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

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ABSTRACT

We present an agent-based system for modeling, analyzing and reasoning in the maritime domain with the emphasis on detecting, anticipating and preventing illegal activities, such as contemporary maritime piracy. At the core of the system is a data-driven agent-based simulation which combines a range of sources of crime-related real-world 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 number of advanced reasoning methods for analyzing illegal activities and for planning active counter-measures. In combination with experiment support tools and a powerful user frontend based on Google Earth, the testbed provides a complete environment for the development and evaluation of anti-maritime-crime methods based on the multi-agent approach.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence—*multiagent systems*

General Terms

Algorithms

Keywords

agent-based simulation, learning, planning, game theory, adversarial reasoning, transport security, maritime crime

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 cost of piracy in the Pacific and Indian ocean alone was estimated at US$15 billion in 2006 and continues to rise[2]. Various 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 fighting piracy and other categories of maritime crime. At the center of the testbed (see Figure 1 for an architecture overview) is a data-driven agent-based simulation platform which combines simulated vessel operation with a wide range of real-world data on maritime activity. A number of advanced methods are integrated with the simulation, both for analyzing illegal 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 anti-crime methods integrated with the platform[1].

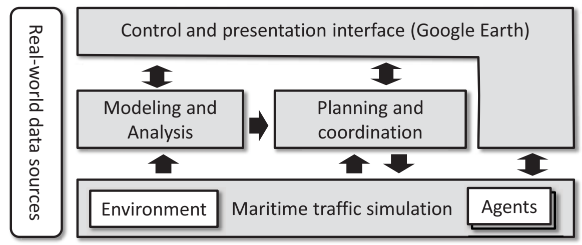

Figure 1: Layered architecture of the AgentC testbed. Information flows between individual components are depicted.

2. MARITIME TRAFFIC SIMULATION

The simulation platform has been designed to allow easy incorporation of various data sources and to support systematic experimentation with agent-based anti-crime 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 pirates.
- **Short-range transport vessel** – small-to medium-size vessels carrying passengers and/or cargo close to the shore or across the Gulf of Aden.
- **Fishing vessel** – small- to medium-size vessels performing fishing within designated fishing zones; fish-

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[1]More information about the testbed can be found at `http://agents.felk.cvut.cz/projects/agentc/`

Figure 2: Google-Earth-based testbed interface

ing vessels launch from their home harbors and return back after the fishing is completed.

- **Pirate vessel** – medium-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]. The vessel operational characteristics (length, tonnage, max speed etc.) are based on real-world data[2] too.

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.
- **Geographical data (operational)** – geographical information specific to the operation of simulated vessels, in particular the location of main piracy hubs, piracy zones, fishing zones and transit corridors. These data come from specialized sources.
- **Behavioral data** – information on the movement and behavior of vessels, in particular real-world vessel trajectories obtained from AIS databases, detailed information about piracy incidents as well as aggregate analytical reports from UNOSAT and other organizations.

2.3 User Frontend

The operation of the testbed, 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 via dynamically constituted KML data streams.

3. MODELING AND ANALYSIS

Building on earlier work on vessel trajectory modeling (e.g. [3]), we have developed a method for learning characteristic motion patterns for individual classes of vessels based on their historic trajectory data. The method works on two levels. On the first level, it 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. The trained hidden Markov models are then employed to determine vessel type, predict further vessel behavior or detect anomalous vessels. The combination of probability mixture models and hidden Markov models enables the method to capture both spatial and temporal aspects of vessel movement. 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 includes a 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 for effective deployment of maritime patrols.

4. GAME-THEORETIC ROUTE PLANNING

As a possible anti-piracy measure, we have developed a game-theoretic method for (near-)optimum selection of risk-minimizing routes for vessels transiting known pirate waters. Specifically, extending the work on *ambush games* [4], we have formalized the problem 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 advanced techniques for reducing the game's very high complexity have been introduced – a network-flow reformulation of the transiting vessel's strategy space and a template-based representation of pirate's strategies. Combined, these optimizations enable to solve large 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.

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