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Adaptive Multi-agent System for Multi-sensor Maritime Surveillance

Jean-Pierre Mano, Jean-Pierre Georgé, and Marie-Pierre Gleizes

Abstract. Maritime surveillance is a difficult task as its aim is to detect any threatening event in a dynamic, complex and hugely distributed system. As there are many different types of vessels, behaviours, situations, and because the system is constantly evolving, classical automated surveillance approaches are unrealistic. We propose an adaptive multi-agent system in which each agent is responsible for a vessel. This agent perceives local anomalies and combines them to maintain a criticality value, used to decide when an alert is appropriate. The importance of the anomalies and how they are combined emerges from a cooperative self-adjusting process taking user feedback into account. This software is currently under development in ScanMaris, a project supported by the French National Research Agency.

Keywords: Multi-Agent Systems, Self-Adaptation, Self-Adjustment, Complex Systems, Maritime Surveillance.

1 Maritime Surveillance as a Complex Multi-sensor System

Supported by the French National Research Agency, ScanMaris project 1 aims to increase the efficiency of maritime surveillance and management activities by producing a prototype system assisting human operators, indicating suspicious vessels and quantifying this suspicion.

A Complex and Dynamic Problem is there in concern as there are many different types of vessels, behaviours, situations, and because the system is constantly evolving and hugely distributed. Ultimately, each vessel can be seen as a multi-sensor data source as our prototype collects information from different sensors (AIS or Automatic Identification System, HFSWR or High Frequency Surface Wave Radar and classical radars) and databases (environmental, LLOYD Insurance, TF2000 Vessel DB, Paris MoU, ICCAT) and regroups them for each vessel. By analysing each vessels situation using a rule-based inference engine, anomalies can be detected, like a sudden change of direction, abnormal speed, specific zones

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entering... These usually simple anomalies seldom constitute a threat by themselves but can be cumulated for a given vessel and the operator is informed of the state of the vessel. This mechanism of alert raising is based upon numerous parameters which adjustments enable to avoid false positives and be efficient in the detection of threatening situations.

Typical alert raising systems 2, which can be found in the medical, network or manufacturing domains, rely on the definition of "normal" behaviours and scenarios. This can be done using probabilistic and statistic methods, or neural networks. Any behaviour outside these specific boundaries raises an alert. This can not be applied to maritime surveillance where the heterogeneity of vessels and behaviours, and the constant evolution of the behaviours render the definition of behaviours or scenarios too costly. Few multi-agent system approaches exist in the maritime domain 3 and they are currently not able to adapt and learn. More exist in network intrusion detection 4, for meteorological alerts 5 or medicine but there are notable differences between these domains and the maritime domain precluding a simple transposition as they rely heavily on expert knowledge.

For a system to be able to adapt, its functional parameters will need to be adapted or to self-adapt. Manual adjustment by an expert is the most forward but of course unrealistic in a large-scale system. Using mathematical analytical models requires being able to produce an exact model. Genetic Algorithms and Neural Networks as with many bio-inspired approaches are time consuming and delicate to instantiate to a given problem.

Self-adaptive multi-agent systems have already been successfully applied to flood forecast 6 and preliminary aircraft design 7 for instance. A similar approach has been used in the ScanMaris prototype with the design of a self-adaptive multi-agent system (MAS8) able to efficiently raise alarms by self-adjusting the parameters regulating its functioning. We built a first MAS where each agent is responsible for a vessel and defined the agent's behaviour so that it perceives local anomalies and combines them. We then build a second MAS, responsible for adjusting each vessel-agents functional parameters dynamically (during runtime) and autonomously (without supervision) in response to environmental feedbacks. Both MAS will be presented below.

2 A Multi-agent System for Multi-sensor Surveillance

In a MAS, Each agent is an autonomous entity able to observe its environment, acts upon it, communicates directly or indirectly with other agents, and possesses its own representation (or knowledge), skills, state and goals.

Self-adaptation is achieved in our work by relying on the AMAS (Adaptive Multi-Agent Systems) theory 9 which is based on the well-discussed advantages of cooperation 10. The cooperative attitude between agents constitutes the engine of self-organization. Depending on the real-time interactions the multi-agent system has with its environment, the organization between its agents emerges and constitutes an answer to the difficulties of complex systems modelling (indeed, there is no global control of the system) 11.

Sensors, Data and the Architecture of *ScanMaris* are compound to emphasize, among a huge amount of data, elements that characterize abnormal behaviours or situations. Raw data from sensors are combined with data from databases to identify any detected ship. Then the inference rule engine (RE) analyse the ship status in its current environment from the space-time enriched map (EM): location, sea depth, presence or not in regulated areas (fishing zone, traffic separation scheme...), and neighbourhood. Other close ships are screened for collision headings and other abnormal behaviours like chasing, sudden heading or speed alteration. If an event breaks a rule, it becomes an anomaly and is sent to concerned vessel-agents. All those multimodal data are transferred to agent-vessels. Each of them, by weighting new events with its previous status, will compute a criticality value.

The Operative Multi-Agent System (OpMAS) communicates with the JBOSS application server encompassing IS, RE and EM 1 via the AgentComLink. This core class of OpMAS links vessel-agents between them and with their environment, carrying out message transmission, vessel-agent creation and updates according EM data.

The vessel-agent model has been designed using MAY (Make Agents Yourself: www.irit.fr/MAY) and is composed in first hand of 4 groups of communication components (dedicated respectively to IS, RE, EM, other agents), and in a second hand of representations: a module of representations of its properties, a module of representations of its environment, a module of representations of anomalies.

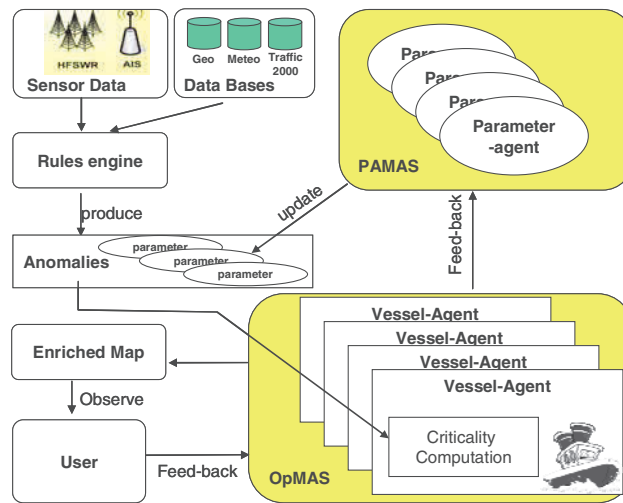


Fig. 1 General architecture of ScanMaris Project

The vessel-agent's life cycle grants its autonomy in an individual thread. The initializing step is associated with a request to RE and then, all threads are synchronized by the push messages from EM. At each cycle, a vessel-agent carries out the data processing of received messages. After analyzing three kinds of

messages (events from EM and invariance server including mark detection, anomalies from others vessel-agents and anomalies from the rule engine), a vessel-agent computes its own criticality. This can lead to the triggering of an alert if its criticality rises over the alert threshold.

Detection of Illegal Transshipment is required when a reefer ship that does not transmit AIS signals positions itself beyond the bounds of territorial water, which means out of RADAR detection. During several hours, several fishing ship will sail round trips between fishing quota regulated areas and the meeting point defined by the reefer ship. The transshipment occurs when a fishing ship stops close to the unnoticeable reefer ship, moreover; this brief stopping of a fishing ship in sea should not by itself trigger an alert at the RE level, and the period of time between two fishing vessels converging to the meeting place is not easily noticeable by a human operator.

Cooperating vessel-agents of the OpMAS can detect such an abnormal/illegal behaviour by sending marks to the EM. When a vessel-agent slows down and stops, it sends a request to the RE and simultaneously drops a stop mark containing its ID number in the EM. The RE answers with a stop anomaly. When later another vessel-agent slows down and stops at the same place, it will be informed besides its own stop anomaly, of the presence of one or more previous stop marks. So the current "transshipping" vessel-agent drops two marks in the EM, its own stop mark and a collective stop mark. As a result, vessel-agents mark the place of the undetectable reefer vessel with a collective stop and all of them that have participated this illegal activity, receive a warning flag.

The interest of the ScanMaris approach lies in the distributed and collective detection of complex abnormal situations by the organisation of vessel-agents rather than producing complicated rules in a centralized overwatch system. Complete OpMAS will require several hundreds of parameters and an automated process for tuning the parameters is necessary. A second MAS is in charge with their adaptation and is presented in the next section.

3 Self-adaptive Parameter Adjustment

OpMAS uses many parameters as each anomaly consists of 3 criticality parameters: an "initialisation" parameter related to the occurrence of the anomaly, an "increase" parameter related to anomaly enduring and a "decrease" parameter used to reduce the criticality when the anomaly ends. Marks consist of 2 criticality parameters: initialisation parameter related to the drop, and decreasing parameter used to reduce mark intensity in a pheromone like evaporation.

Moreover, each anomaly parameter is weighted by a vessel-agent parameter in order to discriminate that the same anomaly, for example a stop, has not the same meaning for a fishing vessel, as for a tanker, or another category of vessels. A second parameter combination concerns marks interpretation. In the end, with currently 17 recorded anomalies, 6 categories of marks and 4 categories of vessels, there are 137 interrelated parameters evolving in given intervals, defining a 10242 wide search space that **PAMAS** (Parameter Adjustment MAS) has to resolve.

Parameter-agents of PAMAS have been designed following the Adelfe methodology 12. To produce a valid criticality function for the vessel-agents, a parameter-agent will cooperate with other parameter-agents to adjust its value or propagate requests of adjustment.

The criterion of adjustment/propagation is based on the parameter-agent's own notion of criticality. The more a parameter-agent is used in the vessel-agent criticality function, the higher its own criticality is. By cooperating, they prevent the criticality of the worst parameter-agent to get worse while they are negotiating to absorb a feed-back. As a result, the organisation of parameter-agents continuously acts to ensure the global converging of the parameters represented by PAMAS.

4 Discussion

In the final OpMas, about 10.000 vessel agents are expected. Nevertheless, adaptation will only concern the same 137 interrelated parameters. At the moment, PAMAS is tested with about 60 parameter agents on a period of time of 5 hours (300 step). This choice fulfil both a realism criterium (a maximum of 15 anomalies affecting a single vessel-agent during 5 hours) and an acceptable time of learning. The next step for the ScanMaris prototype will be to test it on real-world large-scale situations. Currently, DCNS is recording all data on several large portions of the French coast during several days. The alert detection system will then be able to "learn" on a selection of situations and its relevance tested on the other situations. A demonstration is planned for January.

This prototype is only a first proof-of-concept and validation before launching two following project which will start shortly. The first, SisMaris, supported by the French Industry Ministry, will lead the prototype towards deployable ready-to-use software. The second, *I2C*, a European FP7 Security Research project starting later aims at enhancing the prototype's functionalities even further to tackle specific needs of other European partner states.

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