A Multi-Agent System for Coordinating Vessel Traffic (Demonstration)

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ABSTRACT

Environmental, regulatory and resource constraints affects the safety and efficiency of vessels navigating in and out of the ports. Movement of vessels under such constraints must be coordinated for improving safety and efficiency. Thus, we frame the vessel coordination problem as a multi-agent path-finding (MAPF) problem. We solve this MAPF problem using a Coordinated Path-Finding (CPF) algorithm. Based on the local search paradigm, the CPF algorithm improves on the aggregated path quality of the vessels iteratively. Outputs of the CPF algorithm are the coordinated trajectories. The Vessel Coordination Module (VCM) described here is the module encapsulating our MAPF-based approach for coordinating vessel traffic. Our demonstration of VCM is conducted using two maritime scenarios of vessel traffic at two geographical regions of Singapore Waters.

1. INTRODUCTION

The movement of vessels into and out of the ports is constrained by the environment, regulation and resource availability. Vessel Traffic Service (VTS) monitors and coordinates the vessel traffic by offering non-action-oriented information to the vessels [6]. The shipmasters and pilots rely on the VTS information and onboard instrumentation for navigating the vessels at the transit waters and port waters respectively. Despite such an arrangement, collisions among vessels are still occurring [2]. A possible way forward is to use agent-based techniques to address such issues [1]. Many decision support systems [3, 4] addressing maritime issues are also known. However, the problem of coordinating the movement of vessels remains inadequately addressed.

In this paper, we will describe our approach of framing the problem of coordinating the movement of vessels as a multi-agent path-finding (MAPF) problem. Described and evaluated rigorously in [5], we focus on the presentation of the logical construct of the Vessel Coordination Module (VCM) that encapsulates the Coordinated Path-Finding (CPF) algorithm and the input and output mechanisms. Experiments are conducted to evaluate the efficacy of VCM for coordinating the movement of vessels in two regions in the Singapore Straits. The quantitative results of the vessel traffic in these two scenarios show the aggregated path quality can be improved more when the region is larger. This demonstration will show how the vessels move on the coordinated paths to improve safety and efficiency.

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2. VESSEL COORDINATION MODULE

The VCM coordinates the movement of a fixed number of vessels in a specific area-of-interest (AOI) over a fixed duration. The sequence diagram seen in Fig. 1 illustrates the logical construct of VCM. It encapsulates the initialization process, the coordination task and the path following tasks.

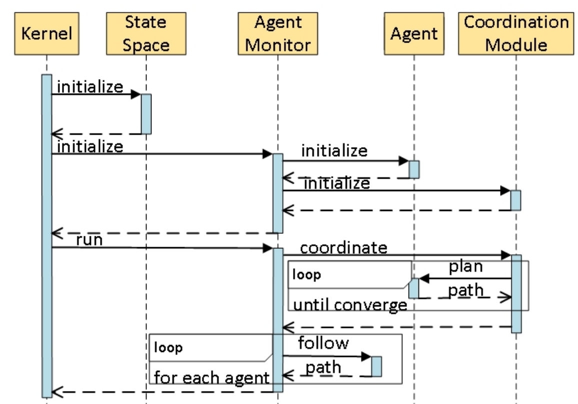

Figure 1: Illustration of the main steps of the Vessel Coordination Modules.

2.1 The Initialization Process

The sequence diagram seen in Fig. 2 illustrates the initialization process of the main modules. Due to the dependency among them, the main modules are initialized in a particular sequence. From Fig. 2, each agent is shown instantiating a path planner. The initial position and path of the agents are obtained after instantiating these modules.

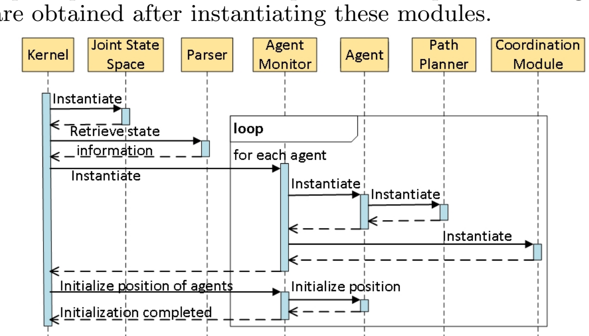

Figure 2: Illustration of the initialization process.

The AOI is a part of the water passageways where the movement of the vessels in it is coordinated. A discretized AOI is referred to as the joint state space $\mathcal{G} = \{N(\mathcal{G}), E(\mathcal{G})\}$. A node $k \in N(\mathcal{G})$ is an unit of area in the AOI. At time t, agent i is positioned at the center of Node k. The cost of node k is a function of time-independent and time-dependent costs. The time-independent costs are the cost of the Electronic Navigation Chart (ENC) features. The time-dependent costs are based on position of agent i with respect to agent j, start node s_i and goal node g_i. Node k is only initialized with the time-independent costs.

The vessels are abstracted as agents. A collection of agents is referred to as the agent population $\mathcal{N}$. Agent i is initialized with a start node s_i, a goal node g_i, a physical radius r_i and a safety perimeter s_i. Necessary for coordination, the ship domain of agent i is a collection of neighboring nodes derived using r_i and s_i. Trajectory π_i of agent i is a list of node identification numbers stored in the order it is to be traversed. When the VCM is used in *live* mode, $\Pi(\mathcal{N}, 0)$ is predicted using the start node s_i and the goal node g_i of each agent. When the VCM is used in *historical* mode, $\Pi(\mathcal{N}, 0)$ is retrieved from the historical AIS data of the vessel.

2.2 The Coordination Strategy

The Coordinated Path-Finding (CPF) algorithm detailed in [5] is used for discovering paths with better path quality for a collection of agents $\Theta \subset \mathcal{N}$ such that the aggregated path quality $\mathcal{Q}(\Pi(\mathcal{N}, T_s))$ at search iteration T_s is most improved, i.e., $\max\{\mathcal{Q}(\Pi(\mathcal{N}, T_s))\} > \mathcal{Q}(\Pi(\mathcal{N}, 0))$. The solution is a set of paths $\Pi(\mathcal{N}, T_s)$ with $\max\{\mathcal{Q}(\Pi(\mathcal{N}, T_s))\}$.

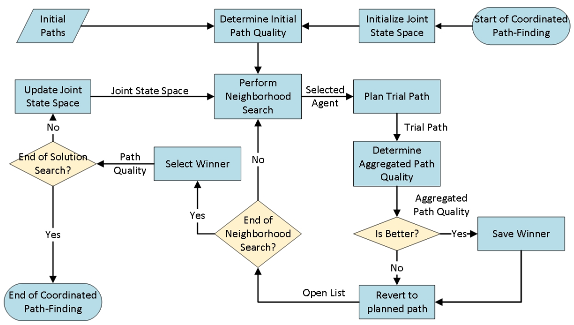

Figure 3: Illustration of the Coordinated Path-Finding (CPF) Algorithm.

From Fig. 3, the CPF algorithm searches for the solution by conducting the neighborhood search iteratively. The search for the solution will terminate at search iteration t_s when $\mathcal{Q}(\Pi(\mathcal{N}, t_s)) \equiv \mathcal{Q}(\Pi(\mathcal{N}, t_s - 1))$. The neighborhood search discovers multiple winning candidate agents at each solution point. A winning candidate agent is an agent whose trial path π_i^t improves $\mathcal{Q}(\Pi(\mathcal{N}, t_s))$ at t_s. After a neighborhood search, a winning agent is determined among the winning candidate agents using the winner-takes-all approach.

2.3 Effects of Coordination

The output of VCM is the solution $\Pi(\mathcal{N}, T_s)$. Changes to $\mathcal{Q}(\Pi(\mathcal{N}, t_s))$ are illustrated by plotting path quality versus search iteration. The aggregated effect of coordination is also illustrated using heatmaps seen in Fig. 4. Agents moving on the coordinated paths can be animated using a GIS-based visualization tool [7] seen in Fig. 5.

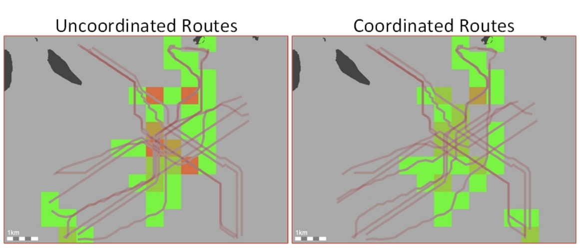

Figure 4: Heatmaps for illustrating the aggregated effect of coordinating the movement of the vessels.

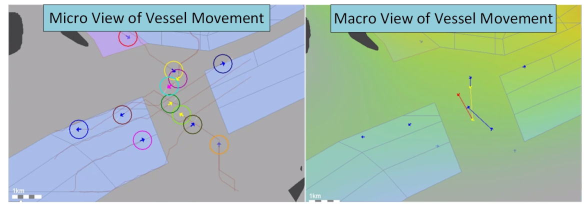

Figure 5: Illustration of the coordinated movement of vessels using a GIS-based visualization tool.

3. CASE STUDY

The efficacy of the VCM on coordinating the movement of vessels within a defined region over a fixed duration is illustrated using two maritime scenarios as seen in Fig. 6

3.1 Maritime Scenarios

From Fig. 6, VCM coordinates the movement of 10 vessels in Region 1 and 12 vessels in Region 2.

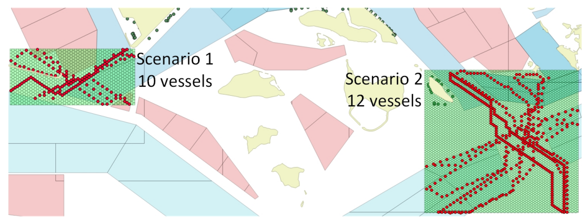

Figure 6: Illustration of the two areas-of-interest.

3.2 Simulation Results

The plots seen in Fig. 7 compares the aggregated path quality of vessels from the two regions. From Fig. 7, VCM can have higher $\mathcal{Q}(\Pi(\mathcal{N}, t_s))$ when the region is large enough for the vessels to move apart.

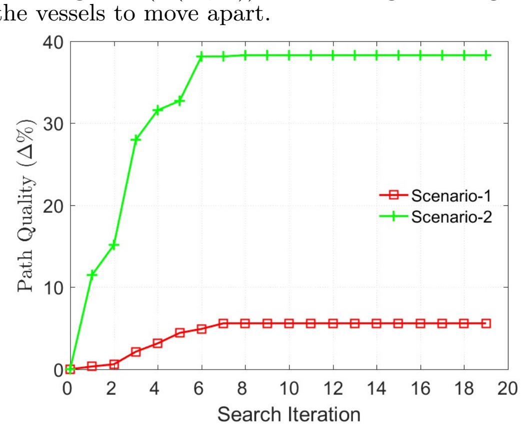

Figure 7: Illustrations of $\mathcal{Q}^*(\Pi(\mathcal{N}, t_s)$ for $t_s \in [0, 19]$ of the vessels from the two regions.

4. CONCLUSIONS

This demonstration paper adds to [5] by providing further details on the logical construct and illustrating the efficacy of the Vessel Coordination Module for coordinating more than 10 vessels in two geographic regions of the Singapore Waters. The experiment results show that the path quality of the coordinated paths is dependent on the number of agents and the size of the Area-Of-Interest. A video demonstration of the coordinating the movement of 12 vessels in Scenario 2 is at https://youtu.be/nVlFU5ZkAM8.

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REFERENCES

[1] M. Jakob, O. Vaněk, and M. Pěchouček. Using agents to improve international maritime transport security. *IEEE Intelligent Systems*, 26(1):90–96, 2011.

[2] Maritime Port Authority of Singapore. Collision of container vessels WAN HAI 301 and APL DENVER. MPA Press Release, 2017.

[3] L. Parrott, C. Chion, C. C. A. Martins, P. Lamontagne, S. Turgeon, J. A. Landry, B. Zhens, D. J. Marceau, R. Michaud, G. Cantin, N. M. enard, and S. Dionne. A decision support system to assist the sustainable management of navigation activities in the St. Lawrence River Estuary, Canada. *Environmental Modelling & Software*, 26:1403–1418, 2011.

[4] U. Simsir, M. F. Amasyali, M. Bal, U. B. Çelebi, and S. Ertugrul. Decision support system for collision avoidance of vessels. *Applied Soft Computing*, 25:369–378, 2014.

[5] T.-H. Teng, H.-C. Lau, and A. Kumar. Coordinating vessel traffic to improve safety and efficiency. In *Proceedings of AAMAS*. May 2017. To appear.

[6] UK Hydrographic Office. *Passage Planning Guide - Malacca and Singapore Straits*. Witherby Publishing Group, 2015.

[7] I. Watanabe, H. Suzuki, T. Saitou, and S. Ito. Macro-level and micro-level visualization of vessel movement. GIS Visualization Toolkit, 2016.