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ARCHITECTURE OF MARITIME AWARENESS SYSTEM SUPPLIED WITH EXTERNAL INFORMATION

ABSTRACT

In this paper, we discuss a software architecture, which has been developed for the needs of the System for Intelligent Maritime Monitoring (SIMMO). The system bases on the state-of-the-art information fusion and intelligence analysis techniques, which generates an enhanced Recognized Maritime Picture and thus supports situation analysis and decision-making. The SIMMO system aims to automatically fuse an up-to-date maritime data from Automatic Identification System (AIS) and open Internet sources. Based on collected data, data analysis is performed to detect suspicious vessels. Functionality of the system is realized in a number of different modules (web crawlers, data fusion, anomaly detection, visualization modules) that share the AIS and external data stored in the system's database. The aim of this article is to demonstrate how external information can be leveraged in maritime awareness system and what software solutions are necessary. A working system is presented as a proof of concept.

Keywords:
maritime awareness, AIS, data fusion, information extraction, anomaly detection.

INTRODUCTION

Nowadays more than 90 percent of global trade is carried by sea [International Maritime Organisation, 2012]. As a result, we observe a growing importance of a maritime domain, and thus a maritime economy. Moreover, a maritime surveillance becomes an essential priority for Europe's security. However, development of the seaborne trade has also negative impact. The maritime domain is a space with a relative absence of legal constraints in the high seas, what makes it difficult to provide a worldwide control and protection. As a consequence, the number of threats at sea is growing, which may have various background, like political, economic, ecological or military, including terrorism, piracy and organized crime.

Taking into account these challenges and threats, there is a need for generation of a Recognized Maritime Picture (RMP). RMP is defined as a composite picture of activities in a given maritime area for a given time [Vespe et al., 2008]; it requires timely input from many data sources to determine the location, identity, and activity of ships, in order to provide sufficient information to decision makers.

This requires development of maritime surveillance systems, which would collect, fuse and analyze data from various sources.

Today, the basic pillar of the maritime surveillance systems is radar data and data provided by vessel tracking systems. The latter includes Automatic Identification System (AIS). AIS is an automatic tracking system, used for identification and location of ships in real-time. It has been created as a tool for the avoidance of collision at sea and is based on automatic exchange of data between a ship and other nearby ships, AIS base stations and satellites. AIS includes the basic information about a ship and his voyage (ship's identity, type, position, course, speed, navigational status and other safety-related information), which are sent using 27 types of AIS messages. The scope and length of each type is defined in ITU 1371-4 Recommendation [International Telecommunication Union, 2010].

Despite the existence of many sensor data (e.g. radar, AIS), the maritime surveillance systems are still under development, what especially concerns the integration of data about ships from various sources and the use of intelligent data analysis tools. There exist four important challenges with regard to surveillance capabilities of such systems:

1. Improvement of AIS data quality — AIS is a passive sensor, which rely on data broadcasted intentionally by ships. As a consequence, some of data about ship's tracks are often incomplete or missing. Carried out research show the importance of improving AIS data incompleteness and integrity [Felski et al., 2015]. In most solutions, this missing information needs to be manually searched in other sources or is not available at all. Therefore, there is a requirement to provide a tool, which would be able to supplement data gaps in AIS messages with the information acquired from other sources and this improve the quality of the AIS messages.

2. Providing wider scope of information about vessels - AIS provides only essential basic information about ships. In order to generated the RMP, more relevant information is required (e.g. technical details, owner, security and historical information). To this end, additional information sources need to be used to complement the information provided by AIS. One of such sources is the Internet, which includes a number of data freely available and accessible websites with information about ships.
3. Support in data analysis and detection of suspicious ships — the generation of RMP requires analysis and interpretation of millions of data records. Therefore, information systems with advanced analysis and reasoning methods are required, which would provide real-time assessment of the situation [Pallotta et al., 2013]. Moreover, they shall support a user in identification of potential maritime threats and anomalies.

These challenges are addressed by the SIMMO project: System for Intelligent Maritime MOnitoring. The general aim of the SIMMO project is to develop a prototype of a system, based on the state-of-the-art information fusion and intelligence analysis techniques, which will generate an enhanced RMP. The SIMMO system is to support different stakeholders and users from the maritime domain in situation analysis and decision-making, by providing the up-to-date maritime data from two sources: AIS and open Internet sources, and by automatic detection of anomalies in ship's behavior.

A system with such a functionality requires a proper architecture, enabling sharing and processing of data from both sources. The aim of this article is to present the architecture designed for the SIMMO system, including system's components and results of the first experiments.

The remainder of the paper is organized as follows: in section 2, related work is presented. In section 3, a general overview of the SIMMO architecture is explained, followed by detailed description of system's components. Section 4 includes the initial results of the architecture's evaluation. The article concludes with a summary and directions of future works.

RELATED WORK

Several systems have been developed, which aim at maritime surveillance and anomaly detection. Anomaly detection may be understood as a process of finding abnormal behavior, which does not t into expected patterns or predicted trend. Anomalous behavior may be an indicator of a possible threat, which may be posed by a certain entity, such as a vessel.

One of such systems is SARGOS[1], which was developed to protect of shore infrastructures against threats [Giraud et al., 2011]. It is based on the AIS, navigation radars and infra-red sensors, and provides inference process using Bayesian networks in risk assessment [Bouejla et al., 2014], [Chaze et al., 2012]. Regarding architecture, SARGOS consists of several components. *Detection* is responsible for information collection, which is used for calculating potential risks. A possible avoidance of these risks is suggested by *Reactions* along with *Means Management*. *Visualization* and *Record & Replay* provide access to graphical analysis of the maritime situation and can be used for distinguishing real threats from false alarms. Another example of a comprehensive system is GeMASS [Chen et al., 2014]. It consists of modules for data pre-processing (raw AIS data translation), real-time ship analysis and components for decision/result update (for obtaining training datasets), knowledge discovery and data post-processing (for data accumulation).

Johansson et al. [2007] proposed a system with the anomaly detector, which takes into account training data and experts' knowledge. Riveiro et al. [2008], in turn, proposed a solution based on an interactive visualization using Gaussian Mixture Models. The process of abnormal behavior detection is divided into acquisition, processing and analysis, and relies on training data and clustering of sensors real world information. In contrary to Johanson's, this solution requires an end-user to analyze detected anomalies and decide whether it is a false alarm.

Fisher and Bauer [2010] suggest a system based on an object-oriented world model (OOWM). OOWM is focused on providing an interface for doing more high-level operations like an anomaly detection, rather than doing it itself. Its architecture consists of classification, fusion manager, data association module and an instance manager. All these parts are to provide object-oriented representation of instances (vessels) and its attributes via access interface, which may be queried from external applications.

An important success factor for all described maritime surveillance systems is merging data from many different sources. This concept is called data fusion. Data fusion is a challenging task, since there are many issues arising from the data to be fused, such as data imperfection, correlation, inconsistency, disparateness and ambiguity. The solutions described above focus on providing

[1] http://en.sofresud.com/Maritime-Surveillance/SARGOS [access 14.09.2016].

data fusion techniques, which combine mainly sensor data such as AIS, Vessel Traffic Services (VTS), radars or video cameras [Kazemi et al., 2013]. A more sophisticated approach, which assumes enrichment of sensor data with open data, data available in various databases or data stored in structured or unstructured documents (e.g. Web pages, historical reports and comments on ships behaviors) is still missing [Brax, 2011].

THE SIMMO ARCHITECTURE

The architecture of the SIMMO system consists of set of components responsible for data processing and reasoning, two components responsible for data storing and a component responsible for visualization. The system was designed according to Design Science in Information Systems principles [Hevner et al., 2004]. According to these rules, the system and underlying methods constitute an artifact. Problem relevance is tightly coupled with a huge demand for robust maritime awareness solution (as in e.g. Brax [2011]). While some similar solutions exist [Giraud et al., 2011], to the best of our knowledge it is the first system focused on data quality in such a domain, which makes a clear research contribution. Referring to design as a search process, numerous anomaly detection methods were tested under research rigor. Regarding the communication of research, the results are deployed as a convenient web application, which can be used by non-scientific experts with the domain knowledge (see Evaluation section). The general overview of the SIMMO system's architecture is presented in Figure 1.

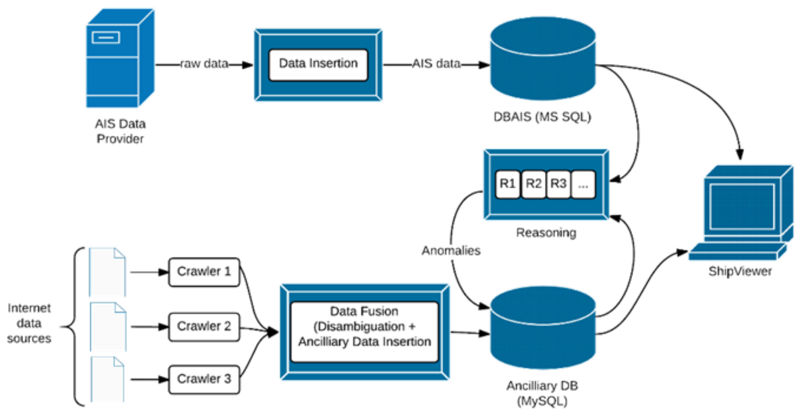

Fig. 1. An overview of SIMMO system infrastructure

In general, there are two data flows executed in parallel. The first flow is related to AIS data and consists of three elements:

- *FTP server of the AIS data provider* — a server, responsible for making raw AIS data (satellite and terrestrial) accessible for the SIMMO system. The raw AIS data are continuously and in real-time transferred from this server via FTP communication;
- *Data Insertion* — a module responsible for processing raw AIS data and inserting it into a database;
- *DBAIS* — a database, where processed (decoded) AIS data is stored.

The second flow is connected with acquiring, processing and fusing additional data from open Internet sources. It consists of the following elements:

- *Crawlers* — components responsible for systematic monitoring of selected Internet data sources, downloading and parsing the content of a Website to select important data. For each Internet source, a separate crawler is provided;
- *Data Fusion* — a component responsible for fusing data from different Internet sources, coping with disambiguation of data and writing the retrieved data to a database;
- *Ancillary DB* — a database, where the fused data from Internet sources are stored.

Apart from the above-mentioned elements, there are software modules responsible for analyzing AIS and ancillary data, collectively referred to as *Reasoning*. They are illustrated as separate boxes (R1, R2, ...) representing various analyses, in a plug-in-like way. They shall use data stored both in DBAIS and Ancillary DB, and based on them perform anomalies detection analysis. The detected anomalies are then written back by this component to Ancillary DB and is ready to be used by visualization component.

The last component of the SIMMO system is *ShipViewer*, a module for visualizing the current state at the sea and presenting detected anomalies in ship's behavior. This component uses data stored both in *DBAIS* and *Ancillary DB*. In the following sections, each module is described.

AIS data processing

The input for the SIMMO system are AIS messages, which are not yet processed (further called raw AIS data) and encoded according to the AIVDM/AIVDO protocol[2]. Example of the raw AIS message is presented in Listing 1.

[2] http://catb.org/gpsd/AIVDM.html [access 14.09.2016].

Listing 1. Sample AIS message.

!AIVDM ,1,1,,B,177KQJ5000G?tO‘K>RA1wUbN0TKH ,0*5C

The architecture of the SIMMO system assumes that the raw AIS data can come from any AIS data provider, and files containing these messages can be stored in any location. In case of the raw AIS data used in the SIMMO project, the messages are kept in text files, which are stored on an external FTP server of the AIS data provider. Therefore, all data are downloaded through File Transfer Protocol. At this stage, AIS data about all types of ships are transferred. Later, a filtering of the selected types of AIS messages or the selected types of ships can be performed by Data Insertion and DBAIS modules.

The SIMMO system is designed to process data continuously. It means that raw AIS data are transferred from *FTP server* to *Data Insertion* as soon as new data appears. The raw as well as the processed (decoded) AIS data are stored in *DBAIS*. For this purpose, a relational database was chosen. In case of the SIMMO project, it is the MS SQL database.

The process of data loading is performed by the specially developed *Data Insertion* command line application, which transfers data from *AIS Data Provider* to *DBAIS* and initializes its processing. *Data Insertion* application extracts binary data from raw message and assigns e.g. a unique internal number and timestamps to it. At this stage of data processing, all AIS data (regarding all ships) are inserted to a temporary *raw_data* table in *DBAIS*. Due to its relatively fast performance, stored procedures are used for the raw data processing. In this particular case, the aim of stored procedures is to extract information from (decode) raw AIS messages, which were loaded to the database.

At first, special stored procedure decodes raw message and, most importantly, extracts vessels' MMSI[3] and message type. The selection of messages of the selected type can be done at this stage. In case of the SIMMO, only messages of type 1,2,3,5 or 27 are saved into database. Depending on the extracted message type, the stored procedure also extracts additional fields (for example navigational status).

Additionally, before the insertion of the decoded data to the table, in which it will be stored, filtering of specified types of ships can take place. For this end, another stored procedure is used, which gathers all MMSI numbers from the newly

[3] MMSI is Maritime Mobile Service Identity and allows to uniquely identify a ship.

inserted messages and compares them with MMSI numbers of all ships of the specified type, already stored in the database. Finally, other procedures take care of keeping up to date connection between information sent in different AIS message types by the same vessel.

Data prepared in the manner presented in previous section are ready for visualization purposes and further analysis.

Internet Data Sources

Apart from data obtained from AIS, the SIMMO system retrieve ancillary data from many different Internet data sources. Each of these sources may have different structure and may publish data in different ways. Internet data sources utilized in the project may be divided into four groups:

– shallow Web — data available in a form of HTML documents, available to standard Web engines;
– deep Web — data sources, where documents with required data are dynamically generated (e.g. using AJAX technologies) as a response to queries submitted through a query form;
– data published in a form of PDF files;
– data published in a form of CSV files.

For each data source a separate module called *Crawler* must be prepared, which will be able to fetch the data from this particular source. The modules will differ from each other substantially, as they must be adjusted to the specific structure of the particular data source and they must be able to retrieve the data published in completely different ways. For example, to fetch data from PDF files, a library for text extraction from such documents must be utilized, which is not required for retrieval of data from data sources of other types.

The data acquired from the selected Internet data sources is stored in *Ancillary DB* database. The data concerns different types of entities: ships, maritime companies, ports, flags and Classification Societies. For each such entity, there are separate tables in the database, which represent entity's certain attributes and relations with other entities.

An important fact concerning this data is that data about a single entity retrieved from different sources may differ from each other. In other words, for each attribute of a certain entity there may be different values in different data sources. In *Ancillary DB,* for the specified attributes we want to store all values, which were retrieved from different sources. For example, if a given attribute has different values in two different sources, we want to keep both values in the database, with additional information about what is the source of a given value for the attribute. To store multiple values of the same attribute, for each entity we store multiple rows describing it. To each row, a source identifier is assigned, so that for each value, its source may be easily checked. Thus, by listing all rows concerning a given entity, it is possible to learn, what values were assigned to analyzed attributes in different data sources.

What is also important, data describing a certain entity may change over time. These modifications reflect changes, which have happened in relation to a particular entity. In the SIMMO project, it is important to store in *Ancillary DB* not only the current data, but also the historical ones, as they still may be useful in some analysis scenarios. Thus, the data model is prepared to enable storage of both the current data as well as historical values of the selected features. Data concerning a specific entity is to have the same identifier assigned regardless the source that it comes from.

The data, retrieved using the methods described above, has to be subsequently written to *Ancillary DB* to enable performing different analysis. However, before saving the data in the database, an additional step of data disambiguation is performed. For example, a certain ship may be described in different ways in different sources (e.g. ship's name may be spelled in various ways). By disambiguation we understand assignment of an identifier to a given data set. To each entity (e.g. ship, port), a unique identifier is assigned. For each data set, regardless of the source, if the data concerns a given entity, the identifier of this entity is assigned. Such identifiers link data concerning the same entities coming from different sources. Without such identifiers, it would be impossible to perform required inferences.

The disambiguation is performed using special disambiguation modules, which together form a disambiguation pipeline. The disambiguation pipeline is performed in this way that a given object is processed sequentially by each disambiguation module. The sequence of modules used in the pipeline is defined in a configuration file. Thanks to this, in case of implementation of new disambiguation modules, only this configuration file must be edited to update the disambiguation pipeline.

Each disambiguation module contains a series of instructions. The instructions de ne steps which are to be undertaken in order to perform the disambiguation.

Such steps may significantly differ from each other, as they depend on the type of entity, which is to be disambiguated. Also, even for the same type of entities different disambiguation modules may be specified, implementing different logic and performing the task with different accuracy.

Once the data is disambiguated, the final step is to insert the data into *Ancillary DB*.

Reasoning

Reasoning is a SIMMO module implementing any analysis that based on collected data, both AIS and external, infers new facts and stores them back in a database. New facts can be used in many ways: visualized in *ShipViewer*, sent as an alert to subscribed users, be consumed for anomaly detection task, used to reason about more facts.

Reasoning module has intentionally interfaces with only two other modules: *DBAIS* and *Ancillary DB*. The assumption is that all data necessary for analysis (e.g. anomaly detection) should already be stored in a database. Communication with *DBAIS* is set up only to obtain relevant data concerning location and trajectory of ships, while all other data is to be retrieved from *Ancillary DB*. Although such an approach seems to be conservative, it is necessary to maintain expected quality of the system. In case, when new kind of analysis requires additional data (not yet stored in the system), such data needs first to be gathered via *Crawlers* and *Data Fusion*. For this end, dedicated crawlers have to be developed in accordance with the SIMMO framework and new data also entails changes in the data model of *Ancillary DB*.

The reasoning about new facts is carried out according to analysis scenarios, which reflect the requirements of the SIMMO system. In the architecture overview (see Fig. 1) the module is represented as a number of boxes, each devoted to different kind of analysis: changes in static AIS elements, ambiguous identification of the tankers, inclusion on the list of offences, and loitering at high sea. The enumerated scenarios are collectively referred to as anomaly detection. They are provided as plug-in and can be performed on different servers. It is important to note that analysis scenarios are the closed catalogue this is a consequence of a conservative approach to data collection. If new analysis is to be performed, a new analysis scenario and additional data required for this scenario needs to be defined and included in the system.

The analysis of related work related to anomaly detection in maritime domain points out that efficiency of analysis is one of the biggest challenges. Some algorithms, although very precise, cannot be accepted because of poor performance. There is always a kind of trade-o between performance and precision. Therefore, algorithms should be capable of on-line processing and incremental learning. There is no place for batch processing, when prompt reaction for anomalies is necessary. Regardless of algorithms optimization, taking into account number of vessels at the sea and velocity of the stream of AIS data, significant processing resources are necessary.

EVALUATION

The presented solutions have been partially evaluated in the testing environment. The performed evaluation concerned only the data flow related to AIS data. The preliminary results with AIS data from around 18 months shows that performance of the presented solution is sufficient. The tests were performed on a virtual machine with 180 GB RAM and 8 2.13 GHz virtual processors.

The files used in the SIMMO project consist typically of around three to four thousands of lines of raw AIS messages each. Average file size is 200–350 KB. The size of all transferred files with the raw data from one day is around 1.7 GB (which results in approximately 50 GB/month). The amount of collected files is equal to around 5600 per day. On average, around 4 new files appear in Data Insertion module every minute. The process of uploading AIS messages from a single file to the database generally takes 2–4 seconds, which is sufficient to process all AIS messages in near real-time.

The system itself has an intuitive graphic interface, which facilitates vessel tracking. One can use anomaly detection algorithms for a quick search of suspicious behavior (Fig. 2). Thanks to the reasoning module and ancillary data, anomalies can be filtered and displayed depending on their type, such as ambiguous identification, being in detention/banned list, belonging to an underperforming company, flying a blacklisted flag or flag of convenience, or having a suspended or withdrawn status.

The detailed vessel information view (Fig. 3) also makes a use of ancillary data and, therefore, allows to inspect data not available in raw AIS messages, such as home port, classification surveys, inspections, detentions, and ship pictures (if available). The proposed architecture turned out to suit Maritime Domain Awareness needs in terms of usefulness and speed.

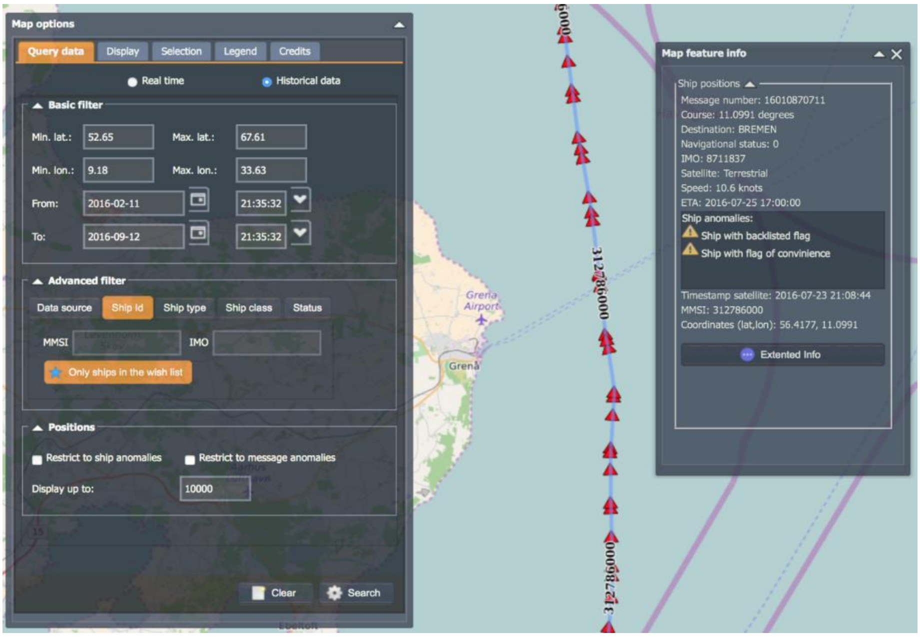

Fig. 2. The map view of the SIMMO system

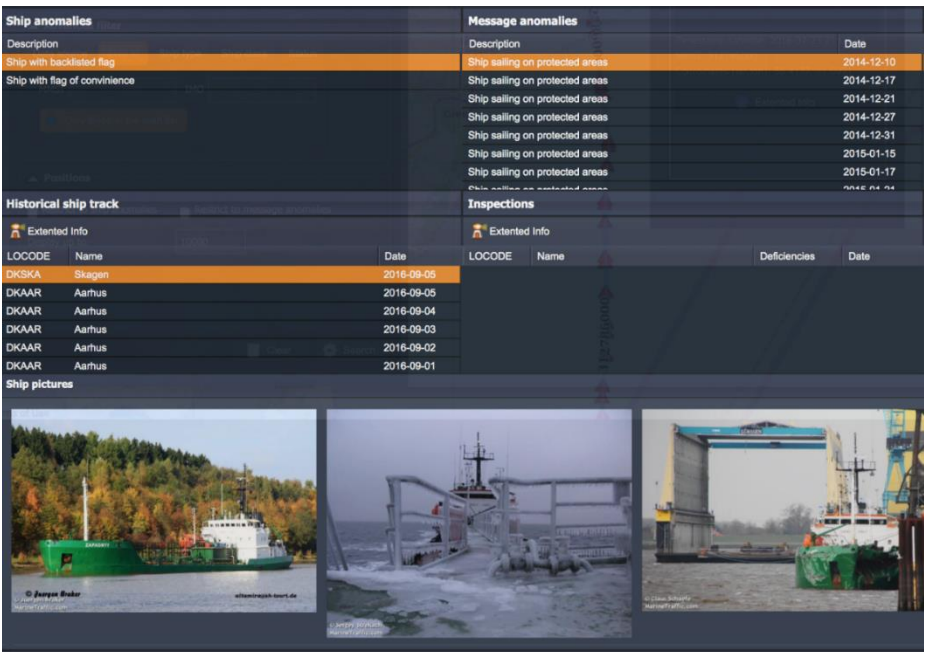

Fig. 3. Vessel anomalies and ancillary information in the SIMMO system

CONCLUSIONS AND FUTURE WORK

The paper presents the designed system's architecture with definition of the system's components and data repositories, and description of connections and data flow between different modules. The SIMMO system aims to integrate up-to-date maritime data from two types of data sources, 1) AIS and 2) open Internet sources. Therefore, there are two separate groups of components designed (one for AIS data and one for the Internet sources), responsible for retrieval, fusion and insertion of data, and two data repositories, one responsible for storing AIS data and second for storing data from external sources. Based on the integrated data, data analysis within the reasoning module is performed, aiming at identification of suspicious vessel behaviors. The data retrieved by the system as well as suspicious ships is presented to a user via a visualization module, which aims to aid a user in decision making.

Future work will focus on leveraging contemporary solutions for managing big datasets. In-memory solutions seem to be attractive for the purpose of data analysis. Beside closed and expensive solutions like SAP HANA, more and more open solutions are developing like Apache Spark or VoltDB. In the first step, application of big data technologies is foreseen for the data analysis components. In a later stage it can be applied to the whole SIMMO architecture. This, however, would require reimplementation of the whole AIS data collection stack.

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STRESZCZENIE

Prezentowany artykuł omawia architekturę oprogramowania opracowanego na potrzeby projektu System for Intelligent Maritime Monitoring (SIMMO). System ten bazuje na najnowszych osiągnięciach w dziedzinach fuzji oraz inteligentnej analizy danych w celu generowania wzbogaconego obrazu sytuacji na morzu i wspomagania decyzji. SIMMO w sposób automatyczny łączy dane dotyczące ruchu morskiego z systemu AIS z danymi pochodzącymi z otwartych źródeł internetowych. Dzięki zebranym danym możliwa jest analiza w celu wykrycia podejrzanych zachowań na morzu. Funkcjonalność systemu stanowi wypadkową zawartych w nim modułów (ekstrakcja danych, fuzja danych, detekcja anomalii, wizualizacja) współdzielących dostęp do baz z danymi AIS oraz z zewnętrznych źródeł. Celem artykułu jest demonstracja sposobu wykorzystywania zewnętrznych informacji w systemach przeznaczonych do monitorowania ruchu morskiego, a także prezentacja działającego systemu.