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A cloud based architecture capable of perceiving and predicting multiple vessel behaviour

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ABSTRACT

Progressively huge amounts of data, tracking vessels during their voyages across the seas, are becoming available, mostly due to the automatic identification system (AIS) that vessels of specific categories are required to carry. These datasets provide detailed insights into the patterns vessels follow, while safely navigating across the globe, under various conditions. In this paper, we develop an Artificial Neural Network (ANN) capable of predicting a vessels future behaviour (position, speed and course), based on events that occur in a predictable pattern, across large map areas. The main concept of this study is to determine if an ANN is capable of inferring the unique behavioural patterns that each vessel follows and successively use this as a means for predicting multiple vessel behaviour into a future point in time. We design, train and implement a proof of concept ANN, as a cloud based web application, with the ability of overlaying predicted short and long term vessel behaviour on an interactive map. Our proposed approach could potentially assist in busy port scheduling, vessel route planning, anomaly detection and increasing overall Maritime Domain Awareness.

1. Introduction

Safety of navigation can be defined as “such conditions of conducting the ships at sea which ensure that ships are not endangered by collisions, stranding or storm damage” [1]. Nowadays, Information and Communication systems are been widely deployed, in an attempt to ensure such conditions or at least provide aids to those navigating dangerous waters. These systems make use of radio or satellite communications to transmit vessel and environment related information, such as a vessel’s navigational properties and traffic conditions, but also safety and distress warnings. As of December 2004, the International Maritime Organization (IMO) requires all vessels over 299GT to carry an AIS transponder on board, which transmits their position, speed and course, amongst other static information (such as vessel’s name, dimensions and voyage details). AIS transponders include a GPS (Global Positioning System) receiver, which collects position and movement details, and a VHF transmitter, which transmits periodically this information on two VHF channels (frequencies 161.975 and 162.025 MHz) making this data available to the public domain. Much of this data is filtered through to the general public via the Internet. Authorities are interested in using this data to gain a better understanding of conditions at seas and thus uncover threats to security, but also operate as an aid in search and rescue operations, accident investigation and navigation.

While in the past, surveillance had suffered from a lack of data, current tracking technology has transformed the problem into one of an overabundance of information, leading to a need for automated analysis. The major challenge faced today, is developing the ability to identify patterns emerging within huge amounts of data, fused from a variety of sources and generated from monitoring large numbers of vessels on a day-to-day basis. The extraction of implicit and often unknown information from large datasets belongs to the field of data mining. This is a multidisciplinary field, which draws input from a variety of domains including machine learning, statistics, database technologies, artificial intelligence and others. Specifically, machine learning provides the technical basis for data mining; it is used to extract useful information from raw data and to infer underlying structures [2].

In this manuscript we investigate the use of an Artificial Neural Network (ANN), in order to develop a model of short and long term multiple vessel behaviour prediction, with the objective of

Abbreviations: AI, artificial intelligence; AIS, Automatic identification system; ANN, Artificial Neural Network; GPS, Global Positioning System; JDL, Joint Directors of Laboratories; MDA, Maritime Domain Awareness; MMSI, Maritime Mobile Service Identity; MSE, mean squared error; MVC, Model View Controller; REST, Representational State Transfer; SOAP, Simple Object Access Protocol; VHF, very high frequency.

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increasing overall Maritime Domain Awareness (MDA). The main concept of this study is to determine if an ANN is capable of inferring the unique behavioural patterns each vessel follows on its passage across the Aegean and successively use this as a means for predicting their behaviour into a future point in time. The ANN is tasked with acquiring knowledge of vessel patterns from real world observations, regarding a selection of passenger vessels navigating across the Aegean Sea during the summer months of 2013. Due to the size of the dataset and with the intent of building a scalable infrastructure that can potentially deal with larger datasets, we employ a cloud computing infrastructure to train the ANN in a timely fashion. We design, train and implement a proof of concept neural network, as a cloud based web application, with the ability to overlay predicted short and long term vessel behaviour on an interactive map.

This manuscript is organized as follows: Section 1 provides an introduction to the problem space, Section 2, provides related research literature and discusses our proposed approach to the problem, Section 3, describes the tasks of data collection and processing before introducing the model architecture, while Section 4 presents implementation details and evaluation results of the trained ANN. In Section 5, we describe our approach to implementing the neural network as a cloud service using the Model View Controller pattern, while in the successive sections we discuss our conclusions and provide related literature references.

2. Approach

2.1. Data fusion and MDA

Maritime Domain Awareness (MDA) is the effective understanding of activities, events and threats in the maritime environment that could impact global safety, security, economic activity or the environment [3]. The primary goals of MDA include "enhancing transparency in the maritime domain to detect, deter and defeat threats" and "enable accurate, dynamic, and confident decisions and responses to the full spectrum of maritime threats" [4]. Maritime threats include nation-wide, terrorist and piracy threats, but also environmental and social threats. The collection, fusion, analysis and dissemination of maritime intelligence and information are the fundamental building blocks of MDA. Data fusion combines multi-origin information to determine relationships among data; thus improving the understanding of a current complex environment, but also attempting to predict its future state. As such, data fusion can enable improved estimation of situations and, therefore, improved responses to situations [5]. The JDL Data Fusion Group defines data fusion as

> "*a process dealing with the association, correlation, and combination of data and information from single and multiple sources to achieve refined position and identity estimates, and complete and timely assessments of situations and threats, and their significance. The process is characterized by continuous refinements of its estimates and assessments, and the evaluation of the need for additional sources, or modification of the process itself, to achieve improved results.*"

The JDL proposed a number of possible ways of differentiating among types of data fusion processes, named fusion levels, that were later improved by Steinberg et al. [5] "to more accurately representing logically different types of problems, which are generally (though not necessarily) solved by different techniques". These levels were defined as [5]

- **Level 0**. *Sub-object*: Assessment estimation and prediction of signal or object observable states on the basis of pixel/signal-level data association and characterization.
- **Level 1**. *Object assessment*: estimation and prediction of entity states on the basis of observation-to-track association, continuous state estimation (e.g. kinematics) and discrete state estimation (e.g. target type and ID).
- **Level 2**. *Situation assessment*: estimation and prediction of relations among entities, to include force structure and cross force relations, communications and perceptual influences, physical context).
- **Level 3**. *Impact assessment*: estimation and prediction of effects on situations of planned or estimated/predicted actions by the participants.

Higher-level fusion aims to enhance situational awareness and assessment [6,7]. Currently large data sets of vessel activities and behaviours are becoming available. Data of sufficient quantity and quality is believed to provide a fair representation of the current state of reality; if the data covers all aspects of a situation in a timely manner, one can then say that complete and continuous situational awareness has been achieved [8]. Most current approaches to vessel monitoring using AIS data are assessed at levels 0 and 1 fusion levels, object assessment, ultimately providing an estimation and prediction of vessel states on the basis of observation to track association and continuous state estimation (Vessel ID, kinematics and vessel type). In the aspect of improving MDA, it is now becoming a necessity that related Information Systems (IS) progress to higher levels of data fusion. This requires that related IS's develop the capabilities to accurately capture contextual information related to vessel routes, estimation and prediction of vessel behaviour; thus progressing to levels 2 and 3 of data fusion.

A pattern is composed of events that repeat in a specific timeframe and predictable manner. Vessel behaviour can be defined as the sum of all characteristics defining vessels movement, such as vessel position, course, heading and speed, observed over a given period of time. Vessel behaviour monitored over time, provides insights into the navigational patterns followed by each vessel on specific routes. Machine learning techniques, can be employed to "learn" vessel behaviour and be used for predicting vessels behaviours. Such an approach can assist in busy port scheduling, collision avoidance, vessel route planning, but also anomaly detection and thus increasing overall Maritime Domain Awareness.

The development of global ship tracking systems opens possibilities of advancing maritime security far beyond the simple collision prevention. Anomaly detection has been identified as a critical component in order to achieve Situation Awareness in the context of information fusion and maritime surveillance [6,8–14]. Laxhammar et al. [10] define anomaly detection as a method that supports the situation assessment process at JDL level 2 by indicating objects and situations that, in some sense, deviate from the expected, known or "normal" behaviour and thus may be of interest for further investigation. Generally, the methods which are used in the context of anomaly detection are based on statistical/probabilistic models [15–18], such as the Gaussian Mixture Model (GMM) and the adaptive Kernel Density Estimator (KDE) [10,19], Bayesian networks [13,14,20,21], but also neural networks [6,9,22] and hybrid approaches [23].

2.2. Neural networks

An ANN is a machine learning information processing paradigm inspired by biological nervous systems. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurons), which work in unison to solve specific problems [24]. In general, a neural network is a parallel system, capable of resolving problems that linear-computing cannot [25]. The unique characteristics of ANNs, adaptability, nonlinearity, and