FVRD: Fishing Vessel Relations Discovery through VMS Trace Analysis

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***Abstract*—The sailing information of fishing vessels are recorded through Vessel Monitoring Systems (VMS), which provides the basis to discover the spatial-temporal pattern of fishing activities. Previous research calculates the fishing density distribution from VMS traces, however, the relationships between fishing vessels are neglected. These kinds of relations, such as fishing vessel groups, may have some impact on fishing density distributions. This paper reveals the potential to construct fishing vessel relations through VMS trace analysis. It takes the VMS traces of all fishing related vessels in the East China Sea in 2016 as the object. The proposed system exploits the parallel Map-Reduce computation model to evaluate the spatial closeness among vessels in order to construct the vessel relation model over different time periods. After constructing the relation model, some key conclusions are revealed from the relation model. It shows that 72% vessels share the cooperation relations over one week, confirming the intuition that most fishing vessels are sailing together for fishing. Moreover, 42% vessels are in the long-term cooperations (over four weeks), representing the core members in each individual group.**

I. Introduction

Vessel Monitoring Systems (VMS) are originally designed to enforce and control vessel sailing security. It records the sailing information of the vessel including the position, heading, speed, and date, etc. As the fishing vessels are deployed with VMS clients, a large amount of trajectory data has been collected, which brings a new opportunity for fishing research. For example, Mullowney et al. [1] and Yuan et. al. [2] calculate the places where fishing activities happened and create the fishing density distributions, while OceanRoad [3] reveals the fishing regions with the sailing roads among them.

Previous research depicts what the fishing density distributions are by exploiting VMS data, however, it still need to answer on how and why the distributions are like this. For example, most fishery vessels are sailing in groups for fishing in the China East sea. On one side, this group pattern may reveal the cooperation among vessels. On the other side, it may have the impact on fishing density distribution.

VMS data contains the potential to provide the clues on fishing vessel groups. The key challenges on digging fishing vessel relationship from VMS data lies in two folds: (1) how to construct the vessel relationship while the VMS traces only reveal the spatial-temporal data of each fishing vessel. (2) It is computation-extensive with vast VMS data.

We propose the fishing vessels relationships discovery system (FVRD) based on VMS traces. FVRD exploits the parallel Map-Reduce computation model [4] to evaluate the spatial closeness among vessels in order to construct the vessel relation model over the time window of one day, one week, two weeks and four weeks. After constructing the relation model, FVRD reveals some key conclusions from the relation model by calculating some properties. Therefore, FVRD solves the first challenge by evaluating on the closeness of spatial vessel distributions within different time windows. The second challenge is conquered by using parallel Map-Reduce computing model.

FVRD is applied to the VMS traces logged by China Beidou satellite system in the East China Sea in 2016, whose storage is 12.9 GB. The fishing vessel type covers Otter Trawl, Gill Nets, Transportation, Stow Net, Purse Seine and others with the vessel number of 7355, 3321, 1778, 1377, 468 and 1795 respectively. The time resolution for Beidou traces are about 5 minutes. We interpolate the missing and error points to the time resolution of 5 minutes in preprocessing. After that, the vessel relation model is constructed through parallel executions and the statistics on the relation models are calculated.

FVRD shows that 72% vessels share the cooperation relationships over one week, confirming the intuition that most fishing vessels are sailing together for fishing. Moreover, 42% vessels are in the long-term cooperations (over four weeks), representing the core members in each individual group. The comparison between these two numbers shows that the cooperations among fishing vessels are only stable for nearly half core members of each group while loose for the other half.

II. Materials and Methods

A. Data

This research takes the VMS traces of all fishing related vessels in the East China Sea in 2016 as the object. The traces are recorded by China Beidou satellite system, giving them about 5 minutes for the time resolution. The fishing vessel type covers Otter Trawl, Gill Nets, Transportation, Stow Net, Purse Seine and others with the number of 7355, 3321, 1778, 1377, 468 and 1795 respectively. There are 877148686 VMS records for 2016, whose storage is 12.9 GB.

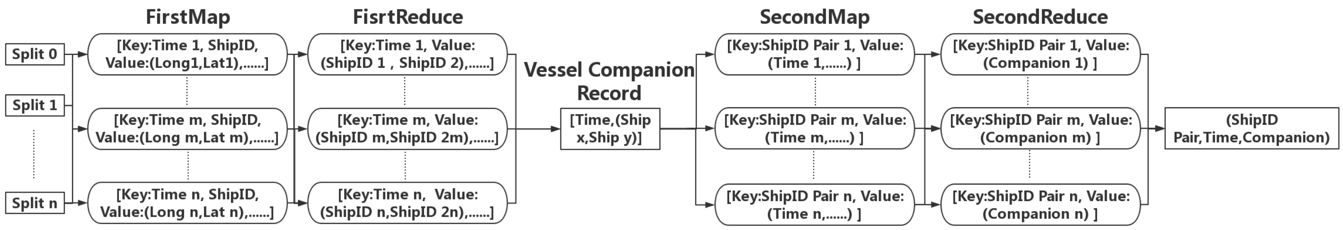

Fig. 1. Map-Reduce model to create the relation records

B. Methods

The vessel relation is defined as two vessels sailing along in the close distance for some certain period. Here we choose the threshold of one nautical mile for the distance, which comes from the questionnaires with the fishermen. We create the relation model with certain sailing along period between two vessels.

FVRD contains two key blocks in its design. The first block is used to construct the vessel relation model and the second calculates some key properties of the relation model. The first block exploits the parallel Map-Reduce computation model to construct the vessel relation model. Figure 1 shows the Map-Reduce model sketch.

The first tier workers read the raw VMS traces to create key and value for each record. Here each key for map and reduce is calculated from the time stamp and the vessel ID, while the position values will be kept as values. The time stamp are mapped according to half an hour as the interval. After the mappers create key and value for each record, the key and value pairs will be shuffled to each reducer according to their keys. The reducers will calculate the distance between each pair of vessels from the local key-value pairs. If the distance is below one nautical mile, the reducer will create a new record contains the time stamp of the current half an hour and the corresponding two vessels' IDs. We call such records as the raw companion records, which are output to the intermediate files for the second layer of map-reduce process.

The workers from the second layers read the raw companion records from the file system. This time each worker create key from the pair of two vessels' IDs and treat the time stamp as the value. The records with the same key will be sent to the reducer. Then the reducer will check the raw companion records with the same key, and combine the time stamps to the periods if two records are continuous in time. If the companion period for two vessels are longer than one day, the reducer will output the record to the result file of one day. Meanwhile, the reducers also check the threshold of one, two, four weeks and write the records qualified for these thresholds to three different files.

Therefore, the relation model are stored as these four files. FVRD's second block reads different files and creates the vessel relation graph and calculates some key properties on the relation graph, including the number of nodes, edges and weakly connected components, and average path length, degree distribution and edge weight distribution.

III. Results

FVRD treats each companion record as an edge in the relation graph, where the related vessels are labeled as nodes and the companion period are set as the edge weight. This section first depicts the relation graph of the relation over one day for the vessels belonging to Ruian County of Zhejiang Province as an example for visual clarity. We then calculate statistics on three different time period of one week, two weeks and four weeks to evaluate the stable relation on different period scales for all vessels of Zhejiang Province.

The relation graph of the vessels belonging to Ruian County of Zhejiang Province is shown in Fig. 2, where red dots represent Otter Trawlers, green dots represent Pair Trawlers, blue dots represent Shrimp Trawlers, pink dots represent Gill Nets, while dark green dots represent Transpositions. Figure 2 are created by social network visualization tool Gephi [5]. All together, there are 368 fishing vessels in Fig. 2. Each link indicates that the two corresponding vessels had sailed along over one day in 2016.

Figure 2 shows that there are five communities in the relation graph, where each community represents one type of fishing vessels. This agrees to the intuition that the fishing vessels form the groups within the same type. However, there are some exceptions for these communities of the same types. There are two blue nodes in the green community as shown in Fig. 2 i.e. two Gill Nets mostly attended the group of Pair Trawlers. To explore this fuzzy phenomena, we dig into the trajectory of these two vessels, which is shown in Fig. 3. Figure 3 exhibits that the trajectories of these two vessels follow the clear pattern of the pair trawlers. So we contacted these two vessels, which reported that these two vessels have changed into pair trawlers and worked in as a team, but their information in the database have not been changed. The same happens with the two pink nodes in the blue communities and one blue dots in red communities. Therefore, the relation graph can help in finding the wrongly registered fishing vessels.

There is another interesting observation in the Transportation community that more than half transportation only share relationship inside each other, but have no relationship with fishing vessels of other types. Because the function of Transportation is to transfer the catches for other fishing vessels

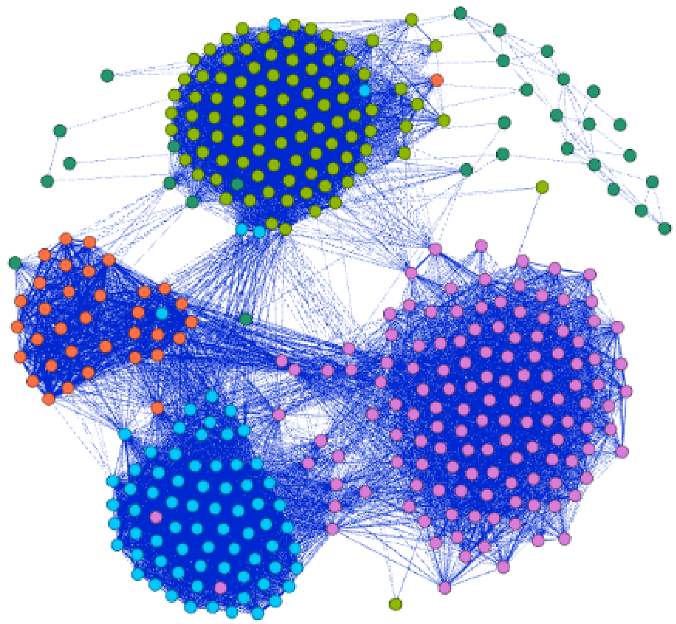

Fig. 2. Relation graph for vessels belonging to Ruian County in 2016

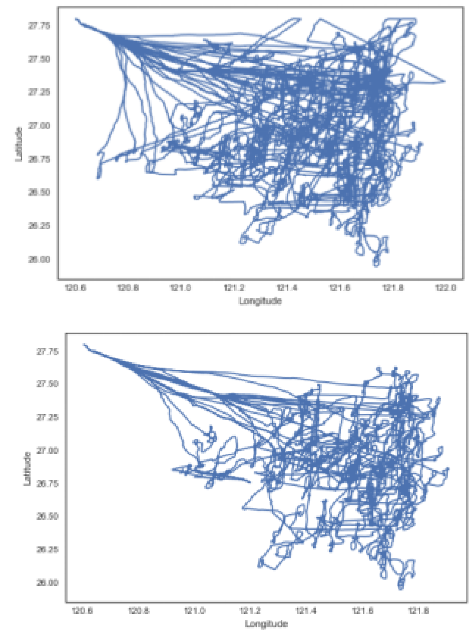

Fig. 3. Illustration of trajectory of two questionable vessels

from offshore to ports, this observation is somehow strange. We contacted the local fishing administrations and found out that those vessels were mainly serving the fishing vessels from the nearby province.

We can create the same relation graph for all fishing vessels in Zhejiang Province. However, the whole relation graph have too many nodes and edges for visualization. So instead showing the graph directly, we calculate the edge weight distribution from the relation graph and shows the results for four typical types of fishing vessels in Fig. 4. These four types of vessels are chosen because they share most stable relations with other vessels. The edge weight indicates that how many days that two vessels have sailed along. Figure 4 shows that the same group pattern for four types of fishing vessels that the vessel only have stable relations with a few other vessels. The percentage of the stable relation over than one week is below 5% for all types of fishing vessels. The stable relation is need to be further analyzed.

We conduct the statistics on the key properties of the relation graphs over one week, two weeks and four weeks for all the vessels in 2016. The statistic results are shown in Table I. It shows that 72% vessels share over one week companion relation with other vessels, confirming the intuition that many vessels are sailing together for fishing. Tracing back to every vessel with over one week relationship, it shows that most vessels are of type Otter Trawl, Gill Nets, Transportation and Purse Seine. Comparing to the node number for over two and four weeks, it shows that the companion relationships are stable when the periods last to two weeks but decrease near half for over four weeks. This may come from that most fishing trips are over two weeks but less than four weeks. Moreover, it also indicates that there are long-term

TABLE I
PROPERTIES OF VESSEL RELATION GRAPH FOR VMS TRACES IN 2016: NUMBER(#), WCC(WEAKLY CONNECTED COMPONENT),APL(AVERAGE PATH LENGTH)

Period	#Node	#Edge	Diameter	#WCC	APL
Over one week	11653	92118	36	200	11
Over two weeks	9904	40772	73	737	24
Over four weeks	6900	14646	18	1433	4

cooperations among 6900 nodes in the relationship graph of four weeks. The comparison between these properties shows that the cooperations among fishing vessels are only stable for nearly half core members of each group while loose for the other half.

Comparing on both the node and edge numbers, it shows that the average degree for each node decreases half from one to two and four weeks. This shows that the group pattern may have some core vessels with smaller size i.e. the core vessels for each group has the average size of nearly four, shown by the over four week data. The diameter changes illustrate that one week's relation graph are more connected than two week's graph, while the four weeks are mainly disconnected. This conclusion are also confirmed by the weakly connected component number and average path length.

In order to give a direct impression on the relation graph over one week, we plot the relation graph of period over one week for vessels belonging to Ruian Country in Fig. 5. Comparing Fig. 5 to Fig. 3, the topology are more clear with four communities, while only one transportation is left in the middle of Fig. 5.

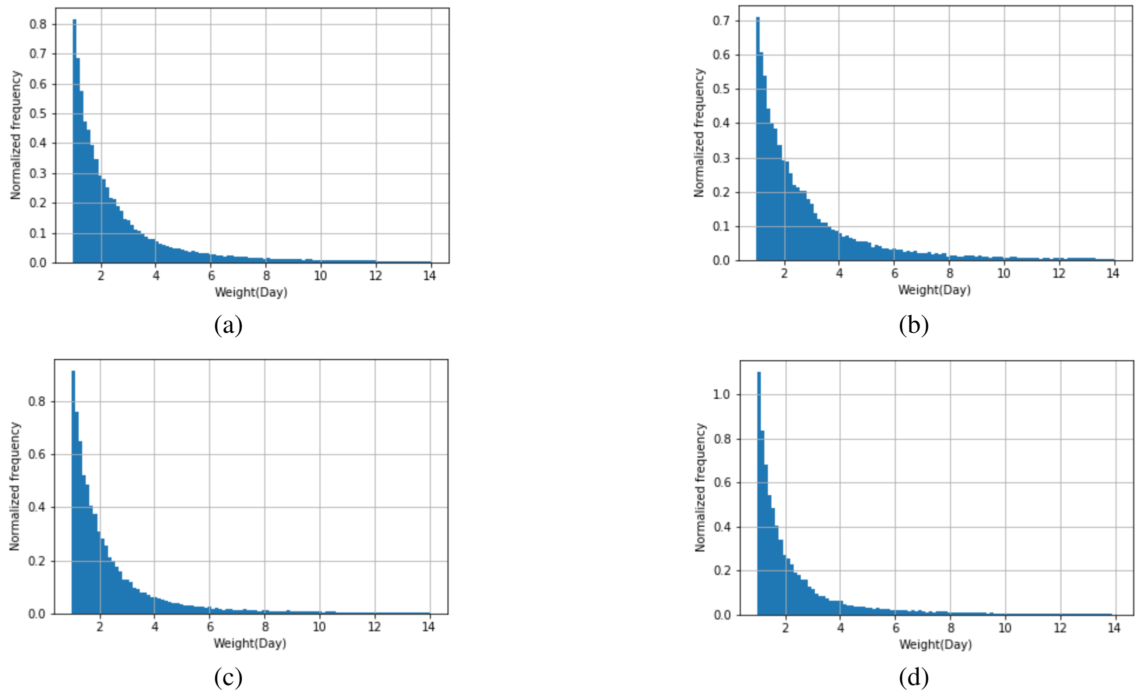

Fig. 4. Weight distribution of different types of fishing vessels (a) Otter Trawl (b) Purse Seine (c) Gill Net (d) Transportation

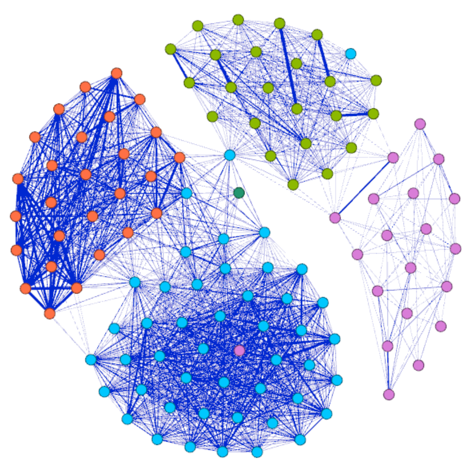

Fig. 5. Relation graph of period over one week for vessels belonging to Ruian County in 2016

IV. Conclusion

This research explores the potential of VMS traces to discovery the relationship between fishing vessels. The proposed system exploits the parallel Map-Reduce computation model to evaluate the spatial closeness among vessels and construct the vessel relation model over the different time periods. The results confirm that the cooperations between fishing vessels exist but somehow only stable with half core members for each group. This half stable cooperations may have impacts on the fishing density distributions, calling for further research.

Acknowledgment

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