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Illegal, Unreported and Unregulated (IUU) Fishing and Transshipment Identification System Design Towards a Resilient Indonesian Marine

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Abstract

The Indonesian sea, as one of the main trade routes in the world, is very vulnerable to infringing practices, including Illegal, Unreported, and Unregulated (IUU) fishing and transshipment. Therefore, strong fisheries and marine regulations are imperative to uphold the principles of state sovereignty, ecosystem sustainability, and people's welfare. One of the strategies to improve Indonesia's maritime security is through the design of systems that identify all forms of sea infringements. This study designs an IUU fishing and transshipment identification system using the fuzzy type 2 (SLF-type-2) method. The dynamic data input variable is obtained from Automatic Identification System data by building 3 subsystems, which are the selector subsystem, the IUU transshipment decision maker, and the IUU fishing decision maker. The test is carried out in two ways that involve the generation of ship motion pattern data and the validation of ship data. The results showed that the constructed identification system successfully identified IUU fishing and IUU transshipment actions, with a maximum accuracy of 85.0377% and a minimum accuracy of 75.5%.

Keywords: AIS, IUU fishing and transshipment, fuzzy, SLF-type 2, marine

1. Introduction

From 2012 to 2017, the Indonesian fishing industry experienced significant growth. The increase in production drives the escalation in the export value of fishery products amounting to 5 billion USD [1]. However, the potential of existing marine resources may be disrupted by Illegal, Unreported, and Unregulated (IUU) fishing and transshipment. The threat of IUU transshipment is caused by the current condition of the global fisheries sector, which has decreased fish stocks, due to restrictions in some countries on granting fishing permits, while the demand for fishery products increases. On the other hand, the supervision of Indonesia's marine and fishery resources is inadequate [2]. According to the Ministry of Maritime Affairs and Fisheries, IUU fishing and transshipment are a serious peril to Indonesia, since the country has more than 3000 species of fish which point to an enormous potential of marine resources that can be exploited by anyone. Furthermore, the vast sea border area in Indonesia makes monitoring of IUU fishing and transshipment very challenging.

Several technologies that have been employed so far to monitor IUU transshipment are Automatic Identification System (AIS), Vessel Traffic Services (VTS), and radar. AIS is an automated ship tracking system operated on ships and shore stations and functions to identify and track vessels. Unfortunately, the information contained in the AIS data has too much unnecessary data, as a consequence, information about the ship's path is often inaccurate. In 2018, Zhang et al. [3] proposed a ship path reconstruction model by eliminating noise in AIS data, thus more accurate ship path information was obtained. Research conducted by Damastuti et al. [4] regenerates data by building information from missing AIS data enabling ship monitoring able to be carried out continuously. Bal Beşikçi et al. [5] 2016 made

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a decision-making system with an artificial neural network (ANN) model to predict fuel consumption on ships with an error of 0.14%.

IUU Fishing has a negative impact on the fishing business since many fishermen quit their profession due to competition with other larger industrial groups that engage in illegal practices. IUU fishing is not only Indonesia's problem but also a global issue. It is estimated that 78% of the world's oceans have been spoiled by IUU fishing activities [6]. These illegal practices are transnational crimes that have a very detrimental impact on the fishing industry, as well as on issues related to the environment [7]. Based on the above background, this research will design an identification system to detect ships that are commiting illegal practices using a type-2 fuzzy method. In this study, the input variable uses dynamic data derived from AIS data by building 3 subsystems, which are the selector subsystem, the IUU transshipment decision maker, and the IUU fishing decision maker.

IUU stands for IUU which in essence is a violation of an activity regulation. Illegal fishing is an illegal fishing activity without having a license to catch fish. Unreported fishing is the result of fishing that is not proclaimed to the authorities. Unregulated fishing activities are violating the regulations, such as fishing using bombs or prohibited nets. Transshipment happens when the fish is caught in the sea area, it violates the law since all transactions should be carried out on land [8].

IUU fishing and transshipment activities can be identified through the pattern of changes in vessel speed and vessel trajectory. Ships that are currently conducting fishing activities, generally have a pattern of ship changes. This pattern of changes in the speed of fishing boats is divided into 4 processes that are searching, casting, towing, and hauling. Regulations regarding the prevention of ship collisions in the middle of the sea are formulated by the International Maritime Organization. This regulation discusses basic safety measures that must be fulfilled by a ship in order to avoid collisions between ships in the sea. Some maneuver techniques stated in the regulation as a precaution against ship collisions are head-on, crossing, and overtaking. Figure 1 is an image of the ship maneuvering technique used to review ships carrying out transshipments based on the close distance between ships [10].

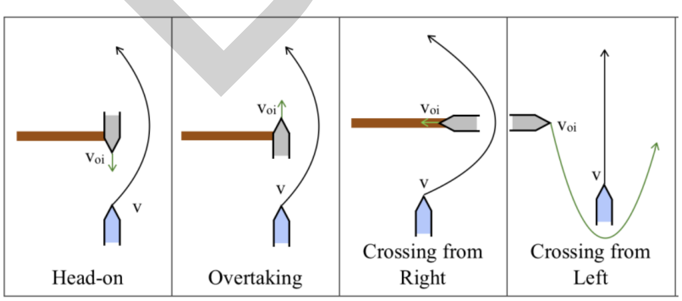

Figure 1. *Anti-collision maneuver pattern [11]*

2. Materials and Methods

2.1. Data Collection

The data mobilized in this study is divided into two: validation data and test data. Validation data is the ship's AIS data obtained from AIS-Institut Teknologi Sepuluh Nopember (ITS) as a reference for validating the system's ability to identify real AIS data. AIS data consists of static data—that is almost never changed—and includes information on, for example, ship type and maritime mobile service identity. Dynamic data are automatically updated continuously, which consist of position, speed, and course over ground [12]. Validation data is also used as the basis for generating test data, that follows the movement pattern of ships committing IUU fishing and transshipment activities. The test data is AIS data on IUU fishing and transshipment vessels, built using the Google Earth website application, employed for simulation and system performance testing. The variables taken from the actual AIS data and generated for usage in the system are the latitude and longitude position data of the ship, ship heading, and ship speed.

2.2. System Design

The system design is divided into two parts, which are the selector system and the decision system as shown in Figure 2. The input from the selector system is the distance difference and the heading difference between the two ships. This selector system is utilized to select data on vessels suspected of carrying out IUU, to determine whether the data concerns IUU fishing or transshipment. The output of the selector system is a value of 0 to 100. If the output value of the selector system is 0-50, then the ship is suspected of conducting IUU fishing. Meanwhile, if the output value of the selector system is 51-100, it can be assumed that the ship is committing IUU transshipment.

The IUU fishing decision system operates 4 input variables, such as the speed of the ship when casting fishing nets, the speed of the ship when towing fishing nets, the speed of the ship when hauling fishing nets, and changes in the position of the ship in nautical miles. Changes in position under review are changes in the total position of the ship. Thus it is able to reduce the rule base used in the system and in capacity to speed up the system evaluation process. The output of the IUU fishing decision system is a value of 0 to 100, which represents the percentage of alleged IUU fishing actions. The greater the value, the higher the suspicion toward the ship engaging in IUU fishing. Meanwhile, the IUU transshipment decision system has 3 input variables, which are the distance between the two ships, the difference in headings between the

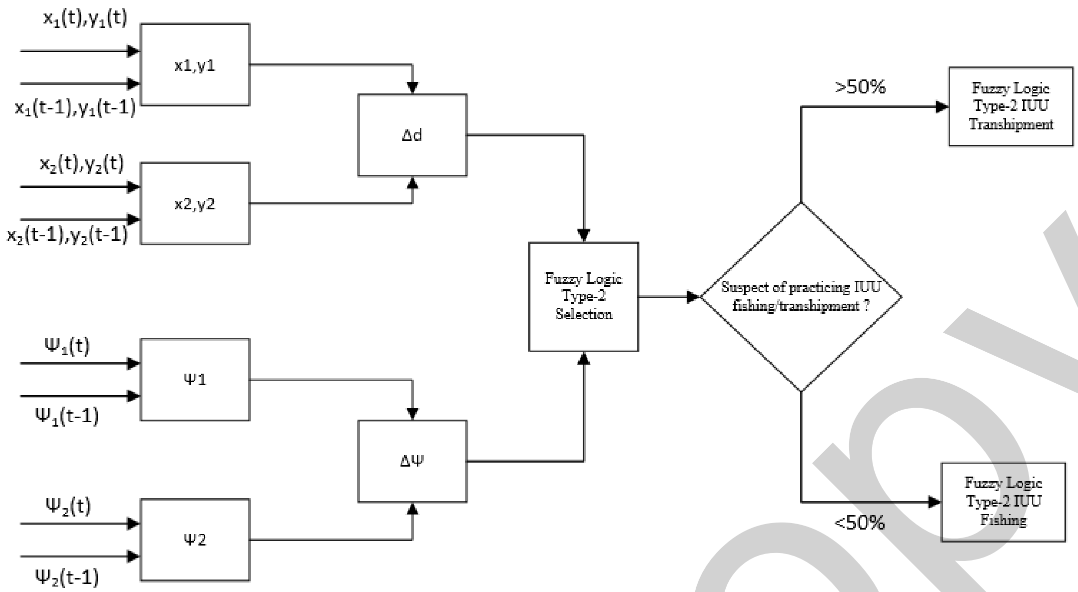

***Figure 2.** Selector system design*

IUU: Illegal, unreported and unregulated

two ships, and the difference in speed between the two ships. The block diagram of the IUU transshipment and fishing system can be described in Figures 3 and 4.

Input variables in research can show in Table 1.

The selector system will process the input data in the form of the distance between the two ships (Δ*d*) and the difference between the headings of the two ships (ΔΨ). The parameters used in each input membership function of the type-2 fuzzy logic system are based on the competence of marine experts. Parameters on the input variable of the distance between the two ships are determined with a range of 0-800 meters. The distance of 500-800 meters becomes the alert distance between two ships with a total length of 20-200 meters, while more than that is considered a safe distance. The value of the distance ships is obtained by operating the value of the position of latitude and longitude of both ships into the Haversine equation (1) where ΦA is the degree of latitude of ship 1, λB is the degree of latitude of ship 2, λA is the degree of longitude of ship 1 and λB is the longitude degree of ship 2.

$$a = \sin^2\frac{(\Phi B - \Phi A)}{2} + \cos\Phi A \times \cos\Phi B \times \sin^2\left(\frac{\lambda B - \lambda A}{2}\right)$$
$$c = 2 \times atan2\left(\sqrt{a}, \sqrt{(1-a)}\right)$$
$$d = R \bullet c \quad (1)$$

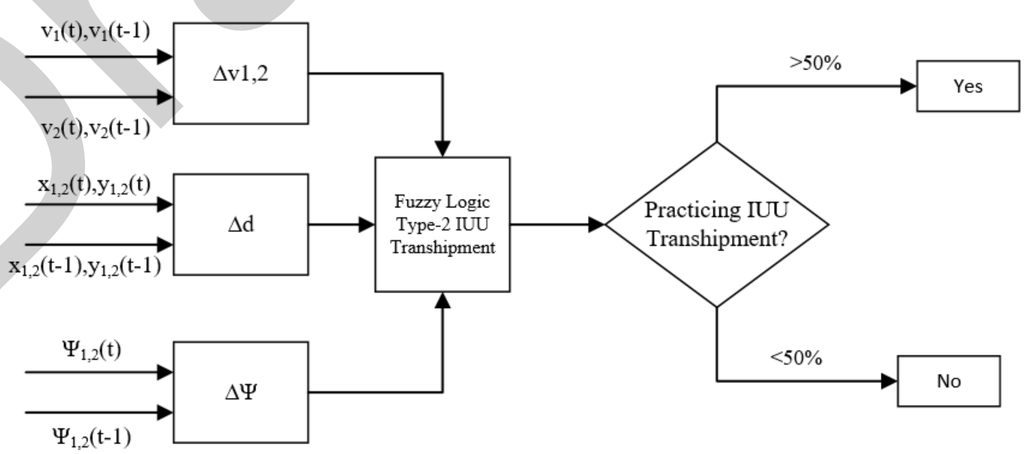

***Figure 3.** IUU transshipment decision system block diagram*

IUU: Illegal, Unreported and Unregulated

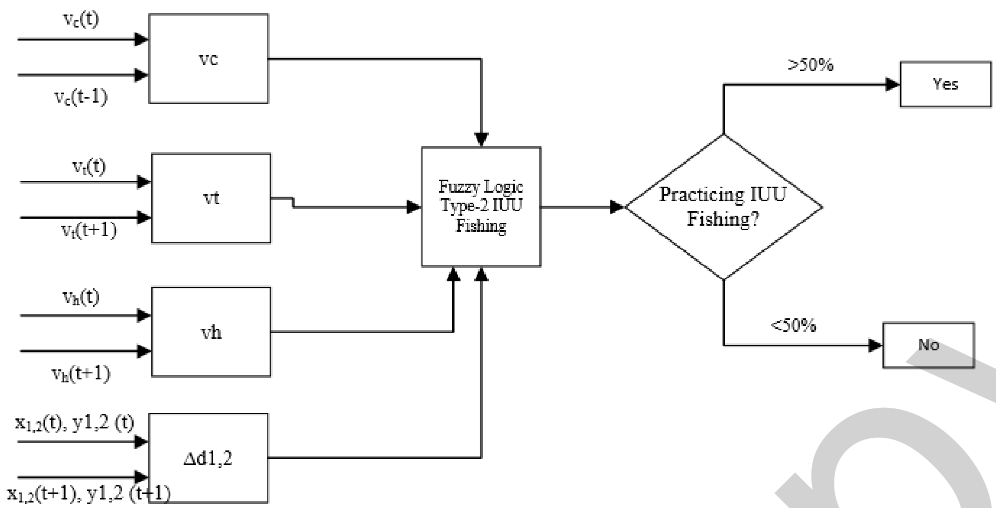

Figure 4. *IUU fishing decision system l block diagram*

IUU: Illegal, Unreported and Unregulated

Table 1. *Input variables in research*

No	Notation	Remark
1	$dv_{1,2}$	The difference in speed off ship 1 and ship 2
2	Δd	Distance between ship 1 and ship 2
3	$\Delta\Psi$	The difference between the headings of ship 1 and ship 2
4	x_1,y_1	Latitude and longitude of ship 1
5	x_2,y_2	Latitude and longitude of ship 2
6	Ψ_1	Ship heading 1
7	Ψ_2	Ship heading 2
8	v_c	Ship casting
9	v_t	Ship towing
10	v_h	Speed hauling
11	$\Delta d_{1,2}$	Change of ship position

Two ships with a gross tonnage (GT) of more than 30 GT with a distance of less than 800 meters on the high seas can be suspected of conducting IUU transshipment actions and the data will be processed by the IUU transshipment decision system. Concurrently, two ships with a distance of more than 800 meters, are considered in a reasonable distance between two ships with a total length of 20-200 meters. The length of the vessel is assumed to be 20 to 200 meters to accommodate cantrang fishing vessels which generally have a length of 20 meters to tankers which measure up to 200 meters. Hence, if the two vessels reviewed in this system have a value above 800, the data will be further evaluated in the IUU fishing decision system.

2.3. IUU Fishing and Transshipment Identification System Design

The IUU fishing and transshipment identification system is designed using a type-2 fuzzy logic system. overall fuzzy type 2 system is illustrated in Figure 5.

In the system selector, fuzzy action is done to alter the input value into a linguistic variable. The division of the input value for the distance between two ships, that are “near” and “far” with a value range of 10-800 meters.

The input value for the difference in the direction of the ship which is divided into 3 parts, such as Overtake (OT), Crossing©, and Head on (HO) employs a value range of -6 to 186 degrees. Meanwhile, the output of the selector subsystem has a value between 0 and 100, in which a value of 0-50 is suspected of executing IUU fishing and a value of 50-100 is suspected to be a vessel committing IUU transshipment.

Rule base is set as follows:

1. If (delD is *near*) and (delHead is HO) then (Out is IUUTran)

2. If (delD is *near*) and (delHead is C) then (Out is IUUTran)

6. If (delD is *far*) and (delHead is OT) then (Out is IUUFis)

2.4. IUU Transshipment and Fishing Decision System Design

In the decision system process for IUU transshipment, the input values are divided into Near, Medium and Far using a value range of 0-55 meters (Figure 6).

3. Results

The system that has been designed is then tested with diverse variations of ship trajectory patterns. Tests were carried out using 4 cases; 3 cases of IUU transshipment and 1 case of IUU fishing. The IUUL transshipment case used is the case

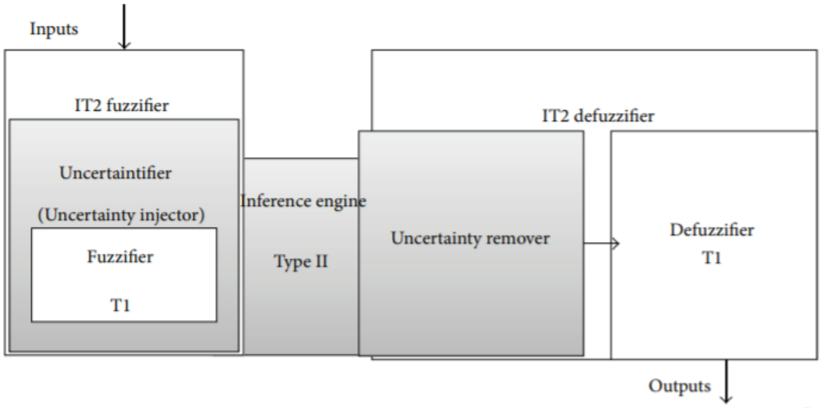

Figure 5. *The role of uncertainty in an IT2FS or IT2 FLC [13]*

IT2FS: Interval type-2 fuzzy set, IT2 FLC: Interval type-2 fuzzy logic controller

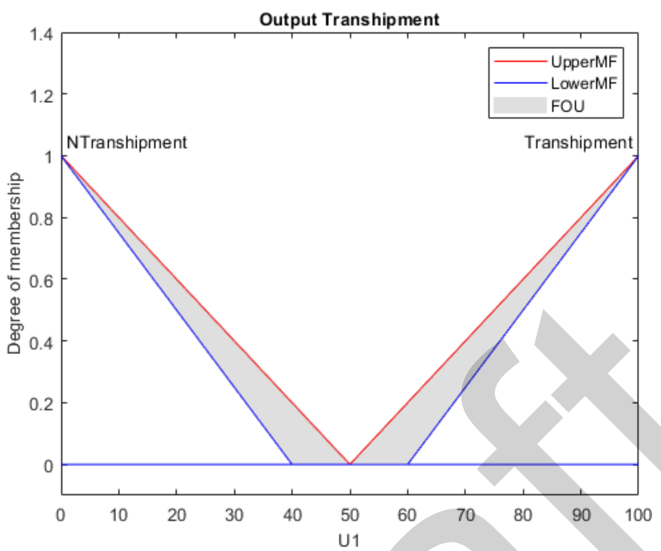

Figure 6. *Fuzzy set output system*

that occurred in the Arafuru Sea. The following are the results of the system test on several cases of IUU transshipment,

3.1. IUU Transshipment Testing Analysis

The first test, the system is tested in the case of IUU transshipment with the pattern of ship movement in Figures 7-9.

The result of the selector system with the input values in Table 2 is 85.0377. The output of the selector system indicates that the evaluated data is from ships suspected of performing IUU transshipment thus the next system working is the decision system of IUU transshipment, the following displays input data of decision system for IUU transshipment and the result of the IUU transshipment decision system is 75.5. The output value that exceeds the value of 50 indicates that the two vessels can be suspected of carrying out IUU transshipment actions with an alleged rate of 75.5%.

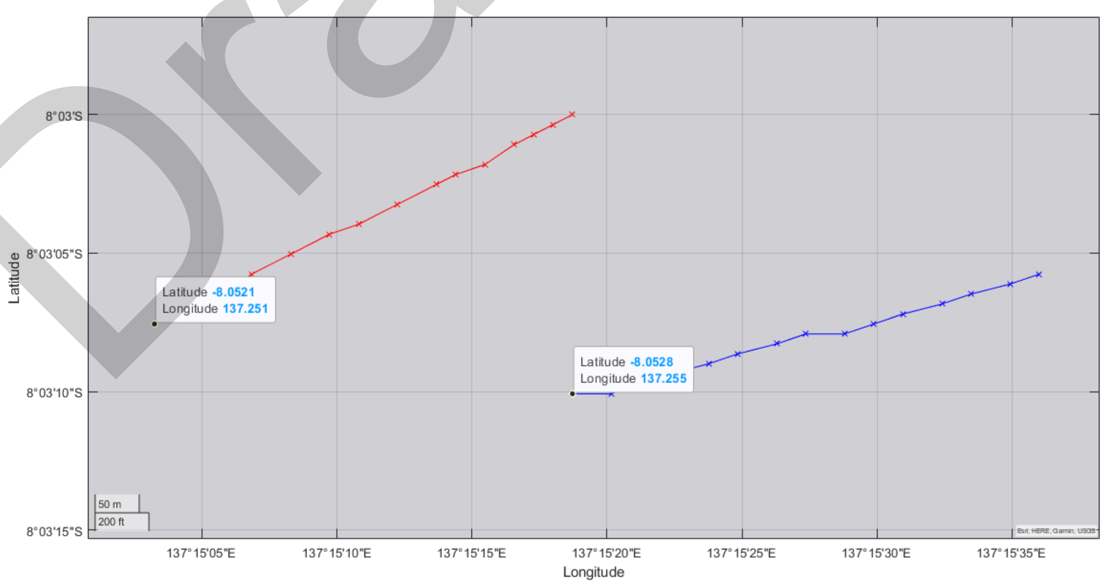

Figure 7. *Trajectory ship 1 (blue) and ship 2 (red) transshipment case 1*

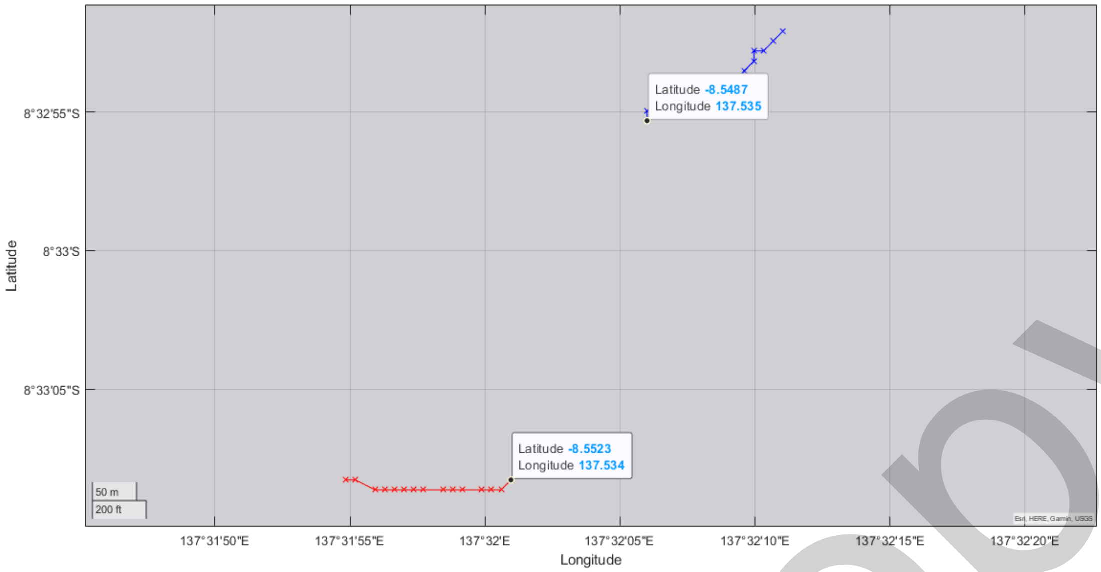

Figure 8. *Trajectory of ship 1 (blue) and Ship 2 (red) IUU transshipment case 2*

IUU: Illegal, Unreported and Unregulated

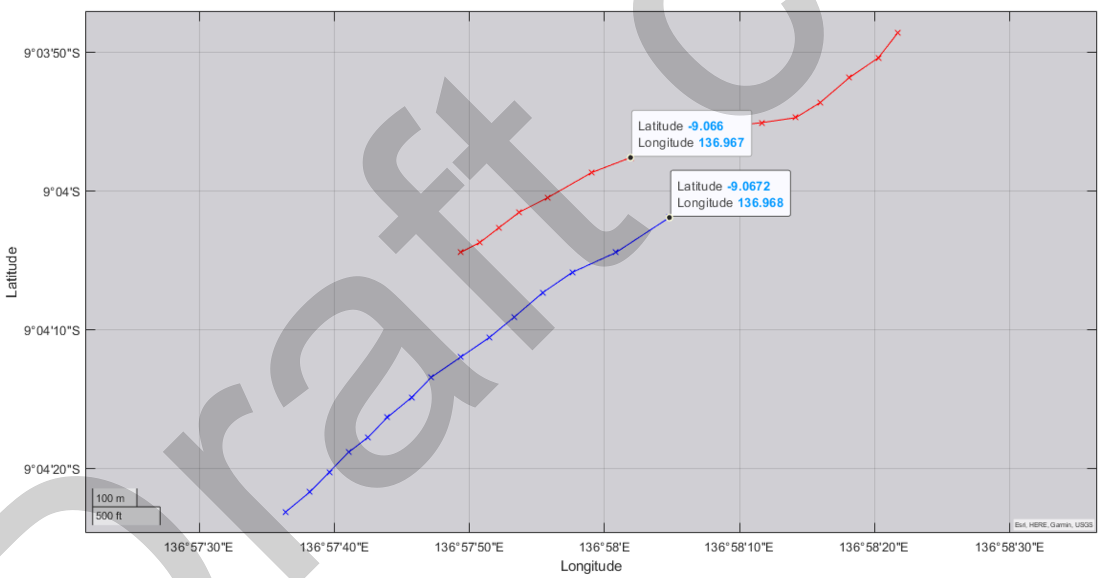

Figure 9. *Trajectory of ship 1 (blue) and ship 2 (red) IUU transshipment case 3*

IUU: Illegal, Unreported and Unregulated

Table 2. *Values of input variables for transshipment 1*

Data input	Transshipment 1			
	Selector	**Remark**	**Decision**	**Remark**
Distance of 2 ship	565.2	Near	12	Near
Heading difference	35	Crossing	33	Crossing
Speed difference			0.0001	Small

System selector results with input values in the Table 3 is 85.0377. The output of the selector system indicates that the data evaluated is from ships suspected of executing IUU transshipment, by that the next to operate is IUU transshipment decision system, the following showcase the input data of IUU transshipment decision system and the results of the IUU transshipment decision system with input values is 83,035. The value issued by the IUU transshipment decision system is the estimated value for the two ships. Thus, with a value above 50, it is found that the two ships are able to be suspected of performing IUU transshipment actions with an estimate of 83,0365%.

Table 3. *Values of input variables for transshipment 2*

Data input	Transshipment 2			
	Selector	Remark	Decision	Remark
Distance of 2 ship	593	Near	14.8	Near
Heading difference	81	Head on	183	Head on
Speed difference			0.09	Small

System selector results with input values in the Table 4 is 75.5. Therefore, based on the system design, if the output of the selector subsystem is above 50 then the subsystem that will work next is the IUU transshipment decision system and the results of the IUU transshipment decision system is 75.5. Based on the system design, if the output of the IUU transshipment decision system is above the value of 50, then the two ships can be suspected of conducting IUU transshipment actions.

3.2. IUU Fishing Test Analysis

The system was also being tested using AIS data on IUU fishing vessels with the trajectory pattern. The input value of the selector subsystem in the first IUU fishing pattern test.

Table 4. *Values of input variables for transshipment 3*

Data input	Transshipment 3			
	Selector	Remark	Decision	Remark
Distance of 2 ship	664	Near	18	Medium
Heading difference	-4	Overtake	-2	Overtake
Speed difference			0.0001	Small

The result of the selector system with the input values in Table 5 is 15.2435. Based on the results with a value below 50, there is no indication that the two vessels are carrying out IUU transshipment actions, therefore it is unnecessary to review the IUU transshipment decision subsystem, and however there is still the possibility of IUU fishing actions. So that the next working subsystem is the IUU fishing decision subsystem. The results of the IUU fishing decision system with the input value of ship 1 in case 2 is 75.8943. The output value of the IUU fishing decision system that exceeds the value of 50 indicates the ship 1 in the case of IUU fishing 1 action is possible to be suspected performing IUU fishing activities, with an estimated value of 75.8943.

3.3. Validation

The system is validated with ship AIS data obtained from NASDEC-ITS to test the system's ability to identify real AIS data. Validation is operated using AIS data for Nordic Bahari ships which are assumed to be executing IUU transshipment with a ship whose position is represented by a ship anchored at Sorong Harbor. The data taken are AIS data on April 16, 2016, at 11:00 Western Indonesian Time (WIB) - 11:15 WIB. The data source used is from marinetraffic.com. Input selector system is presented in Table 6.

The result of the selector system with the input values in Table 6 is 84.1616. The output of this selector system exhibit that the data being evaluated is data from a ship suspected of carrying out IUU transshipment, the output of the selector system becomes input for the IUU transshipment decision system. The outcomes of the IUU transshipment decision system with input values is 82,464. The output value that exceeds the value of 50 indicates that the two ships are possible to be suspected of having IUU transshipment actions with an estimated level of 82,4641%. The second

Table 5. *Values of input variables for fishing case 1*

Data input	Selector	Remark	Data input	Decision	Remark
Distance of 2 ship	3681	Far	Casting speed	12	Medium
Heading difference	0.0001	Overtake	Towing speed	33	Medium
Speed difference			Hauling speed	0.0001	Low
Ship position changes				0.001	Low

Table 6. *Values of variables validation IUU transshipment case 1*

Transshipment 1				
Data input	Selector	Remark	Decision	Remark
Distance of 2 ship	634.6	Near	15.7	Medium
Heading difference	19	Crossing	183	Medium
Speed difference			0.2	Low
IUU: Illegal, Unreported and Unregulated				

validation was carried out using AIS data from the Eagle Seville and Lurongyuanyu 105 ships which were carrying out IUU transshipment of crude oil cargo in Batam waters on May 2, 2016 at 11.30 WIB until 11.45 WIB. AIS data obtained through marinetraffic.com, and processed to be entered into the identification system. Input of the selector system in Table 7 and the result is 82.4453. The output of the selector system pointing out that the data evaluated is data from ships suspected executing IUU transshipment, as a consequence, the next system operating is IUU transshipment decision system. The following is data input of IUU transshipment decision system.

The result of the IUU transshipment decision system with the input value is 75.5. The output value that more than 50 demonstrates that the two vessels can be suspected performing IUU transshipment actions with an alleged rate of 75.5%. The system validation for the first IUU fishing was carried out using AIS data on fishing vessels that were catching fish in the Singapore Strait using cantrang fishing gear on August 21st, 2017 at 02.40 WIB to 05.38 WIB. The ship's AIS data is processed, enabling it to be input into the identification system.

The system validation for the first IUU fishing was carried out using AIS data on fishing vessels that were catching fish in the Singapore Strait using cantrang fishing gear on August 21st, 2017 at 02.40 WIB to 05.38 WIB. The ship's AIS data is processed enabling it to be inputted into the identification system. The following is a system selector input variable System selector results with input values in the Table 8 is 16.44. Based on the results of the selector system with a value below 50, there is no indication that the two vessels are committing IUU transshipment, therefore review on the IUU transshipment decision subsystem is not required. However, there is still the possibility of IUU fishing actions, by that, the next working subsystem is the IUU fishing decision subsystem.

4. Discussion

The identification system for IUU fishing and transshipment violations designed in this study has slightly different outputs compared to the identification system designed using a type-1 fuzzy logic system, since in this study the system was designed using a type-2 fuzzy logic system. The following is a comparison of the output of the system that has been previously designed with the system designed in this study. Based on the comparison of the output of the system that has been designed with the system in previous studies, it was found that the system designed produced more values that were lower than the previous designed system. It show case that the system designed in this study cannot produce neither a higher estimated value nor more convincing output than the previous system. The reason is the decrease in the membership value that arises due to system input data. Furthermore, the deterioration in membership value is caused by the process of finding the middle value in each membership function by a type-2 fuzzy logic system.

The IUU fishing and transshipment identification system designed using a type-2 fuzzy logic system isn't more superior than the IUU fishing and transshipment identification system designed using a type-1 fuzzy logic system. The identification system designed is still able to identify cases of IUU fishing and transshipment, with a minimum system output accuracy of 75.5% and a maximum of 85.0377.

Table 7. *Values of variables validation IUU transshipment case 2*

Transshipment 2				
Data input	**Selector**	**Remark**	**Decision**	**Remark**
Distance of 2 ship	648.6	Near	12.7	Near
Heading difference	116	Head on	175	Head on
Speed difference			0.0001	Small
IUU: Illegal, Unreported and Unregulated				

Table 8. *Values of variables validation IUU fishing case 1*

IUU fishing 1					
Data input	**Selector**	**Remark**	**Data input**	**Decision**	**Remark**
Distance of 2 ship	1000	Far	Casting speed	0.2	Small
Heading difference	110	Head on	Towing speed	1	Medium
Speed difference			Hauling speed	0.01	Small
Ship position changes				0.01	Medium
IUU: Illegal, Unreported and Unregulated					

The identification system for IUU fishing and transshipment designed in this study demonstrates a relatively high level of accuracy, ranging from a minimum of 75.5% to a maximum of 85.04%. These results have several practical implications for policies and practices related to maritime surveillance in Indonesia.

From a policy perspective, the system can be integrated with existing maritime monitoring infrastructures, such as radar and VTS, to enhance the early detection capabilities for IUU fishing and transshipment activities. Such integration would strengthen the capacity of oversight institutions like the Ministry of Marine Affairs and Fisheries (*Kementerian Kelautan dan Perikanan*-KKP) and the Indonesian Maritime Security Agency to prioritize areas or vessels that warrant closer inspection. By leveraging existing AIS data, the system reduces errors caused by information overload, enabling more efficient data processing. Additionally, the analysis provided by this system can support data-driven decision-making in determining which vessels require further investigation, thereby saving time and resources.

Strategically, the system provides a foundation for strengthening technology-based maritime policies in Indonesia. Its high accuracy supports the formulation of more effective policies to combat IUU fishing and transshipment in Indonesia's extensive waters.

However, to further improve the accuracy and effectiveness of the system, several developmental suggestions can be proposed. First, integrating the system with additional sensors, such as maritime radar or satellite monitoring, can complement AIS data and provide a more comprehensive view of vessel activities. Second, incorporating machine learning techniques can enhance the system's ability to recognize new patterns in more complex data, allowing it to adapt to changes in vessel behavior aimed at evading detection. Third, increasing the resolution of processed data, such as more precise vessel position data or shorter time intervals, can improve the detection of subtle changes in vessel movement patterns. Fourth, international collaboration is a strategic step to address the transnational nature of IUU fishing. The system could be used to facilitate international cooperation in data sharing and information exchange to combat such violations. Lastly, developing an intuitive visualization interface would help operators and policymakers quickly and effectively understand the system's analysis.

With these developments, the designed system has the potential to become an integral part of maritime surveillance efforts in Indonesia. However, successful implementation of this technology will require strong collaboration among researchers, the government, and private sectors to ensure its widespread and effective application.

5. Conclusion

Based on the above test and analysis, a conclusion can be drawn, that the IUU fishing and transshipment identification system is designed to be able to recognize IUU fishing and transshipment actions through ship movement patterns using position, speed and heading or ship direction variables.

The IUU fishing and transshipment identification system which is designed using a type-2 fuzzy logic system produces an identification system performance with a system accuracy value of a minimum of 75.5%, and a maximum of 85, 0377%.

Footnotes

Authorship Contributions

Concept design: N. Damastuti, A. Aisjah, and A. A. Masroeri, Data Collection or Processing: N. Damastuti, Analysis or Interpretation: N. Damastuti, Literature Review: N. Damastuti, Writing, Reviewing and Editing: N. Damastuti, and A. Aisjah.

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