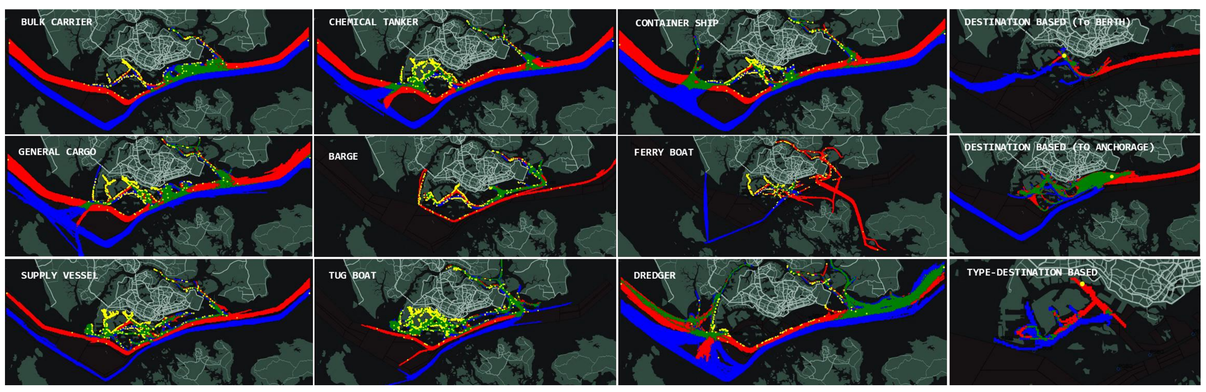
Route Planning over Waterway Knowledge Base Embedded with Rich Features

Introduction

Maritime service intelligence relies on the sensing and machinery data gathered from maritime service networks and domain information systems.

Waterway patterns, as a type of fundamental knowledge bases, play an essential role in various tasks to assist situation awareness and decision support in traffic & operation services. Firstly, we propose a novel waterway pattern mining method for port waters. The method has a compact footprint design and is featured with multiple granularities (type, destination, type-destination joint) extracting, waypoint labelling and directional labelling, forming a knowledge base with rich traffic features. Secondly, relying on the extracted waterway patterns as “map context”, we further enhance the renowned Theta* path planning algorithm by taking the extracted waterway features (direction, destination label, and cost metric etc.) into the consideration.

Based on the big traffic data collected for Singapore port and strait water, the developed solution combining both the extracted waterway patterns and enhanced Theta* algorithm has been applied to several practical domain use cases, including a) Passage plan generation; b) Waterway pattern-based trajectory reconstruction; and c) Vessel movement estimation and forecasting. These use cases and exploration studies have proved the usefulness of the proposed solution, its feasibility for other port waters, and potential use on a global scale.



Vessel type-based waterway extraction. Colour code for waterway direction encoded: Red – westbound; Blue – eastbound; Green – through (both directions); the first three columns indicate type-based extraction, the last column illustrates destination based and type-destination based extraction.

Waterway Extraction and Feature Embedding

Based on the year’s Automatic Identification System (AIS) and radar fused dataset for Singapore waters, the proposed method has been employed to extract the knowledge base of waterway patterns in multiple granularities respecting vessel type, destination, and type-destination combination.

One of crucial considerations in our design is to label the waterway grids with the direction information, which implies the navigation rule that a vessel should follow. The direction label is enclosed with grids on the waterway, and will be brought as a constraint into route planning to generate practical routes. The detailed algorithm is given in Algorithm 1.

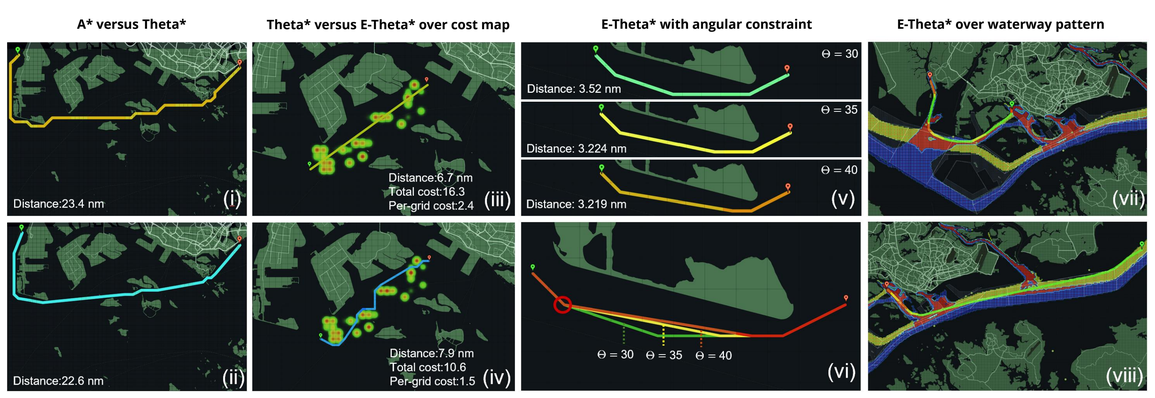
Algorithm 1 Waterway pattern extract - aggregating

```
/* Vessel list query, λ = [type|destination|type-destination] */
list_vessel := query(λ);

/* Prepare variable to store intermediate output */
gridmap_west < id_grid, unit_grid >= {}
gridmap_east < id_grid, unit_grid >= {}

/* Iterate vessels to load and process grid based waterways */
foreach mmsi ∈ list_vessel do
    list_traj = queryTraj(mmsi)
    foreach traj ∈ list_traj do
        grids = traj.getGrids()
        foreach grid ∈ grids do
            if grid.cog) ∈ [0, 180) then
                /* Zero initialization for a new unit if not in the map */
                unit_grid = gridmap_east.get(grid.id)
            else
                /* Zero initialization for a new unit if not in the map */
                unit_grid = gridmap_west.get(grid.id)
            unit_grid.[sog, cog, count, ...] = oper(grid.[sog, cog, count, ...])

/* Aggregate the east & west grids for combined waterway pattern */
gridmap_east = DBSCAN_grid(gridmap_east)
gridmap_west = DBSCAN_grid(gridmap_west)
eastSet = gridmap_east.keys()
westSet = gridmap_west.keys()
throughSet = eastSet ∩ westSet
gridmap = merge(gridmap_west, gridmap_east, throughSet)
store(gridmap)
```

Route Planning over Gridded Waterway

An Enhanced Theta*(E-Theta*) route planning algorithm is elaborated through its implementation details. Comparing with the initial Theta* algorithm, it accommodates several practical constraints embedded in the grid-based waterway patterns.

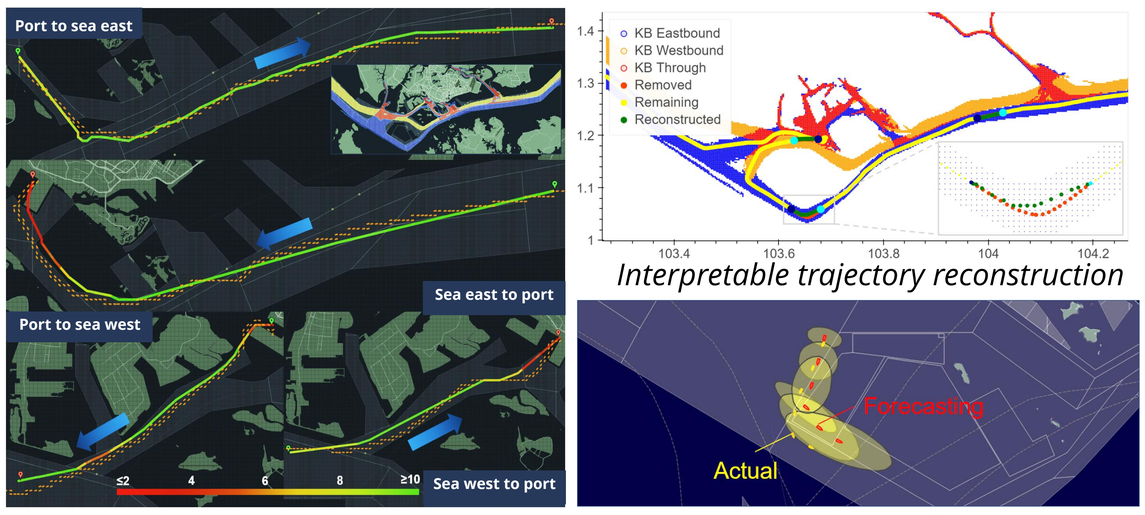
Several demonstrative route planning results by comparing A*, Theta*, E-Theta* with different settings are illustrated in the following set of figures.



Demonstrative route planning based on A, Theta*, E-Theta* with the settings considering cost map, angular limit, and waterway pattern features: (i) and (ii) A* versus Theta*; (iii) and (iv) Theta* and E-Theta* over cost map; (v) and (vi) E-Theta* with angular constraint; (vii) and (viii) E-Theta* over waterway.*

Use Cases and Discussion

The extracted waterway patterns and the E-Theta* algorithms, packaged as a backbone core for machine usability, are capable of supporting some domain use cases and services for system automation and intelligence. Several practical use scenarios are explored and demonstrated including passage plan generation, interpretable trajectory reconstruction and vessel movement forecasting.



Passage plan generation

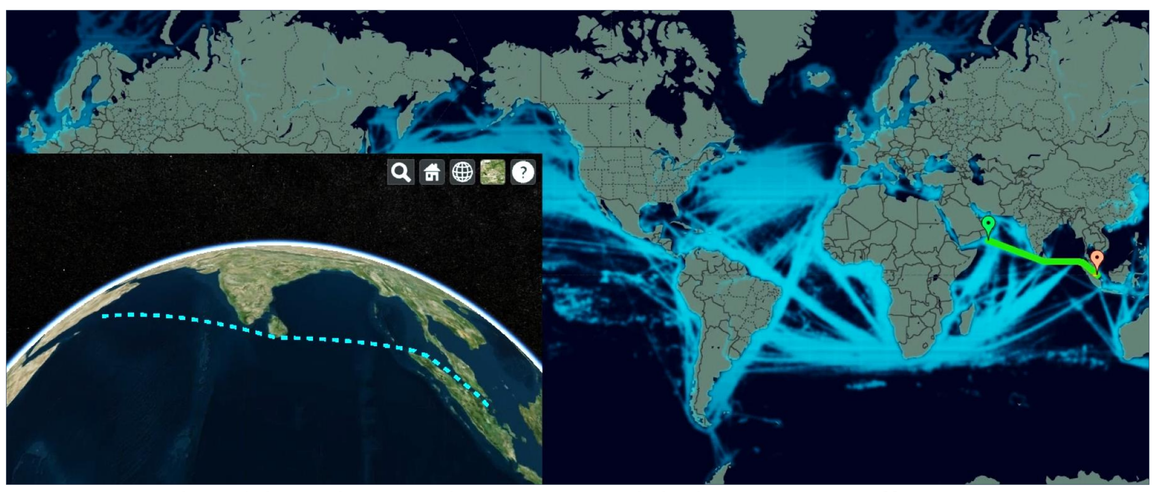
Interpretable trajectory reconstruction

Vessel movement forecasting

Summary

A waterway mining and route planning framework to support domain services for system automation and intelligence has been proposed. The waterway pattern mining and extraction method establishes the waterway patterns with rich features, serving as a map context input for the route planning algorithm.

The proposed solutions are also attempted to be applied for global maritime traffic pattern extraction and route generation. The implemented prototype suggests its applicability on a global scale.



E-Theta based route planning over global maritime traffic pattern*

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