A MULTISOURCE COMMUNICATION GATEWAY AND AN ADVANCED VISUALIZATION INTERFACE FOR MARITIME SURVEILLANCE SYSTEMS BASED ON THE INTER-VTS EXCHANGE FORMAT SERVICE

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ABSTRACT

Despite the great attention that the field of maritime surveillance has gained nowadays, special effort is required to remove the barriers of collecting and integrating heterogeneous data into a common picture to be shared among all relevant parties and achieving a reasonable level of interoperability for improved efficiency of maritime surveillance systems. Traditional solutions offered mainly rely on the usage of either custom data models or the automatic identification system (AIS) types of messages which, although widely accepted, has significant restrictions regarding the types of data that can transmit (e.g. support of additional information and metadata). Based on the more modern, XML-based, inter-VTS exchange format service (IVEF) introduced by the IALA, we present the design and implementation of a uniform communication gateway (UCG) and an advanced user interface (AUI) for maritime surveillance systems, implementing the IVEF service model and protocol. The UCG consists of a set of interconnected processes implementing data listeners for acquiring raw vessel traffic data, translators from AIS or custom data models (based on reusable libraries) to the IVEF data model, a merging process for integrating the data streams and a IVEF-compliant and SSL/TLS-secured server serving the data to any IVEF-compatible client. For monitoring UCG data traffic, a web-based interface presenting statistics for the reception and sending rates is offered. Moreover, maritime environment data stemming from the EU Copernicus service are map illustrated. The AUI is a front-end system specifically designed to provide multiple categories of users (e.g. radar designers, operational users, result stream subscribers) with the functionalities required to operate and exploit the results of diverse sources of data reception (including AIS traffic and proprietary radars). Its basic component is a map-centric GUI displaying nautical charts, radar cells, vessels tracks and alerts and providing end-users analysis tools. Both implementations have been tested and validated in real operational environment.

Keywords: IVEF, AIS, Maritime Surveillance, Vessel Tracking

1 INTRODUCTION

Maritime surveillance was always of critical importance due to the central role of maritime trade to the integrity of the global economy. Moreover, the growing vessel traffic as well as the increased rate of irregular activities are of great interest to maritime security. Thus, the effective collection of vessel traffic information by utilizing numerous heterogeneous data sources is thought critical. International organizations related to the field, as well navies and coast guards, are adapting themselves by defining modernized strategies and adopting the capabilities offered by new IT technologies. For example, the International Maritime Organization (IMO), a United Nations (UN) agency, has issued the e-Navigation strategy [1]. Additionally, a Strategy Implementation Plan (MSC 85/26/Add.1, Annex 20) has been developed by IMO with the contribution of intergovernmental and non-governmental organizations. By this plan, five e-navigation solutions have been prioritized for the period 2015–2019, which include improved, harmonized and user-friendly bridge design; means for standardized and

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automated reporting; improved reliability, resilience and integrity of bridge equipment and navigation information; integration and presentation of available information in graphical displays received via communication equipment and improved communication of vessel traffic service (VTS) portfolio. In this context, IALA has published a significant number of standards, guidelines and recommendations [2] including the draft of inter-VTS exchange format service (IVEF) (recommendation V-145) [3] designed for exchange of information on sea traffic between the vessel traffic systems and the vessels.

In the context of the European project RANGER (H2020-BES-2015, Grant agreement ID: 700478), a uniform communication gateway (UCG) and an advanced user interface (AUI) for maritime surveillance systems, implementing the IVEF service model and protocol, have been developed. Although being part of a broader architecture (see Section 3) the combination of the UCG and the AUI systems alone is offering an end-to-end solution for acquiring, processing, merging and sharing multiple sources of maritime surveillance-related data as well as visualizing them in an efficient and with advanced functionalities front-end system.

In this paper, the implementation details as well as the capabilities of the UCG and AUI systems are presented, while the results of their testing in an operational environment are demonstrated.

2 MARITIME SURVEILANCE SYSTEMS AND DATA SOURCES

In this section, a survey of the available and already widely used maritime surveillance systems and data sources is presented including also the data exchange mechanisms and technologies either used or having the potential to be used for maritime applications.

2.1 Maritime surveillance systems and data sources

2.1.1 AIS and LRIT

The automatic identification system (AIS) [4] is an automatic tracking system, which is used in navigation primarily for collision avoidance. AIS is standardized by the International Telecommunication Union (ITU) and adopted by the IMO. It provides static and dynamic vessel information and safety-related information. The AIS consists of the AIS transceiver working in the Very High Frequency (VHF) band, equipped with a GPS receiver and base stations along the coastline, which can receive the AIS signals or alternatively satellite-based AIS receivers. The AIS receivers can process the AIS information and send it via any means (e.g. internet) to a central database or application that can further utilize the information. AIS receivers report ASCII data packets as a byte stream over serial or USB lines, using the National Marine Electronics Association – NMEA 0183 or NMEA 2000 data formats [5]. The NMEA standard uses two primary sentences for AIS data: "!AIVDM" (received data from other vessels) and "!AIVDO" (your own vessel information). S-AIS [6], also referred as the space-based AIS, has been introduced as a global ship surveillance system that uses small low orbit satellites carrying AIS transponders. The long-range identification and tracking (LRIT) system provides for the global identification and tracking of ships and was established by IMO [7]. LRIT is a satellite-based, real-time reporting mechanism that allows unique visibility to position reports of vessels. LRIT information is provided only to governmental agencies and is used by search and rescue (SAR) authorities, flag, coastal and port states. While the main application areas of AIS are collision avoidance, VTS, fleet and cargo monitoring and control, LRIT is developed to enhance maritime safety and security and to protect the marine environment.

2.1.2 Legacy marine surveillance systems

Marine radars are the core legacy systems in use for maritime surveillance. They can be either stationary radars installed at coastal areas, or ship radars installed on vessels. Coastal radars are deployed in areas surrounding coastal ports and in areas with access to waterways, keeping track of vessel movements and providing navigational safety in a limited geographical area, and their core capabilities are focused on detecting large ships at a distance of many tens of nautical miles. Ship radars are mainly focused on providing bearing information as well on providing the distance of ships and land targets in the vicinity of the own ship. They are used for navigation and collision avoidance. For wide-area surveillance, over-the-horizon (OTH) radars are a promising solution. The use of low frequencies of these radars implies low spatial resolution, and therefore these systems should be complemented by radar solutions with high spatial resolution.

2.1.3 Earth observations and meteorological data

Marine earth observations and meteorological data may be collected and provided as a service by various organizations or free of charge over the internet (e.g. from Copernicus Marine Environment Monitoring Service). These data may contain the following types of data: weather forecasting, wind speed and direction, wave heights, surface temperature, atmospheric pressure, rainfall etc. These can be a very useful source of information in marine surveillance systems. These data may be collected and processed by a network of observation buoys, coastal stations as well as earth observation satellites.

3 THE RANGER PROJECT

RANGER is an EU-funded project, within the H2020 Horizon programme, and is innovative by combining novel and groundbreaking radar technologies with state-of-the-art supporting systems deployed in maritime environment. Its main goal is to deliver a surveillance platform that exceeds the capabilities of current radar systems, offering surveillance, tracking and early warnings in support of SAR and other coast guard operations in both open sea and close to maritime borders.

The RANGER system architecture follows a modular approach supporting the seamless integration of radar solutions, interoperability with legacy systems (including the AIS system), enhanced situation awareness and usability. The RANGER system is composed of several discrete, although interconnected and interoperable, elements. The OTH radar (https://www.diginext.fr/en/offer/critical-operation-support-systems/hf-surface-wave-radar) is a high-frequency surface wave radar system that has the ability to detect targets at very large ranges. The photonically enhanced multiple-input multiple-output (PE-MIMO) radar [8, 9] is an innovative system that supports the OTH radar for detecting targets in close range over several kilometres with high resolution. The early warning system (EWS) constitutes the backend of the RANGER system and is responsible for early detection of events, data storage and provision of warnings and alerts. The data fusion module [10] performs data fusion from different sensors to obtain a combined set of tracks (routes) of targets. The machine learning module [11] employs artificial intelligence algorithms in order to derive conclusions about the characteristics of the detected/tracked vessels. The UCG acts as the interoperability layer of the RANGER system and enables the integration of legacy surveillance radars, AIS data and complementary data sources related to maritime environment (e.g. weather-related data stemming from the EU Copernicus services). The Common Information Sharing Environment (CISE) translation gateway is the interface that will enable the integration

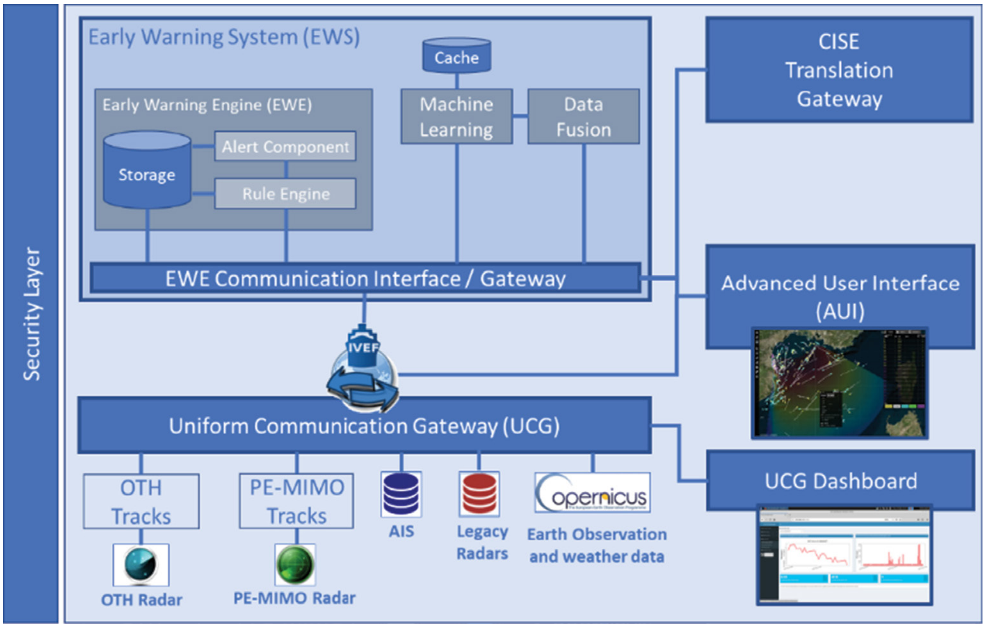

Figure 1: RANGER functional architecture.

of the CISE-compliant RANGER services (OTH radar track service, the PE-MIMO radar track service and the RANGER EWS service) to the CISE network. The AUI is the standalone user interface and front-end of the RANGER system. The functional architecture of the RANGER system is depicted in Fig. 1 and illustrates the various functional elements of the RANGER system. It should be mentioned that security, as a non-functional requirement of the RANGER system design, spans through all the layers of the RANGER architecture.

4 UNIFORM COMMUNICATION GATEWAY

The UCG consists of a set of interconnected processes implementing a data harmonization and merging gateway capable of offering an IVEF-compatible service. The functional description and the internal architecture of the UCG as well as the implementation details and the detailed functionality of the different sub-processes are presented in the following section and sub-sections.

4.1 UCG Functional description, internal architecture, implementation details and deployment

As can be observed in Fig. 2, the internal UCG Architecture exhibits 4+1 layers. The first layer relates to the reception of data from input sources (NMEA listeners, IVEF client, custom data format listeners), the second layer has to do with the translation of the received information to the IVEF data model (NMEA translators, custom data translators), the third layer is responsible for merging the translated data stream in a single and harmonized data stream and finally the fourth layer refers to the provision of an IVEF-compliant service for serving

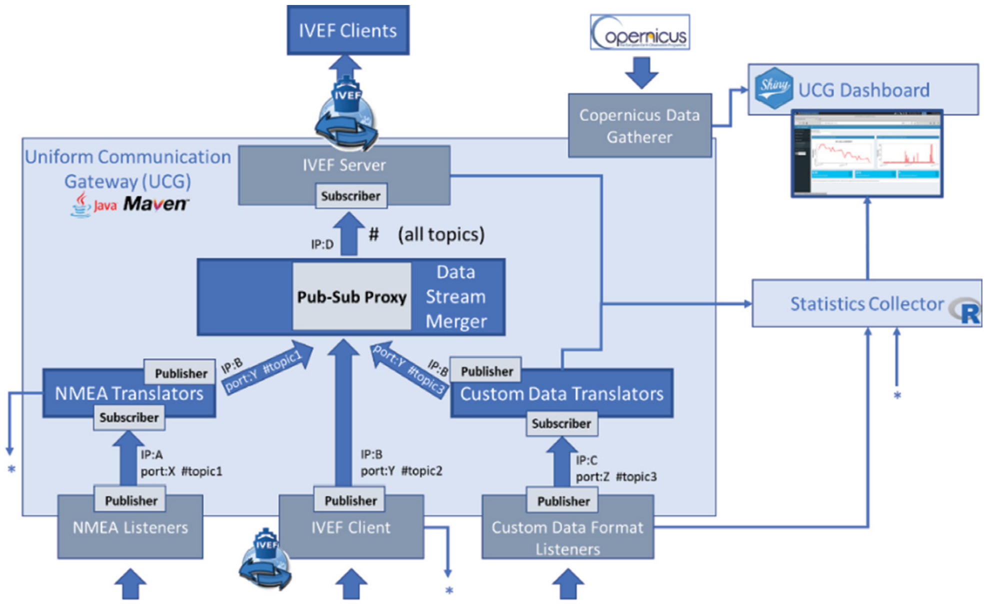

Figure 2: UCG internal architecture.

the data (IVEF server). An additional level refers to the provision of a web-based graphical interface (UCG dashboard). In order for the different layers of the architecture to exchange information (mainly vessel traffic messages), an inter-process communication machinery is used, implementing a publish-subscribe (Pub-Sub) mechanism.

The majority of the UCG internal processes have been developed using the Java programming language (www.java.com), while the Maven (https://maven.apache.org/) build automation tool has been used in order to facilitate the application build process. An exception was made for the Statistics Collector and the UCG Dashboard which were developed using the R programming language (https://www.r-project.org/). The selection of this programming language constitutes the UCG cross platform compatible; therefore the system could be deployed in linux-based and windows-based operating systems. Currently, the UCG is deployed based on a minimal Debian GNU/Linux (https://www.debian.org/) version 9 (Stretch) installation. The system is pre-configured to start all services on boot time requiring no interaction once a main configuration file is ready (bash shell-like file containing all configuration variables used by the service programs in order to control the runtime behaviour of all UCG services/ sub-processes).

In the following sub-sections, the specific functionality of the different UCG sub-processes is presented together with IVEF protocol which was selected as the data exchange protocol between UCG and its clients due to its direct applicability to the maritime surveillance sector.

4.1.1 Inter-VTS exchange format (IVEF)

Inter VTS exchange format (IVEF) service is an ongoing standardization effort by a large group of industrial members of IALA which intends to provide a common framework for the exchange of information between shore-based e-Navigation systems, such as VTS systems, e-Navigation stakeholders and relevant external parties [3]. IVEF service is aimed at establishing a common framework to ensure exchange of ship information between VTS centres gained via automatic ship identification device, CCTV, radar system and other devices. For this, a number of models such as data model, interaction model and security model are being proposed and XML-type basic protocol to deliver them has been distributed.

The IVEF service is based on client/server communication, where clients connect to an IVEF server and receive traffic image data according to their specific preferences and authorizations.

4.1.2 Listeners

The UCG listeners are used for the connection to the data sources to be established as well as for the raw data to be received. Usually, this connection is network based, although reading data from other sources (like local files) is also supported. The basic types of listeners are the NMEA listeners and an IVEF client (de novo developed according to the IVEF service model [3, p.]). In both cases, a TCP/IP connection is established with the data sources; however for the former a line by line reading procedure is followed in order for the NMEA sentences (the case of AIS data) to be received, while for the latter all the necessary steps in order to connect an IVEF server are followed (login messages, service request, etc.) and multi-line XML-based data structures are received. Additionally, the developed Java classes allow the creation of listeners for data with custom format by defining only the data reading procedure. It should be mentioned that for all the cases where TCP/IP connection is used, the security of the network communication can be achieved by using the transport layer security (TLS) and secure socket layer (SSL) protocols for authentication and encryption. Additionally, all the major types of encrypted virtual private networks (VPNs) can be supported by the UCG for connection with the data sources to be further protected. For forwarding data to the next levels, a publish-subscribe messaging mechanism is used, which has been deployed by the ZeroMQ high-performance asynchronous messaging library (http://zeromq.org/) and specifically by its pure Java-based implementation JeroMQ (https://github.com/zeromq/jeromq). Every listener, establishes a publisher using a dedicated port for every process and a distinct publishing topic. Subsequently, ZeroMQ subscribers running in the data translation-related processes are connected to these publishers. The adoption of a publish-subscribe mechanism for the inter-process communication minimizes the runtime dependencies among UCG sub-process as well as gives the flexibility for the sub-processes to even run in a distributed environment and for multiple subscribers to be connected to the publishers for enhancing the redundancy of the system.

4.1.3 Translators

With the exception of IVEF formatted data received by an IVEF client, all the other types of data streams should be first parsed and then translated to the IVEF data model. For the case of AIS data, the NMEA sentences received through the publish-subscribe channel are handled by using the DMA AisLib which is a Java library for handling AIS messages (https://github.com/dma-ais/AisLib). The library parses the received data and creates Java objects that contain the information sent by the AIS system. A mapping study between AIS data model and IVEF data model have been conducted for the translation to the IVEF data model to be implemented. The creation of IVEF data model-based data structures is done by using the Open IVEF SDK (https://github.com/openivef) which was extended in order to validate the content of the IVEF messages under creation based on the IVEF data model definition given in the XML schema XSD.

For the case of custom data formats, only a custom data parser should be developed, while the creation of the IVEF messages is again done by using the Open IVEF SDK.

Similar to the listeners, the translators include a ZeroMQ publishing mechanism in order for the data to be received by the data stream merging process. The same publishing topic with the one for the raw data is used. A significant difference, however, is that the translators (as well as the IVEF client that directly sends data to the merger) are using a different publishing protocol (SUBX-PUBX) which allows using the same IP and port (IP:B, port:Y in Fig. 2) as explained in the next sub-section.

4.1.4 Data stream merger

Following the translation step, the translation to IVEF XML vessel traffic data should be made available to the IVEF server in order to be sent to the connected IVEF clients. This is achieved by utilizing a ZeroMQ pub-sub proxy which listens to all topics in which the publishers using the aforementioned common IP are publishing data. Afterwards, the proxy merges all the data streams and makes them available to the ZeroMQ subscriber of the IVEF server as a single data source (the IVEF server needs to subscribe only to a single IP).

4.1.5 IVEF server

An IVEF service model-compliant server has been de novo developed in order to server the merged data stream to the connected IVEF clients. The stream is included in a single queue of IVEF messages, from which the IVEF service serves the data in a FIFO manner. The server is accessible via TCP/IP network communication, while the security of the network communication is achieved by using the TLS and SSL protocols. All but one required by the IVEF service model functionalities are supported, including the single occurrence and periodic occurrence type of transmission, while the filtering functionality (e.g. to send data only for specific vessel) is to be developed.

4.1.6 Data interchange statistics monitoring and user interface

For monitoring the health status of the internal UCG process, a web-based graphical interface (UCG dashboard) is offered through which the end-user can receive a picture regarding the functioning of the processes as well as several real-time and cumulative statistics for the message reception/transmission procedures. This graphical interface can be accessed through a network connection and using a typical web-browser.

In order for the aforementioned statistics to be measured, each UCG sub-process reports (following a user specified frequency) in two dedicated files (one for the reception and one for the transmission statistics, respectively) the statistics measurements given in Table 1.

The UCG dashboard has been developed using the R programming language as well as the Shiny (https://shiny.rstudio.com/) and ShinyDashboard (https://rstudio.github.io/shinydashboard) packages. The first page of the graphical interface is given in Fig. 3.

The basic structure of the web application has a main panel in which the main information is shown as well as a left-side panel through which the user is able to select the information to be shown, including the process status, the reception and transmission statistics for the UCG sub-processes as well as Copernicus weather-related data (to be discussed in detail in the following sub-section). For the needs of process health status monitoring, the application monitors the status of the UCG services as well as their inter-process communication and illustrates the result using a green/red colour code. An example of the way that the statics related to the functioning of a UCG internal process is given in Fig. 4.

Table 1: The message reception/transmission statistics reported by the UCG sub-processes

Measurement	Description
Period count	The absolute number of messages received/sent during the previous time period. The duration of the period is specified by the user and refers to a time window for which intermediate cumulative statistics are to be kept
Current count	The absolute number of messages received/sent during the current time period
Total count	The absolute number of messages received/sent from the time at which the process has started
Period rate	The rate of message reception/transmission (in messages/second) during the previous time period
Current rate	The rate of message reception/transmission (in messages/second) during the current time period
Total rate	The average rate of message reception/transmission (in messages/second) from the time at which the process has started

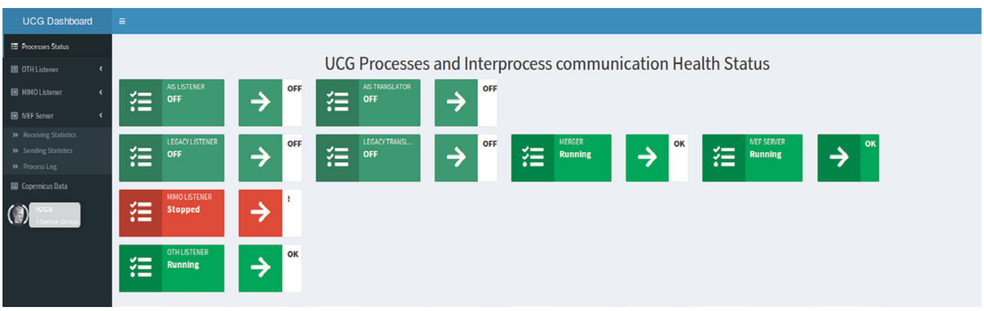

Figure 3: UCG process health monitor page of the web-based graphical interface.

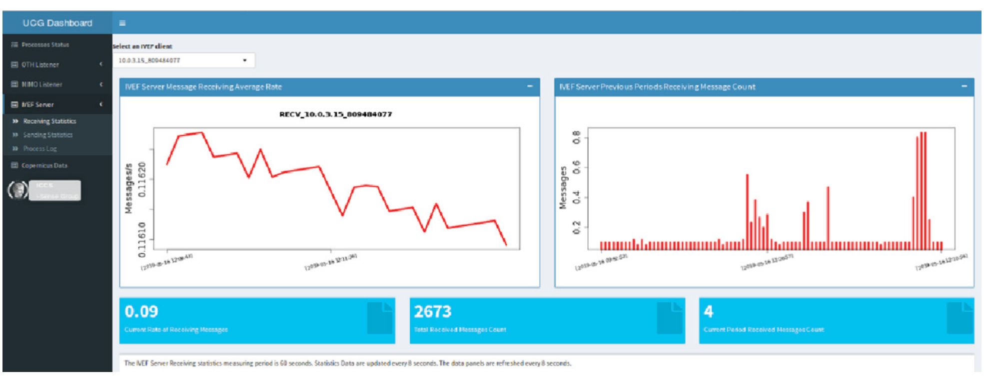

Figure 4: Graphical representations and value-boxes for the message reception-related statistics of the UCG's IVEF server.

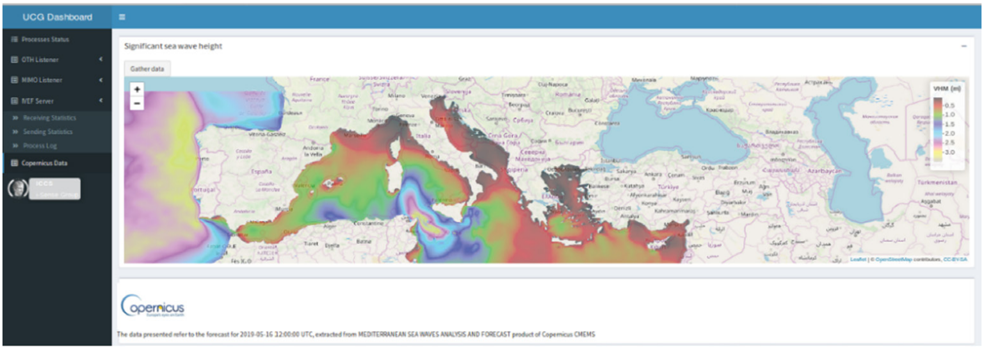

Figure 5: Significant sea wave height data illustrated by the UCG web-based application.

As can be seen, in the two upper white-coloured boxes, the user is able to observe graphical representation of the message reception average rate for the last 30 time points (the frequency of statistics data sampling is defined by the user), cumulative statistics for the rate of message reception observed in previous time periods (the duration of a period is again defined by the user) and values (inside the light-blue boxes) for the current rate of message reception, for the total count of received messages and the number of message received during the current period.

4.1.7 Copernicus data integration

Through the UCG dashboard, the user can observe weather forecasting-related data stemming from the Copernicus Marine Environment Monitoring Service (http://marine.copernicus.eu/) which are overlaid in a map of the area of interest using the leaflet package(https://rstudio.github.io/leaflet/). If the user selects the Copernicus Data option, the map given in Fig. 5 is shown. Finally, the most recent data are continuously available by the UCG in the original .netcdf format through a dedicated http server and can be downloaded through a simple REST call.

The data of the specific example given in the previous figure refer to the forecast (for the time range inside the hour at which the data are shown) for the significant sea wave height, given by the Copernicus platform through the Copernicus Marine Environment Monitoring Service and specifically through the "MEDSEA_ANALYSIS_FORECAST_WAV_006_017" Copernicus product. These data are downloaded in an hourly basis by the UCG by using the provided by Copernicus Service MOTU-client (https://github.com/clstoulouse/motu) which is installed to the UCG.

5 ADVANCED USER INTERFACE

The AUI is a component specifically designed to provide multiple categories of users (e.g. radar designers, operational users, result stream subscribers) with the functionalities required to operate and exploit the results of several sensors of tracks (radars, fusion modules, etc.) according to their needs and without requiring extensive training. This user interface is built on the latest advances in adaptive user interface especially those recently experimented in the field of air traffic control and situational awareness domains and using concepts such as personae to model the user's skills and store his profile, visual clues and metaphors adapted to the skills of the persona, and multimodal interaction including tactile surfaces. In the following sub-sections, the functionalities and the capabilities of the AUI are presented as well as its implementation details.

5.2 Functionalities and capabilities of the AUI

The AUI as cartographic tool manages the display of cartographic data and the display of tracks and their sensor of origin (e.g. for the case of the RANGER project: OTH, PE-MIMO, AIS, EWS, legacy systems) as shown in Fig. 6A. Additionally, it has the ability to display a brief path of the tracks made from the previous position of each vessel, the detailed information for each track by showing geographic information such as position, speed, heading but also meta-information about the vessel like MMSI, name or other data provided by the AIS system and alerts for any tracked vessels (Fig. 6B). Moreover, it displays the status of the system and of the sensors as well as the health status of the communication with the data sources (e.g. the UCG). For receiving data, the AUI supports the IVEF protocol by which it is connected to the UCG.

The AUI interface offers several action buttons to the user which allows to open the interface to IVEF servers and manage connections for as many servers as wanted and check for the status of each of them, to open the track list interface that lists all the currently displayed vessels, alerts or sensors (it is also possible to filter the vessels in the lists and even on the cartographic view by their source type) and to open the alert's servers interface. Moreover, it offers options to activate the display of the vessel's labels on the map that contain each vessel name, to activate and to control the historic of the vessels trajectories on the map, to activate radar coverage maps and to activate the marine chart interface and control the display of marine chart (e.g. their visibility and their opacity) as in Fig. 6C. Finally the user is able

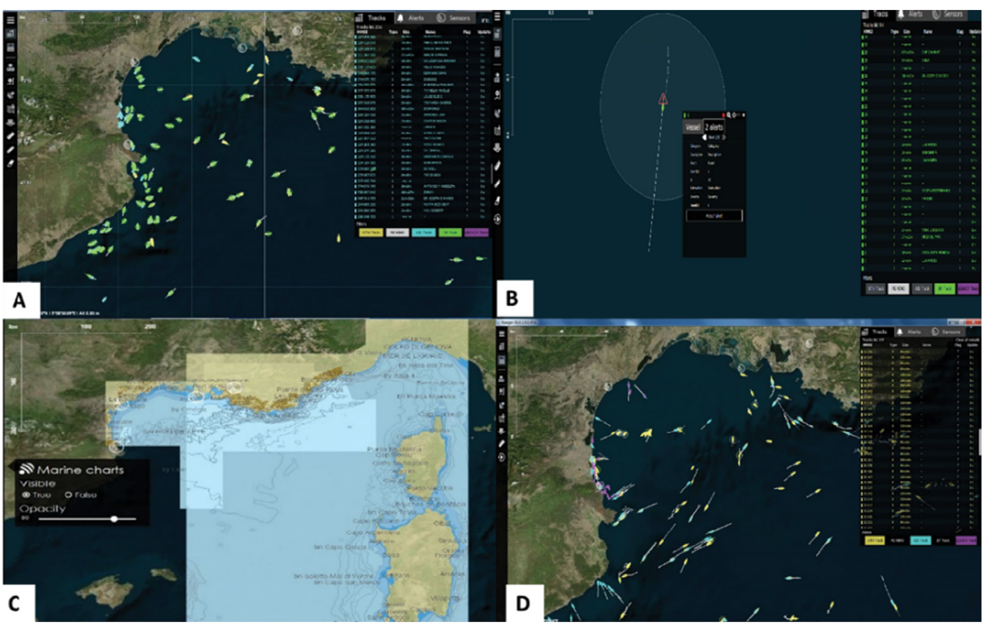

Figure 6: AUI screenshots.

to activate a grid interface (display or hide Lat/long grid, MGRS grid), a measurement tool interface (it can measure distance and angle directly on the cartographic view) and a drawing tool interface (allows the user to draw on the cartographic view).

5.3 Implementation and deployment details

This AUI is a map-centric GUI component displaying multiscale maps, nautical charts, as well as topological information, radar cells and targets, with level of confidence clues, using a state-of-the-art 2D/3D GIS system resulting from the V-Planet and V-City EC projects and sold by DIGINEXT as the VirtualGeo product (http://www.virtual-geo.com). This system enables the real-time visualization of layered 2D/3G GIS information from large datasets (over the whole planet). It supports a large variety of standard formats and protocols enabling the import and the display of digital terrain and bathymetry models (DTM, DTED, SRTM, GLZ, BIL, etc.), rasterized images from satellite, ortho images and maps (GeoTiff, JPEG2000, WMS, etc.), vector files (KML/KMZ, WFS, SHP, DXF, GML, APP-6,etc.) and nautical charts and vectors (IHO S-52, S-57, etc.). As discussed in Section 3, it can be also used to display outcomes of EWS (alerts, notifications, threat classification level using colour code according to confidence or urgency, data from interconnected legacy systems such as AIS and fused picture from all subsystems, etc.).

The AUI uses the VirtualGeo SDK from the Diginext VirtualGeo product for his display and processing capabilities of cartographic data. The UI part of the AUI is built with the Qt 5 GUI framework and its Qt Quick 2 module. Both the VirtualGeo SDK and the AUI are written with the C++14 programming language. The VirtualGeo SDK provides a good Qt programming interface that facilitates integration in any Qt environment such as a Qt Quick desktop application. Besides the marine chart feature, which is to be included as module to VirtualGeo SDK, much of the development tasks involving the implementation of the AUI features were done directly in the client application with the C++, JavaScript and QML languages. The AUI also relies on the SQLite Database Management System to store information about the vessels, their track status and their own alerts. This mechanism allows the user to keep any information between boat supervision sessions and to replay the time at any given past time.

6 OPERATIONAL ENVIRONMENT TESTING AND ADVANTAGES

Both systems have been recently (May and October 2019) tested and validated in a real operational environment during the first and second pilot demonstrations of the RANGER project which took place in the area of French Mediterranean Sea. All the RANGER components described in Section 3 were involved in the demonstration. AIS vessel tracks from the whole French Mediterranean sea, OTH radar detections for the same area, MIMO radar detections and legacy radar detections were handled. The UCG was able to facilitate the reception of data from these multiple sources with very good performance, indicated by the measured Key Performance Indicators (KPIs) given in Table 2, while the AUI successfully visualized the vessel traffic monitoring data as shown in Fig. 6A,D.

Following the evaluation of the systems by the end-users participating in the RANGER project (Greek and French navy) during the operational testing as well as during their design and development, a set of remarks regarding the advantages brought by the proposed systems and the potential integrations with the existing legacy and commercial systems from an operational viewpoint have been provided.

Table 2: UCG KPIs evaluation during testing in operational environment

KPI	Observed value
Message loss	0.0013% Only seven cases of message loss have been identified (5,137 messages have been received by the UCG while 5,130 messages have been sent to the connected clients).
Message reception/ transmission rate	0.0001% The average rate of message reception in UCG input was 0.165346981 mes/s The average rate of message transmission from UCG to the UCG clients was 0.165329208 mes./s
Denial of IVEF service	**0** No cases of denial of IVEF service have been identified
Time to respond to IVEF service request	**<1s**
Number of IVEF server concurrent connections	**4** During the testing, four IVEF clients have been connected and have been served trouble-free. During testing in the laboratory, 20 concurrent client connections have been tested successfully

A general positive comment is related to the open-source implementation of the IVEF protocol by both systems which creates several advantages over commercial solutions. Regarding the UCG, it is characterized by a cost-effective implementation and maintenance that is not linked to vendor-specific terms and conditions. Moreover, operators can easily deploy and extend the UCG according to their operational needs. Specifically, different UCG subprocesses can be deployed according to the operational needs and with different data requirements. As presented in previous sub-sections, the UCG is capable of dealing with multisource data and thus can be seamlessly expanded with additional data sources including legacy systems and commercially available solutions that are able to provide output in a machine-readable format. The UCG has a modular architecture and thus can work in standalone mode or can be integrated with existing enterprise systems. Additional services and data listeners can be implemented on top of the base services without affecting the functionality of the system. Regarding the AUI, the fact that it has a flexible and user-friendly interface that can be easily reconfigured by the operator has been noted as the main advantage of the system. Several display options exist, and different information sources can be visualized independently or overlaid to provide a comprehensive picture of the different track data. Additionally, both the AUI and the UCG are IVEF-compliant systems and thus can be seamlessly integrated with IVEF-compliant systems such as commercial VTS enterprise systems already available in the market. Finally, using the UCG dashboard operators can have a comprehensive picture of the back-end data traffic in real time and in log statistics facilitating the monitoring of the systems' functioning as well as further analysis of the traffic data.

7 FUTURE DIRECTIONS

Although the presented tools have reached a significant level of maturity, proved by their ability to be used in a real operational environment, specific improvements are planned to be done in order to enhance their functionalities.

Regarding UCG, the filtering functionality for the IVEF server is to be developed, while functionalities of the web-based graphical interface is planned to be extended in order to allow the full control of the UCG. Finally, the UCG is planned to be released as an open-source software in a public accessible repository.

Regarding AUI, several development orientations are being considered such as a visual comparison of radar raw data matrix (signal strength in dB for each radar cell in range/Doppler) with Ambient HF noise level (HF noise level is independent of HF radar's transmitted signal) and automatic link between radar detection/tracking maps and radar raw data, in order to analyse detected target signature's and compare it to clutter or interference signatures, Moreover, the addition of a video radar layer is planned, which could be superimposed over radar detection/tracking maps in order to facilitate the analysis of radar performance.

8 CONCLUSIONS

In the present paper, the characteristics as well the implementation details and the results of testing in an operational environment for two IVEF compatible tools have been presented. The combination of UCG and AUI tools is offering an end-to-end solution for acquiring, processing, merging and sharing multiple sources of maritime surveillance-related data as well as visualizing them in an efficient and with advanced functionalities front-end system. To the best of our knowledge, the combination and each tool on its own are among the first IVEF-compliant systems tested in real operational environment. Thus, the results of the present study constitute a significant step towards the implementation of the E-navigation strategy.

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