Semantic Data Exchange in e-Navigation

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Abstract: E-Navigation aims to enhance the safety and security of maritime activities by exchanging, integrating and analyzing the data between and in ship-side and shore-side systems. In this paper, we present the main characteristics of our semantic data exchange concept developed in the COSINUS project. In addition to the main task of exchanging data written in a variety of formats between on-board and onshore systems, each semantic data processor, which is related to a maritime system like ECDIS (Electronic Chart Display and Information System) or VTS (Vessel Traffic Service), defines a context model, which itself concludes information from the transient streams of data, registers the current state and the history of the ships, assigns some important meta-data such as data quality information and applies semantic compression by sending the interesting patterns only. Therefore, the context models in our data exchange represent cooperatively the navigation situation and this enables cooperative control and monitoring on such navigation and ensures the integration between different marine data sources.

Keywords

e-Navigation, Maritime, VTS (Vessel Traffic Service), ECDIS (Electronic Chart Display and Information System), Semantic Data

1 Introduction

Waterways in the German Bight are important economic infrastructures. Safe maritime routes in terms of avoiding accidents and collisions are particularly important for Germany for the international exchange of goods, taking into account that the vast majority of German goods transfers (276 million tones of goods were handled in 2010) are handled by the sea [Win11]. Increasing ship traffic, technical and human errors (often caused by insufficient situation awareness) and extreme weather events (storms, unusual sea conditions) affect clearly the traffic management on the shipping lanes and may cause a wide range of hazards for the ship safety. E-Navigation requires integrated maritime traffic control and safety systems in order to increase the efficiency of maritime transport and the protection of the marine and coastal environment.

More challenges should be reckoned within the German Bight because of the possible conflicts between shipping and other usages of the maritime space like construction of offshore wind farms. According to the Wind Energy Agency Bremerhaven (Windenergie Agentur Bremerhaven)[1], it is planned to construct approximately 4538 plants in 87 wind farms in the German Bight in the next few years, this will restrict the existing shipping routes and increase the risks of possible collisions: ship/ship and ship/wind parks.

The safety of maritime systems, the integration, the improved communication and the cooperation between actors involved in dangerous situations are central objectives of the e-navigation strategy of the International Maritime Organization (IMO) [IMO13]. The National Master Plan Maritime Technologies (NMMT)[2] and the research programme "Maritime next-generation technologies(2011-2015)" [3] have been incorporated for the achievment of these objectives. The International Maritime Organization (IMO) has called for a cooperative communication management between ship-side systems and shore-side systems in order to prevent accidents and increase the safety. The objective of research and development must be an increased degree of safety in maritime traffic. This can be supported by exchanging of useful information between ship-side systems and shore-side systems.

Therefore, the research project COSINUS[4][BB14] examines the integration of navigation systems on ship and shore sides. The main contribution is to produce a comprehensive situational awareness on board a vessel as well as in land-based vessel traffic services (VTS) centers, in order to assist the mariners in the prevention of collisions and groundings and thus to increase the safety of shipping despite the continuous increasing of traffic density.

In this paper, we present the architecture of the semantic data exchange in COSINUS project and we go through the details of two use-cases based on such semantic data exchange. After this general introduction, the rest of the paper will go as the following: in the related work section, we try to point out to the level of knowledge and development achieved in data exchange and e-navigation domain, and the next section will highlight the contribution of our project COSINUS in e-navigation. Then we present the architecture of the semantic data exchange in COSINUS. In the implementation section, we will introduce the complex event processing system we are using in COSINUS and we describe our current progress in the project and the first demonstration we have already done. After that, we go into some details with two use-cases of semantic data exchange and we summarize in the conclusion.

[1] http://www.wab.net/images/stories/PDF/offshore/WAB_Offshoretabelle_A4_Nord-OstseeDE_06-2011.pdf

[2] http://www.nmmt.de

[3] http://ec.europa.eu/research/biotechnology/eu-us-task-force/pdf/strategic-plan-2011-2015.pdf

[4] http://www.offis.de/f_e_bereiche/verkehr/projekt/projekte/cosinus.html

2 Related Work

We will refer in this section to the state-of-the-art projects, which have contributed in data exchange in the e-Navigation domain. These projects have been mentioned in our COSINUS project paper [BB14]. Not all the projects in e-navigation have considered the integration of integrated bridge systems (INS) and VTS systems, for example: The project BaSSy [5]- Baltic Sea Safety and the InterReg project EfficenSea [6] focused on analyzing AIS information and radar images and contributed to risk identification algorithms for VTS systems regardless the data exchange and integration between INS and VTS systems. On the other hand, there are projects have been contributing in data exchange and integration between maritime systems, like ACCSEAS [7] and MonaLisa I + II [8].
ACCSEAS focuses on the development of prototypical e-navigation services and the development of a testbed in the North Sea region to demonstrate the prototype servies. One of the prototypes demonstrates the functionality of route exchange between vessels and VTS systems, and between vessels themselves.
Monalisa I + II focuses also on data exchange in the term of route exchange from ship to shore and ship to ship. The difference between COSINUS and Monalisa is in the architectural design, while Monalisa project assumes a central administrative entity that organizes route planning among different participants in a specific area at sea, ours avoids the need for such a central organizational body, but relies on the judgement of all parties involved (ship masters and VTS operators) instead [BB14].

3 COSINUS with the current e-Navigation Systems

As we mentioned above, the COSINUS project aims to enhance the existing navigational systems by ensuring the data integration onshore and on board. Today, the only communication between ship-side and shore-side is done by the staff in the control centre on shore and the mariners on the vessels. The contribution of COSINUS is the technical support for enabling the cooperation between the both sides.
In today's systems, some data fusion and integrity checks are carried out, e.g. the fusion of AIS (Automatic Identification System) and radar targets in ECDIS. COSINUS aims at the integration of such maritime traffic safety systems on board and on shore like ECDIS and VTS. Additionally, novel concepts for the presentation of enhanced data to the operator and operation of new tools and services as well as decentralized data capturing, processing and storage are investigated.
The data in land-based information systems will be visualized in a way that a complete overview over the traffic situation is given in order to support the navigational operation of the vessel. This includes the presentation of the shared routes and manoeuver plans as

[5] http://meeting.helcom.fi/c/document_library/get_file?folderId=75266&name=DLFE-30282.pdf
[6] http://www.efficiensea.org/
[7] http://www.accseas.eu/
[8] http://monalisaproject.eu/

well as the operational interface to the VTS operator. The goal is to establish a cooperative and task-based picture, which offers a dynamically enhanced view for the bridge crew going beyond traditional ship-based sensor information like the own-ship radar or AIS. The systems, which offer a cognitive ability, are of great interest whenever it comes to critical situations where an enhanced situation awareness is required. This could be information of a higher order, e.g. an indication of the actual anticipated danger level.

4 Semantic Data Exchange Architecture

Many different streams of data, in terms of different formats (syntax) and semantics, are published continuously by ship-side and shore-side systems. Advanced complex event processing systems will undertake the tasks of data exchange, data fusion, data provenance, data integration, data mining, data cleansing and data quality processing.
In figure 1 you can see the abstract design architecture of the semantic processor. There is a semantic processor for each system on-board and onshore. Each semantic processor is responsible of organizing the traffic of different streams in both directions, i.e. the messages sent or received by the related navigation system (ECDIS, VTS).

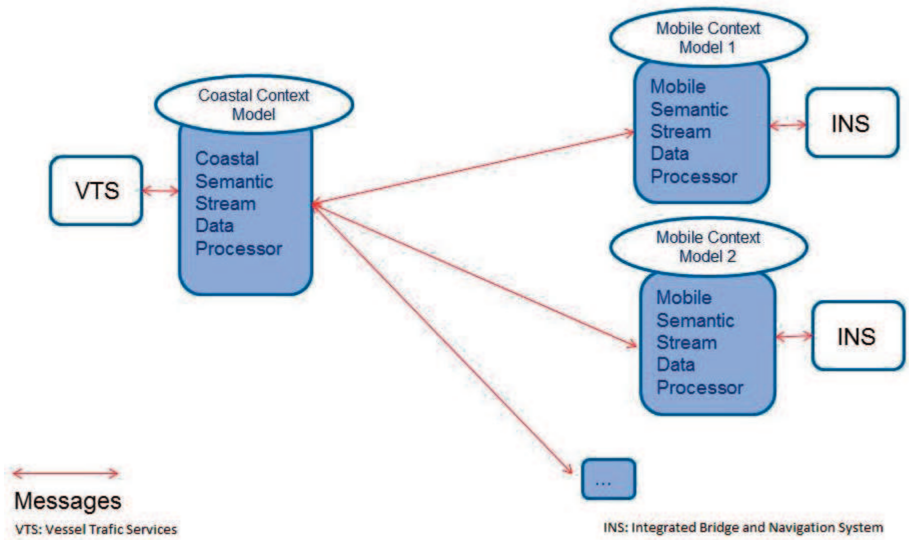

Figure 1: Semantic Data Exchange Architecture

4.1 Coastal and Mobile Semantic Stream Data Processor

4.1.1 Definitions

Definition 1. *The Coastal Semantic Stream Data Processor is an onshore complex event processing system responsible of organizing the traffic of messages (represented in a variety of different formats) sent or received by the VTS.*

Definition 2. *The Mobile (ship) Semantic Stream Data Processor is an on-ship complex event processing system responsible of organizing the traffic of messages (represented in a variety of different formats) sent or received by the ECDIS .*

4.1.2 Functions

The VTS System in use supports the IVEF format [9] among others, such as NMEA and IEC61174. But it will receive messages written in any format (NMEA, IEC61174..) sent by the ECDIS on the ship side via the data processors. On the other hand, the ECDIS will have to receive IVEF messages from the VTS system. Therefore the coastal and mobile data processors will have to convert between the different formats, and may leverage the existing systems by providing them with missing data. Moreover, they can conclude useful information from the passed-through messages and then such information can be used to enrich the related context model. More details about the coastal and mobile context models are available in section 4.2. The main functions of the coastal and mobile semantic transformers can be summarized in the following:

- *Technical (non-semantic) Function:* Conversion (IVEF <->NMEA, IVEF <->JSON, IVEF <->IEC61174) and/or forwarding.
- *Semantic Function:* Enriching the coastal and mobile context models by extracting useful information from the transient (passed-through) messages.

4.2 Context Models

The context models contribute in ensuring a **cooperative control and monitoring** on the navigation situation.
The context model stores a mid-term memory / history of a semantic processor, e.g. one hour sliding time-window (can be specified). The context model will be built up continuously by interpreting the passed-through messages. That means, while the semantic processor is converting between standards and forwarding the messages, the related context model, in parallel, will be enriched with useful information concluded from such transient messages, like the detection of inconsistent information between the ship-side and the shore-side.

[9] `http://openivef.org/`

4.2.1 Mobile Context Model

The mobile context model is an abstract description of the navigation process from the vessel's point of view. Every useful result extracted from the data processing on the transient data should be registered in the related mobile context model. Therefore, if the data cleansing component, for example, detects some outliers and ignores them from the streams, the outliers should be registered.
Moreover, the mobile context model will ensure data traceability by storing a mapping history between the original data and the converted data.
A lot of useful applications can be done upon such context model, for example: When entering the range of a VTS, a ship can send some history of it's context, then the VTS system will be able to analyze such history data and predict the behavior of the new joined ship.

4.2.2 Coastal Context Model

As a counterpart to the mobile context model, the coastal context model stores traffic information coming from all available vessels and coastal surveillance stations. This monitoring includes not only the ships sensed by the VTS system directly, but also those apart from the coverage area of the VTS and their information were received via the semantic processors.
Using this context model, we can also rate the quality of data (e.g., completeness, accuracy) considering the availability of many data sources. Moreover, this coastal context model, as a leader one, should have suitable representations of the mobile context models of the communication partners (vessels). Then, a snapshot on this context model at time t will be useful to check some time-relevant concepts like the range: what could a ship report at time t.

5 Implementation

We have already implemented the data exchange between the ship-side and shore-side. The shore side system (VTS) works with IVEF format. It publishes and is able to receive IVEF messages containing tracks and/or routes.
On the other hand, the ship side system, ECDIS, works with NMEA-0183 format [10], JSON format and may work also with IEC-61174 format in the future. It publishes tracks in NMEA format, the user can import a route written in JSON and the ECDIS can then publish this route.
We have developed protocol handlers for each format in the Complex Event Processing System Odysseus[11][AN12]. Thus, Odysseus can receive the messages, written in any format, parse them and convert them into the counterpart format.
For such data exchange, queries will be prepared in order to receive the data from a mar-

[10] http://www.nmea.de/nmea0183datensaetze.html#gga
[11] http://odysseus.informatik.uni-oldenburg.de/

itime system, parse them using the protocol handler, and then these data will be represented in the internal format of Odysseus, so that we can use arbitrary algorithms like Kalman-Filter for further processing. Finally, a converter query operator is used to convert into the destination format.

First Demonstration

The first demonstration scenario represents a vertical prototype for data exchange between INS and VTS. In this scenario, we receive simulated target data from OFFIS' maritime traffic simulation (MTS)[DH14], and real target data from a sensor box (NaviBox) equipped with radar and AIS receivers also provided by OFFIS. Both targets, real and simulated, are received by Odysseus as NMEA sentences. Odysseus forwards them to the ECDIS and converts them into IVEF before sending them to the VTS. This vertical prototype was used to generate a consistent situational awareness on both systems using simple data such as target data.
The following figure represents the work-flow of operators in the complex event processing query of this scenario. The "MetadataCreationPO" and "SystemTime" are for preparing meta-data inside Odysseus during processing, while the other operators represent the sequence of processing done in this scenario, beginning from receiving the data from MTS and the NaviBox, then converting into IVEF using the "IvefNmeaConverter" and merging the results using the "Merge" operator, and at the end the "TCP-Server" will establish a TCP connection with the VTS system to send it the resulted IVEF data.

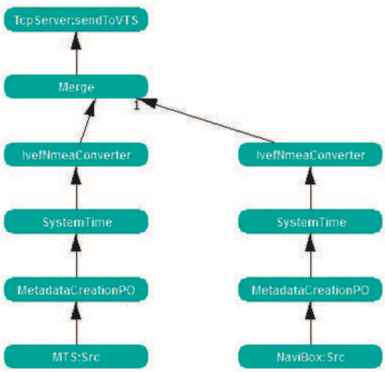

Figure 2: Query Plan: NMEA to IVEF

6 Semantic Data Exchange Features

The aspects, which have been already mentioned, give some details about the basic technical background to be considered when thinking about data exchange between maritime systems. However, data exchange will also allow us to generate high value information when taking the semantic of data into account. This section will present two examples we will address within COSINUS project for the semantic high value data processing. First, taking the semantic of data into account will allow us to compress the data to be exchanged, which is essential due to the low bandwidth available on the vessels. Second, having information from different information sources available will allow us and also enforce us to provide information about data quality to the operators and mariners.

6.1 Semantic Compression

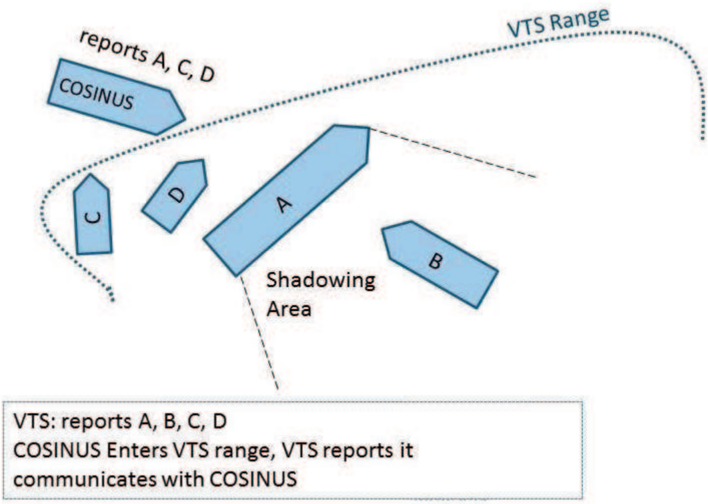

Figure 3: Semantic Compression

The semantic compression concept means to compress the data to be exchanged based on its semantic. We can do such semantic compression by detecting the interesting patterns and send only them instead of sending the whole data, or we can formulate a semantic function and send it's parameters instead, then the receiver side can use the semantic function to calculate the data. We will discuss here a use-case of semantic compression based on detecting the interesting patterns.

Considering the radar shadowing situation as an example, the ship "B" is detected as an interesting pattern for the ship "COSINUS", while the ships "C" and "D" are considered uninteresting patterns for "COSINUS", because the context models can know from the

ranges and the shadowing areas of the ships that "C" and "D" can be detected by "COSINUS"' radar sensor, while "B" cannot be detected because it is located in the shadowing area of "A".
The availability of many sources for the same data in e-navigation can contribute clearly in the reliability. However, we have to compress such redundant and/or unnecessary data based on the semantics of the data in order to enhance the efficiency in data transmission. The authors of [CC08] depend on identifying the interesting events occurring in an unbounded stream to make the compression. Similarly, based on the well-defined semantics, stored in the context models, we can detect the interesting patterns from the very huge amount of data streams and send only them. This semantic compression will increase the transmission efficiency clearly because we will send only a small set of interesting patterns instead of sending every available tuple of data published by a marine system.
According to such detection of interesting patterns, the semantic processors will pass only the interested pattern "B", and avoid sending the others. In parallel, the related context model of the semantic data processor will be enriched with information that tells that an interesting pattern was detected in a shadowing area. Such information in the context model can be useful later for several purposes as well. A useful reaction can be taken on COSINUS as a response of such data exchange, for example modifying the planned route a little bit to avoid a possible conflict with "B".

6.2 Data Quality Assessment (Completeness Example)

We should take into account that the continuous and high rate data streams in e-navigation should not only be converted between standards and exchanged, but also checked regularly in order to adjust or annotate the quality of such data. Data of low quality, which does not exceed some predefined thresholds, could be then ignored, annotated and/or cleansed.
Based on the spatio-temporal characteristics of the incoming data, we can conclude different data qualities in order to annotate them or may be to react with a suitable data cleansing.
Different types of data qualities can be extracted from the continuous transient streams. In this section, we will present a use-case/scenario for the completeness as a data quality aspect, which can be determined by our semantic data processors.
The main key for the data assessment in e-navigation is the availability of many sources for the same data. We can use the available replicas, which have the same semantic but may be written in different formats, in order to rate the completeness of data published by different sources. Thus, using the redundant replicas, we do not have to propose a solution like adapting the smoothing window size based on statistical samples [JF06], but it is enough to detect such missing data, register the detected information in the context model, and simply use another replica has the same semantic to ensure the completeness of the delivered data stream.
Recall the radar shadowing scenario, the VTS system can detect "B", while it cannot be detected by "COSINUS" because "B" is located in the shadowing area of "A". Therefore, the semantic processors will pass the information of "B" to "COSINUS" to ensure the

completeness, and "COSINUS" will know from the annotation registered in the context models that the reason for the inability to detect "B" itself is its location inside the shadowing area caused by "A". Having this information it can predict the time for "B" to leave the shadowing area. Thus, "COSINUS" will know that there is no problem in its radar, if "B" is re-detected again at that predicted time.

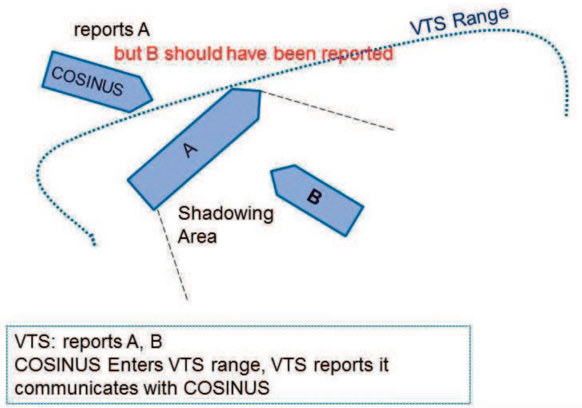

Figure 4: Completeness annotation and ensuring

7 Conclusion

We have presented in this paper our architecture in semantic data exchange in e-navigation. We are applying this semantic data exchange in COSINUS using the complex event processing system, Odysseus, and the maritime systems of our partners: The VTS system from SIGNALES and ECDIS from Raytheon.
We define context models to enable the cooperative control and monitoring on the e-navigation onshore and on-board. Based on the semantics we conclude from the data streams and register in the context models, we can rate the date qualities, apply suitable semantic compression, detect possible outliers and may apply suitable reaction such as data cleansing. For the future work, we can handle the contradictories coming from different data sources for the same target by applying data fusion on them, however, such contradictories should not cause that noteworthy effects when the used sensors and radars are with high qualities. The work presented in this paper has been done in the project COSINUS that is funded by the Federal Ministry of Economics and Energy under the support code 03SX367D.

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