an object belongs by forming discriminate function for each boat group. These functions, which include three active variables, played important role in specifying the boat types. Based on the forming discriminate functions, the highest classification accuracy for discriminating between boat types is 99.7%.

We worked on extracting the coefficients from each segment of all trajectories of two different types of ships using a polynomial function. This helped in getting a good representation of all segments in all trajectories. The used database [4] contains fishing boat’s trajectories (bending trajectories) and tanker ship’s trajectories (simple trajectories). The training and checking datasets are prepared well before uploading them to the ANFIS. ANFIS is used for the classification purpose. In this study, we could obtain a high classification accuracy (99.5%) compared with [3] and [4]. The innovated method is a simple method for getting high classification accuracy between two different types of ships compared with previous study as in [4]. The trajectories of the 4 types of recreational boats [1] are simple trajectories compared with the trajectories of fishing boat (bending trajectories) which were used in this study and previous study as in [4].

6 Conclusions

In this paper, a novel method for classifying the trajectories of two different types of objects (fishing boat and tanker ship) by using the Adaptive Neuro-Fuzzy Inference System has been presented. This method enables us to classify different types of objects that have different trajectories at sea. There are lot of experiments, which are made using a real database, for getting high classification accuracy (99.5%) and lowest average error that is near the predefined tolerance limit.
The performance of the trajectories classification system is evaluated through figuring out the average error where the trained FIS is tested against the training and checking data.

The ANFIS is used for the classification purpose. The ANFIS combines artificial neural network and fuzzy logic system which help in getting a very high level of the classification accuracy. Sugeno FIS is implemented to work on classifying the trajectories. The tasks of features extraction and classification were performed using polynomial function, subtractive clustering and ANFIS. The trajectories of the two ships are partitioned to many segments. The polynomial function is used to extract the features from each segment of all trajectories. These features make the system suitable for trajectories classification. The subtractive clustering is an effective tool to take the details of training data and place them in a group of clusters. The subtractive clustering method is used to estimate the number of clusters and cluster centers in a set of data where each point supposed as a potential cluster center. In other words, each data point is defined as a cluster center based on the density of surrounding data and is computed by the subtractive clustering.

The IFIS is generated by the subtractive clustering with minimum number of rules. The Artificial Neural Network works on training the IFIS for getting the Final FIS which perform to increase the ability of ANFIS in trajectories classification efficiently.

This study proves the ability of the trajectories classification system in classifying different trajectories of two different kinds of ships effectively by using the ANFIS.

7 References


