Analysis of fuzzy logic systems types 1 and 2 in identifying of IUU fishing and transshipment: a case study in Indonesia's vulnerable waters

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Abstract. The identification system for illegal, unreported, and unregulated (IUU) fishing and transshipment of incidents is one effort as early warning and it can be adopted by the Indonesian ministry of fisheries and marine affairs. The system has been developed using several methods. One of them is the artificial neural networks (ANN) have been used, but it is several weaknesses when AIS data is lost. The system able to identify in missing data in a short duration of time only. The development of a system for IUU identification proposed using a fuzzy logic system (FLS). The IUU identification system consists of subsystems: (i) missing data prediction, (ii) anomaly trajectory decision, (iii) IUU selection, and (iv) IUU decision. The performance of FLS is compared between fuzzy type 1 and type 2. The system tested using data of IUU occurrences waters in high frequency. Both SLF type 1 and type 2 are able to give result in very good accuracy for IUU fishing and transshipment identification.

1. Introduction
Illegal, unreported and unregulated (IUU) fishing accounts for 20 percent of the world catch and up to 50 percent in some areas. Likewise, what happened in Indonesia where the ocean area was so large and the marine products were abundant, Indonesian waters became the target of foreign ships to carry out IUU fishing and transshipment. The potential for the product of marine resources for export is increasing, and is marked by the value of fish resources of 12.54 tons per year with an export value of USD 5.2 billion annually [1]. On the other hand, supervision of Indonesian waters remains as a priority in handling incidents that are categorized as illegal. Illegal activities that are commonly carried out in the Indonesian Sea area are illegal fishing, and illegal transfer of cargo in the middle of the sea[2]. These illegal activities are generally referred to as Illegal, Unreported, and Unregulated (IUU) Fishing and Transshipment. These two activities are interrelated with each other, because generally fish caught illegally will not be sold in a legal way. The fish are usually transferred to collector ships that are already waiting in the middle of the sea, then taken out of Indonesia[2]. This action is taken to avoid paying taxes at the port. This practice violates the Regulation of the Minister of Maritime Affairs and Fisheries of Indonesia Number 57/Permen-KP/2014 concerning the Second Amendment to the Regulation of the Minister of Maritime Affairs and Fisheries Number
Per.30/Men/2012 concerning Capture Fisheries Business in the Fisheries Management Area of the Republic of Indonesia.

Several technologies that have been developed for monitoring ship movements, including identification of IUU transshipment violations, such as AIS (Automatic Identification System), VTS (Vessel Traffic Services), and radar devices. AIS is an automated ship tracking system used on ships and shore stations. AIS has functions to identify and track vessels. AIS as an important equipment that supports traffic control and traffic control at sea [3]. The AIS system is mandatory to be installed by all ships with a size above 300 Gross Tonnage (GT) and especially for ships involved in international shipping, both commercial and tourist ships, and sailing ships with a length of more than 20 m are required to use AIS from 1 December 2014 in accordance with the resolution of the Central Commission for Navigation of the Rhine (2013) [4].

The IUU transshipment identification system based on AIS data and radar using fuzzy logic, has been designed in order to assist the ministry of fisheries and shipping in the efficiency of the role of patrol boats that are far away from the position of the offense. The system of alleged violations of IUU in waters in Indonesia is intended to be immediately handled by patrol boats based at the nearest port. The accuracy of the designed system is 83.075% [5]. The design identification system works partially, which is only able to identify separately between alleged violations of IUU fishing or transhipment. The system is designed using type 1 fuzzy logic method, by changing all input and output variables into fuzzy variables. Decision making is based on rules that have been designed, in accordance with the rules of expertise.

Integration of the system is proposed to make it more optimal in decision making. AIS data from various ships can be used to make decisions from two presumed conditions, namely an alleged IUU fishing or an alleged IUU transhipment or a ship sailing in accordance with its normal conditions. The system is said to be an integrated system of systems that produce IUU fishing and IUU transhipment decisions. The accuracy of this system decreases, which is 75% [6]. The weakness of the system is that when filtering data, it has an impact on decreasing accuracy, compared to the results of the previous design. Efforts to improve the accuracy of the system integration, namely by proposing the Adaptive Neuro-Fuzzy Inference System (ANFIS) method, in both the IUU fishing and IUU transhipment identification sub-systems. These efforts showed an increase in accuracy of 89.3% for the IUU fishing identification system and 87.4% for the IUU transhipment identification system [7].

The incident that is often carried out by several ships that violate is by removing the AIS device. The loss of AIS data is a weakness for pre-designed systems. Incomplete AIS data during the voyage needs to be predicted for the trajectory as long as the ship cannot be detected by the receiver system in the ECDIS monitoring system. An integrated system of IUU fishing and transhipment identification by adding a predictor due to missing data in AIS data, is able to provide an accuracy of 99.64% identification [8]. The design system uses a type 1 fuzzy logic method. This very high accuracy value occurs when the data loss is categorized as short duration. Some of the design results that have been carried out need to be analyzed for the system as a whole. Proposals to improve accuracy, namely by designing a type 2 fuzzy logic system. Differences in the identification results due to the type of fuzzy logic will be examined in this study.

2. Methodology

The proposed design system is shown in Figure 1, there are 3 sub-systems, namely: (i) predictor sub-system, (ii) selection sub-system, and (iii) decision-making sub-system. The predictor system is designed using ANN with a function to predict the position and speed of the ship. The selector and decision-making system was designed using ANN, type-2 fuzzy logic system (SLF), and also replaced with FLS type 1. The system was tested using 2 types of data, namely (i) generated data, and (ii) actual data. Both data are AIS data which are categorized as static and dynamic data. Static data used is data on ship type information, while dynamic data used are (i) ship position data in degrees of longitude and latitude, (ii) ship direction, (iii) and ship speed data.
The predictor system to predict information of the position, speed and direction of the missing data ship within a certain time span. Prediction is carried out using the RNN method, which is illustrated in the diagram Figure 2 below. If the data W is missing, which can be equated with the delay in a certain period of time, and then the missing data series can be replaced to be predicted based on the following values: \( x_t \) is the input at each time step, \( s_t \) is the hidden state at each time step \( t \), and \( o_t \) is the output for each step \( t \). RNN consists of a layer that repeats and is called Long-Short Term Memory (LSTM). By using a comparison algorithm worth, then in the period where the data is lost, it will be predictable.

The stages in predicting are, namely: the data training stage, and the processing stage. Both stages are carried out in RNN. The training stage is said to be the forward pass stage, where the input will be propagated to the output layer. The processing stage is the stage where the results of the output will be compared with the correct target data, and in this process using a loss function. The RNN parameters that determine the performance of the prediction results are: the number of input patterns (time steps), the number of LSTM layers, the number of neuron units and the learning rate value. The prediction results will be compared with the results at the validation stage, by using other data. The result of comparing in prediction and validation, if it produces an error within the accepted tolerance, then the parameters of the RNN will be used as RNN predictors.

The stage in preprocessing is to normalize data from all input variables that have the same range, namely 0 to 1. The function of normalization is to speed up convergence during training and testing. The data needed in the simulation is data on ship sailing in areas that indicate the alleged frequent occurrence of trajectory anomalies, for example, the movement of shipping lanes that are not in accordance with the initial set in Natuna waters. The ship position data is processed using the Haversine equation to get the distance between two ships in meters [9]. The direction and speed data of the two ships were calculated to get the heading difference variable and the speed difference variable between the two ships. Actual data obtained from NASDEC ITS. Data generation is done to complete the lack of data obtained.
The missing AIS data will be predicted by the predictor system, to determine the trajectory pattern according to the previous historical data, and the trajectory prediction results will be compared with the reference trajectory data as the initial trajectory setting. The comparison of the two trajectories, namely the magnitude of the distance error will be an input variable in the selector system. The selector system produces an "alleged" output of violations in the IUU. The alleged value becomes the input for the decision-making system, with the output "Yes" or "No" in committing a violation. Figure 3 shows the units in the type-2 fuzzy logic system, which consists of the same 3 units as the type 1 fuzzy logic system and added 1 unit Type reducer - which is placed in the block before the defuzzifier.

There are two input variables in the selection system, the first is difference in distance between 2 ships, and the second is difference in headings for 2 ships. The distance between two ships, expressed in fuzzy variables categorized as: Near and Far, while the difference in headings of 2 ships, is in the categories: Overtake - OT; Crossing - C, and head-On - HO. The two variables mentioned, are expressed in fuzzy variables which are shown in Figure 4 below. The output value of the selection system uses the rule below:

(R1) If (delD is near) and (delHead is HO) then (Out is IUUTran)

(R6) If (delD is far) and (delHead is OT) then (Out is IUUFis)

Figure 3. Block diagram Fuzzy Logic System Type-2 [2]
distance between the two ships and the difference in headings are categorized into 2 categories, namely: big and small. The IUU fishing decision system works based on variables: (i) the speed of the vessel when casting the net, (ii) the speed of the vessel when pulling the net, (iii) the speed of the vessel when lifting the net, and (iii) the change in position of the vessel. Each variable is categorized into 3 fuzzy sets, namely: small, medium, and big. The variables under review are expressed in the form of fuzzy variables as shown in Figure 5. The number of rule bases in the decision system is 81, which is shown as follows:

(R1) If (Vc is Low) and (Vt is Low) and (Vh is Low) and (delD is Small) then (Out is High)
(R81) If (Vc is Big) and (Vt is Big) and (Vh is Big) and (delD is Big) then (Out is Low).

![Figure 5 Membership function of input and output variables of Decision System in IUU Fishing and Transhipment](image)

3. Result and Discussion

3.1. Simulation Result

The predictor sub-system functions to predict the AIS data of the missing IUU transhipment vessel. Predictor sub-system consists of predictor of ship position, predictor of ship speed and predictor of ship heading. Predictors for the prediction of AIS position data (longitude and latitude) and headings of ships carrying out IUU transshipments were designed using a recurrent neural network (RNN). The ship position predictor has RNN parameters in the form of a time step of 5, LSTM layer 1, LSTM unit neurons as much as 20, and a learning rate of 0.005. Meanwhile, heading prediction has RNN parameters in the form of a time step of 2, LSTM layer 1, LSTM neuron units as much as 25, and a learning rate of 0.005. While the design of the predictor to predict the AIS data of the missing ship's speed using the value comparison method by comparing the distance and speed values.

The predictor subsystem was tested using data generated in the Madura Strait. There are 180 missing AIS records. The position and heading predictor of the ship is able to produce high accuracy with MAPE values for prediction of longitude, latitude and heading, respectively, which are 0.00085315%, 0.01214321% and 0.31860183%. While the speed predictor is able to produce good accuracy with the MAPE value for speed prediction of 14.929754%. Figure 6 are the results of the prediction of the ship's position, heading and speed.
3.2. DataAnomaly Identifier Subsystem

The anomaly subsystem serves to provide information on which ships are out of their reference path. Vessels that leave the road indicate that the ship is carrying out IUU fishing or transshipment practices.

Figure 7 shown of the movement of the Lurongyuanyu 105 ship and the Eagle Seville ship carrying out IUU transshipment practices. The data of these two ships is used to test the system that has been designed. After calculating the distance between the reference line and the real position of the ship Lurongyuanyu 105 is 151.5 meters. This value is used as input for the anomaly subsystem. After the system is run, the decision value is 1. This indicates that the system is able to recognize that the Lurongyuanyu ship is out of its reference path, because the decision value is more than 0.5. With this result, the Lurongyuanyu ship was suspected of carrying out IUU fishing or transshipment practices. Furthermore, further identification will be carried out using the selector subsystem.
3.3. Subsystem Selection

Subsystem selection is designed using ANN and FLS type-2. The subsystem was tested with the Lurongyuanyu 105 ship and the Eagle Seville ship which were carrying out IUU transshipment actions in the Batam Sea as shown in Figure 6. Based on calculations using the Haversine theorem [11], it was found that the distance between the two ships was 12.7 meters. With the condition that the relative heading difference obtained from the AIS data of the two ships is 175. The distance value and the relative heading difference between the two ships are the input values for subsystem selection. So as to produce a decision value that is above 75%. The decision value shows that the system can recognize IUU transshipment actions carried out by Lurongyuanyu 105 and the Eagle Seville ship with a confidence level of above 75%.

![Figure 8 Circular Motion](image)

The fishing boat under review performs a circular motion as shown in Figure 8. This is the same as the characteristics of fishing boats that catch fish using cantrang nets [12]. Fishing using cantrang nets is illegal in several areas of Indonesian waters according to the Regulation of the Minister of Maritime Affairs and Fisheries of Indonesia Number 57/Permen-KP/2014 concerning the Second Amendment to the Regulation of the Minister of Maritime Affairs and Fisheries Number Per.30/Men/2012 concerning Capture Fisheries Business in Indonesia. Fishery Management Area of the Republic of Indonesia.

3.4. Subsystem Decision

The final condition of the Lurongyuanyu 105 ship and the Eagle Seville shown in Figure 3 shows that the two ships have a distance of 12 meters between them, with a heading direction difference of 175 and a speed difference of 0 knots. This condition was evaluated in the decision subsystem and resulted in a decision value of the occurrence of IUU transshipment with an estimated level of 75.5%.

The fishing boats evaluated on the decision system have speed data that varies according to the fishing process carried out, namely: (i) casting, (ii) towing, and (iii) hauling [13]. The speed obtained from the ship's AIS data shows the movement pattern of fishing vessels that catch fish using cantrang fishing gear. The speed of cantrang fishing boats is relatively lower than that of purse seine fishing boats [12], because cantrang fishing boats require a low speed to spread nets around a group of fish.

The fishing boat data shows that the boat moves in a circle with an average speed of 0.2 knots, then moves straight for a while with an average speed of 1.0 knots, and finally slows down with an average speed of 0.01 knots. The evaluation carried out by the subsystem decision on the fishing vessel in Figure 4, resulted in the decision value of IUU fishing with an estimated level of 80.8158%.
3.5. Performance Comparison of FLS type-1 and type-2 based System

The IUU transshipment and illegal fishing identification system was compared with the system designed by Novia[6] using the same data. The identification system using FLS type-2 produces lower value than the system designed by Novia. This indicates that the system designed in this study cannot produce a higher estimated value than the previous system. That is, the system that has been designed is not more convincing than the system that has been designed in previous studies. This is caused by a decrease in the value of membership that arises due to system input data. This decrease in membership value is caused by the process of finding the center of gravity of the output membership function by a type-2 fuzzy logic system.

Table 1. Performance of the designed IUU system

| IUU Cases            | Sub-system Selection Result (SLF-1) | System Decision Result (SLF-1) | Sub-system Selection Result (SLF-2) | System Decision Result (SLF-2) |
|----------------------|------------------------------------|--------------------------------|------------------------------------|--------------------------------|
| IUU Transhipment Test 1 | 84.0                               | 83.6                           | 85.0377                           | 75.5                           |
| IUU Transhipment Test 2 | 83.4                               | 83.6                           | 85.0377                           | 83.0364                        |
| IUU Transhipment Test 3 | 81.5                               | 80.5                           | 75.5                              | 75.5                           |
| IUU Fishing Test 1    | 20.4                               | 76.55                          | 15.2435                           | 75.8943                        |
| IUU Fishing Test 2    | 17.0                               | 79.6                           | 15.2435                           | 75.8943                        |
| IUU Transhipment 1 Validation | 84.0 | 83.67                          | 84.1616                           | 82.464                         |
| IUU Transhipment 2 Validation | 84.0 | 83.6                           | 82.4453                           | 75.5                           |
| IUU Fishing 1 Validation | 16.3 | 81.2                           | 16.44                             | 80.8158                        |
| IUU Fishing 2 Validation | 16.3 | 76.6                           | 16.44                             | 75.8943                        |
| IUU Fishing 3 Validation | 17.8 | 24.5                           | 16.44                             | 24.5                           |
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