AgentC: Agent-based Testbed for Adversarial Modeling and Reasoning in the Maritime Domain

Michal Jakob, Ondřej Vaněk, Štěpán Urban, Petr Benda and Michal Pěchouček
Agent Technology Center, Dept. of Cybernetics, FEE Czech Technical University
Technická 2, 16627 Praha 6, Czech Republic
{jakob, vanek, urban, benda, pechoucek}@agents.felk.cvut.cz

ABSTRACT

We present an agent-based system for modeling, analyzing and reasoning in the maritime domain with the emphasis on detecting, anticipating and preventing illegitimate activities, such as contemporary maritime piracy. At the core of the system is a data-driven agent-based simulation which combines a rich array of sources of real-world piracy-related data with simulated operation of thousands of vessels of different types in order to create a rich model of maritime activity. The simulation is integrated with a range of advanced adversarial reasoning methods for analyzing illegitimate activities and for planning active counter-measures. In combination with experiment support tools and a powerful presentation frontend based on Google Earth, the system provides a complete testbed for the development and evaluation of counter-piracy methods based on the multi-agent approach.

1. INTRODUCTION

The recent surge of maritime piracy presents an increasing threat to international transport, fishing and other maritime operations. The insurance rates have increased more than 10-fold for vessels transiting known pirate waters and the overall costs of piracy in the Pacific and Indian ocean alone was estimated at US$15 billion in 2006 and continues to rise[5]. Different methods are explored for putting piracy back under control and/or for mitigating the risks it entails.

In this paper, we describe a testbed developed for prototyping and evaluating (multi-)agent-based methods for counteracting piracy and other illegitimate maritime activities in general [4]. At the center of the testbed (see Figure 1 for architecture overview) is an agent-based simulation platform which integrates simulated vessel operation with a wide range of real-world data on maritime activity. A number of advanced agent-based methods are integrated with the simulation, both for analyzing illegitimate activities and for planning active counter-measures. In the following, we give an overview of the core simulation platform, followed by a brief description of two of the counter-piracy methods integrated with the platform.

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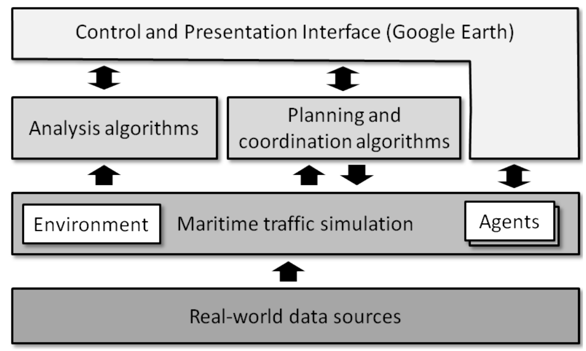

Figure 1: Layered architecture of the AgentC testbed. Information flows between individual components are depicted.

2. MARITIME TRAFFIC SIMULATION PLATFORM

The simulation platform has been designed to allow easy incorporation of different data sources and to support systematic experimentation with agent-based counter-piracy methods under varied operational conditions, both on synthetic and real-world data.

2.1 Vessel Simulation

The platform can simulate the activity of a large number (thousands) of the following categories of vessels:

- **long-range transport vessel** – large- to very large-size vessels transporting cargo over long distances (typically intercontinental); these are the vessels that are most often targeted by pirate.
- **short-range transport vessel** – small-to medium-size vessels which transport passengers and/or cargo close to the shore or across the Gulf of Aden.
- **fishing vessel** – small- to medium-size vessels which perform fishing within designated fishing zones; fishing vessels launch from their home harbors and return back after the fishing is completed
- **pirate vessel** – medium- to large-size vessels operating within designated *piracy zones* and seeking to attack a long-range transport vessel. The pirate control module supports several strategies some of which can employ multiple vessels.

The behavioral models for individuals categories of vessels have been synthesized from the information about real strategies[1, 2]. The vessel operational characteristics (length, tonnage, max speed etc.) are based on real-world data [1].

2.2 Data Sources

The simulation platform incorporates several categories of real-world data:

- **Geographical data (general)** – general information about the geography of the environment, in particular shore lines and ports. These data are supplied directly by Google, although some of them need preprocessing.
- **Geographical data (operational)** – geographical information specific to the operation of simulated vessel types, in particular the location of main piracy hubs, piracy zones, fishing zones and transit corridors. These data come specialized sources.
- **Behavioral data** – collected information on the movement and behavior of vessels, in particular real-world vessel trajectories obtained from AIS databases and detailed information about piracy incidents. These data also contain aggregate analytical reports from UNOSAT and other organizations.

2.3 User Frontend

The operation of the platform, including the output of the analysis and coordination and planning modules, is presented, in an interactive way, using a Google Earth-based frontend. The frontend allows rich, easy-to-navigate display of both static and dynamic information. For the latter, a special Data Synthesizer module was developed for supplying dynamically created KML data streams via an HTTP data link.

3. PROBABILISTIC TRAJECTORY MODELLING

Building on earlier work on vessel trajectory modeling (e.g. [6]), we have developed a method for learning typical motion patterns for individual classes of vessels based on their historic trajectory data. The method works on two levels. On the first level, the method uses the expectation minimization algorithm to build a Gaussian mixture model of the spatial density of maritime traffic. On the second level, vessel trajectories as expressed as sequences of the components of the mixture model; the sequences are subsequently used to train hidden Markov models using the *Baum-Welch algorithm*. The trained Markov models are then employed to determine vessel type, predict further vessel behavior or detect anomalous trajectories.

The combination of probability mixture models and hidden Markov models enables the method to capture both spatial and temporal aspects of vessel motion patterns. On a test data set obtained from traffic simulation, the method achieved 95% accuracy when trained on trajectory samples of length 10. The method is fully integrated with the platform; learning trajectory data are obtained from the platform and the learning results are displayed and can be interactively explored in the Google Earth frontend.

In addition to trajectory modeling, the testbed also contains a preliminary method for estimating the risk of pirate attacks based on past incident reports and the current locations of transiting vessels. The output in a form of a *dynamic risk map* can be used effective deployment of armed patrols.

[1]e.g. `http://www.aislive.com`, `http://vesseltracker.com`

4. GAME-THEORETIC TRAJECTORY PLANNING

Risks associated with illegitimate maritime activities, such as piracy, can be reduced through better planning and coordination of vessel movement through affected areas. To this aim, the trajectory planning module implements a game-theoretic approach for (near) optimum selection of transit routes minimizing the risk of a pirate attack.

Specifically, extending the work on ambush games [3, 7], the problem is formalized as a zero-sum normal game of two players on a graph; an optimum randomized route selection strategy for the transiting vessel is then sought as a mixed-strategy Nash equilibrium of the game. Two novel techniques for reducing the game's very high complexity have been introduced – network-flow reformulation of the transiting vessel's strategy space allows to solve games on areas several magnitudes larger; further 10-fold decrease in computation time is achieved by introducing template-based representation of pirate's strategies. Together, the optimizations enables to solve games of practical sizes.

The method is fully integrated with the platform. The game graph is extracted from the real geography of the transit area; the plans produced by the method can be executed by the vessels transiting the area.

5. CONCLUSION

The presented system combines data-driven maritime traffic simulation with advanced agent-based methods for trajectory modeling and adversarial planning. The ability to control the parameters of the simulation together with the powerful presentation frontend enables rapid development and evaluation of agent-based methods that can help understand and/or mitigate illegitimate maritime activities.

In the future, we will continue improving the core testbed as well as integrating new analysis and planning methods. If sufficient interest develops, we are ready to make the testbed publicly available in order to allow other researchers to test their algorithms.

6. REFERENCES

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