Integration of Vessel Traffic Control Systems and Geographical Information Systems

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1 ABSTRACT

This paper introduces the problems of substantiation and development of the new generation of Vessel Traffic Control Systems (VTCS), together with the potential of intelligent-based Geographic Information System (GIS). Nowadays, it is almost impossible to imagine not only World economics life but also every local economics and social life of human population without sea trade exchanging. The maritime domain generates activities in harbours and coastal areas that cannot be considered from a unique economical point of view. The maritime environment involves a wide range of crucial problems such as navigation safety, ecological safety, counter – terrorist's activities, economical effectiveness and many others. Such huge informational streams largely surpass current capabilities of VTCS as these systems still rely on basic information models and technical facilities, thus making their potential not effective to deal with the diversity and importance of the issues to address. Therefore, there is an urgent need to explore novel information infrastructures and software solutions that will allow maritime authorities and planners to effectively address the large range of issues and challenges faced by the sea. The research presented in this paper advocates a close integration of GIS and VTCS towards what can be considered as an intelligent engine. The work presented combines the experience of SPIIRAS in the development of theoretical foundations and infrastructures, with the one of the Naval Academy Research Institute in France whose developments specifically concern the integration of GIS and maritime navigation systems. Several case studies illustrate the approach from VTCS developed for St-Petersburg and Brest Harbours, and for the Gulf of Finland and the Atlantic Ocean.

2 INTRODUCTION

Advances in telecommunication and positioning systems providing maritime location-based information accessible either in real-time or through large central databases offer new perspectives and challenges to maritime GIS and transportation research. Such systems are of great interest for many maritime applications oriented to the monitoring, management and analysis of activities in harbours and coastal as well as for maritime traffic and transportation.

One of the current limitations to the development of integrated Traffic Control and GIS systems relies in the fact that current GIS models, software and interfaces do not yet provide intelligent engines able to understand complex maritime behaviours and patterns. This poor level of integration of GIS capabilities is often the result of the different paradigms used within GIS and maritime systems, and the resulting fact that the development of integrated solutions implies the re-design of existing software solutions. Moreover, current GISs are not adapted to the management of dynamic phenomena due to the lack of modelling and processing interoperability with real-time navigation systems. The development of real-time GISs, characterized by a high frequency of changes, implies a reconsideration of the storage, modelling, manipulation, analysis and visualization functions whereas current GIS models and architectures have not been preliminarily designed to handle such dynamic phenomena.

Safety and security are constant concerns of maritime navigation, especially when considering the constant growth of maritime traffic around the world, and constant decrease of crews on decks. This has favoured and led to the development of automated monitoring systems such as the Automatic Identification System (AIS), Long Range Identification Tracking (LRIT) and the Electronic Chart Display and Information System (ECDIS) as a support of electronic mapping services. However, officers on the watch and monitoring authorities still require the development of advanced decision-aid solutions and analyses integrated within intelligent Vessel Traffic Control Systems (VTCS). Such solutions aim at solving of one main issue of maritime activities, that is, providing vessel traffic control effectiveness and safety to address the following needs in terms of maritime safety, navigation effectiveness, environmental and ecological protection, coastal and shelf infrastructure :

- Vessel traffic can be very high in specific areas thus increasing the risk of accident;
- Pirates activities;
- Terrorist's threats;
- Risk of accidents in ports and coastal areas.

This non-exhaustive list motivates the search for VTCS solutions. Current problems of VTCS do not provide acceptable solutions: operability, accuracy and completeness of moving and positioning of vessels, weather condition prediction, navigation control, accident control and rescue operation support are examples of open issues to consider.

The simplest decision is to increase a number of work stations for VTCS and as a result to expand staff of VTCS but it is not always acceptable. Moreover some of the selected problems could not be done by traditional mathematical or simulation models because they do not have strong mathematical description. It is also non straightforward to support deployed VTCS because there a need to change scenarios of the system's behaviour. The objective of our proposal is to develop an up-to-date VTCS relying on an intelligent GIS base.

The notion of Intelligent GIS (IGIS) has been discussed in sources [2]. IGIS can be defined as a GIS with some additional intelligent components such as follows: ontology subsystem as a core of knowledge base, scenario subsystem and inference machine. The three main parts of IGIS have been discussed in previous papers [2, 3]. The current paper introduces an aspect of self learning of IGIS for VTCS problems. Tactical Situations (TS) for VTCS is the one of the main focus of this research. The set of tactical situations related to VTCS is rather large and difficult to cover exhaustively in real conditions. It is a great challenge for perspective VTCS.

The theoretical aspects of this proposal are presented in the third section of this paper. A variant of IGIS architecture for VTCS is described in section 4. Case studies of presented approach for St-Petersburg and Brest Harbours, and for the Gulf of Finland and the Atlantic Ocean are discussed in the sections 5 and 6.

3 THEORETICAL BACKGROUND

Situation Awareness (SA) denotes the perception of environmental elements within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future [1]. For real problems VTCS gathers, collects data and information about vessels and moving objects through communication facilities with vessels, coast radio locators, satellite systems and many other sources according to a HIF (harmonization, integration & fusion) conception [3]. Current and near future TS as a rule are presented by visual GIS features on different screens and monitors. According to current and future TS VTCS and/or their staff make some decisions and send it to vessels and/or other different customers. But the problem is when we have a clutter of vessels and other moving objects, and by VTCS we should make decision in real or nearest to real time.

The one of decision of the above problem is an approach according to JDL model [5]. But there is no real work algorithm suggested. Tactical situation assessment, identification and classification can be done by different ways [3] such as Bayesian approaches, neural networks, genetic algorithms, immune computing and some other methods of pattern recognition.

Our proposal is not only a simple development and deployment of a classification system for TS, but moreover a development of a self learning system for SA. The idea is to make integration between SA algorithms and an intelligent subsystem of IGIS. This favours acquisition of new knowledge, new rules when VTCS is working. According to this our knowledge base is not static but dynamic. This VTCS knowledge base is changed during running time by new rule-based knowledge:

$$F_{zv}(d_{zv_e}; e = \overline{1, E_z}) \rightarrow d_{zv_a} \qquad (1)$$

$$z = \overline{1, Z}\ ;\ v = \overline{1, V_z}$$

Where: $F_{zv}(.)$ - denotes a special function that establishes links between facts and spatial depended data d_{zv_a} for an interval of time. These time series favour detection of detect steady sequences for TS and their elements such as vessel behaviour, states of the environment and weather conditions.

Regarding $F_{zv}(.)$ in the rules (1) linear and logical functions can be used. Together with scenario subsystem of IGIS most of complex TS can be formalized. The next important problem is to predict short-term and long-term evolutions of TS in time. For example, for evolution TS $|d_w(T)|$ relative to the initial state $|d_s|$, analysis and synthesis problems can be developed by next algorithm as follows:

$$PRG = PRG\left\{ |d_s|; F_{zv}(d_{zv_e}; e=\overline{1,E_z}) \rightarrow d_{zv_a}; z=\overline{1,Z}; v=\overline{1,V_z}; |d_w(T)| \right\} \tag{2}$$

This means that according to (2) an algorithm should be identified for $|d_s|$ to $|d_w(T)|$ transformation. Initially $|d_w(T)|$ can be detected as an implicit function from evolution time T.

If $t_{PRG_j} \leq T$, the next step j+1 of inference can be done if and only if time of evolution t_{PRG_j} according to algorithm PRG_j do not top of acceptable T. According to this $|d_w(T)|$ can be detected as follows:

$$|d_w(T)| = \begin{cases} |d_w(t_j)|, \; for \quad t_j = T; \quad j=\overline{1,J}; \\ doubt, \quad for\, another \quad case. \end{cases} \tag{3}$$

Where: $|d_w(t_j)|$ - current j result of inference of ; PRG_j

J – Limited number of inference steps.

According to (1) – (3) by direct inference it is possible to obtain short and long-term evolutions of TS.

4 IGIS ARCHITECTURE FOR VTCS

A typical architecture of IGIS can be shown in Fig. 1. It is a generic schema oriented for wide typical purpose and for different systems and VTCS as well. But for practical implementation, IGIS should be specified to practical goals. Moreover IGIS is not a monolithic application. IGIS is a collection of different applications and subsystems on the SOA [2] conception developed as one can be seen in Fig. 1.

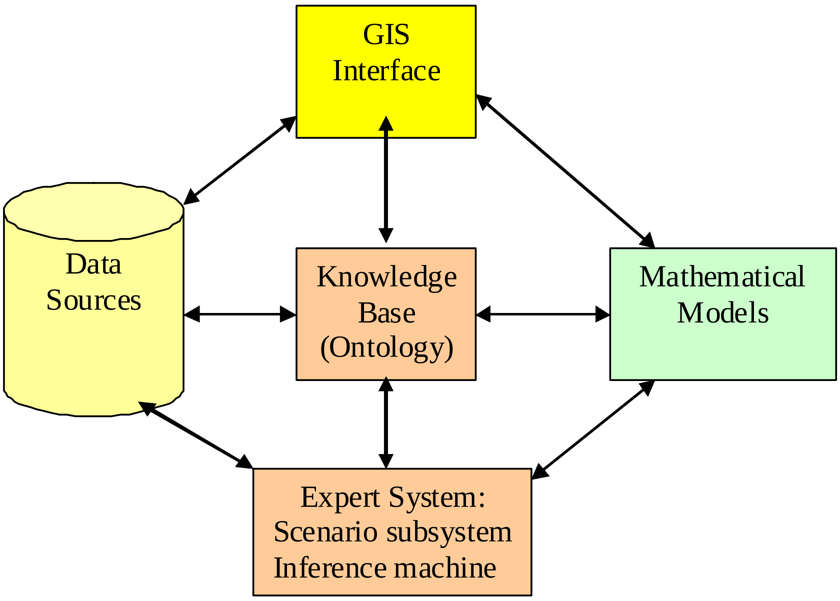


Fig. 1: Architecture of IGIS

The architecture of VTCS on an IGIS base is shown on Figure 2. The GIS initially developed have been designed for navigation needs, thus making a distinction between VTCS and GIS not straightforward (Fig. 1). The other VTCS parts form a set of services as shown on the right side of Fig. 2. The GIS unites are developed using the SOA paradigm, which is relevant for distributed and multi-platform GIS solutions. From this point of view, the SA algorithms and self-learning subsystems are plug-in services for VTCS.

Figure 2 shows a core of the system (IGIS+VTCS), that is, a knowledge base that includes a set of ontologies. Ontology represents main existences and relations between them for different subject domains. Another part of the knowledge base is given by a set of objects and subjects. The knowledge base for VTCS is developed by Protégé – an open source multi-platform tool.

An inference machine shell Drools is used. The main properties of Drools are as follows:

- Environmental changing facts;
- Set of rules;
- Current TS;
- Data initialisation and processing within Protégé.

Data and information exchanges between VTCS units and the external systems are performed XML format.

A set of mathematical models includes applied models for navigation in the wide sense, such as search models, target recognition and tracking, navigation flow optimisation.

The proposed IGIS architecture for VTCS can be considered as an open system, with the possibility of adding new mathematical functions or models. Moreover, an intelligent subsystem allows not only developers but also ordinary users to check and change scenarios and knowledge base without programming procedures.

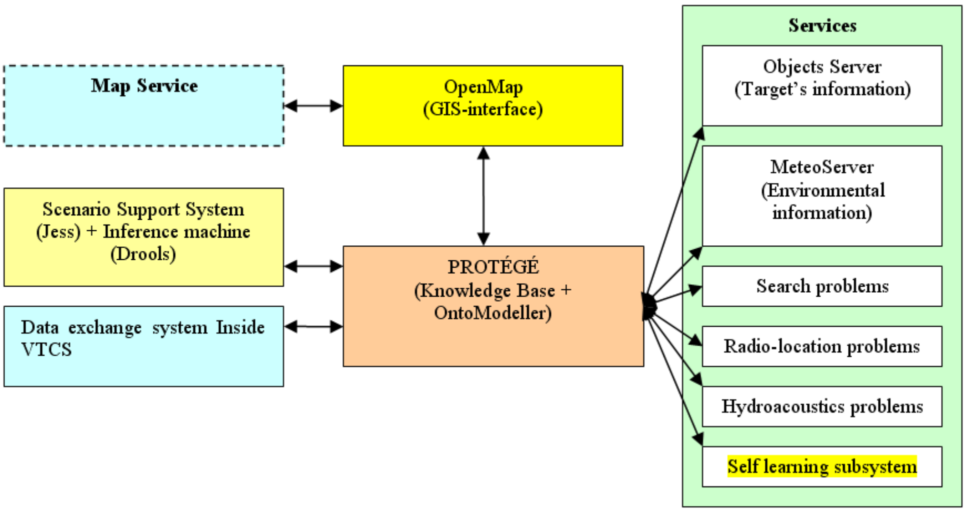


Fig. 2: Architecture of VTCS on IGIS base

5 CASE STUDY FOR ST. PETERSBURG HARBOUR AND THE GULF OF FINLAND

Let us present some screenshots of the system of the St-Petersburg Harbour and the Gulf of Finland. Every picture corresponds to one of particular TS. A common GIS interface looks as follows on Fig. 3. It is a typical interface for VTCS. As one can see a main part of work place is a digital map. There is Kronstadt Harbour on Fig. 3. It is a small Harbour near the St. Petersburg. This interface illustrates some of the TS functions as follows:

- Search operation;
- Navigation support;
- Vessel docking to a berth; properties of vessel and environment (particular properties of berth, depth around the berth, presence other vessels and their properties, harbour rules, weather conditions etc.) should be taken in mind;
- Navigation estimation for every vessel with taking in mind bathymetry, other moving objects and many others.

The following sections examine some selected tactical situations.

5.1 Search operation

An example of graphical interface of TS “Search Operation” is illustrated on Figure 3. This figure presents an episode of search effort allocation and region for search operation for “moving objects” [15]. The intelligent subsystem helps customer step by step. Most of input data from distributed data base is been extracted automatically. There are a set of logical rules to avoid mistakes and logical uncertainly.

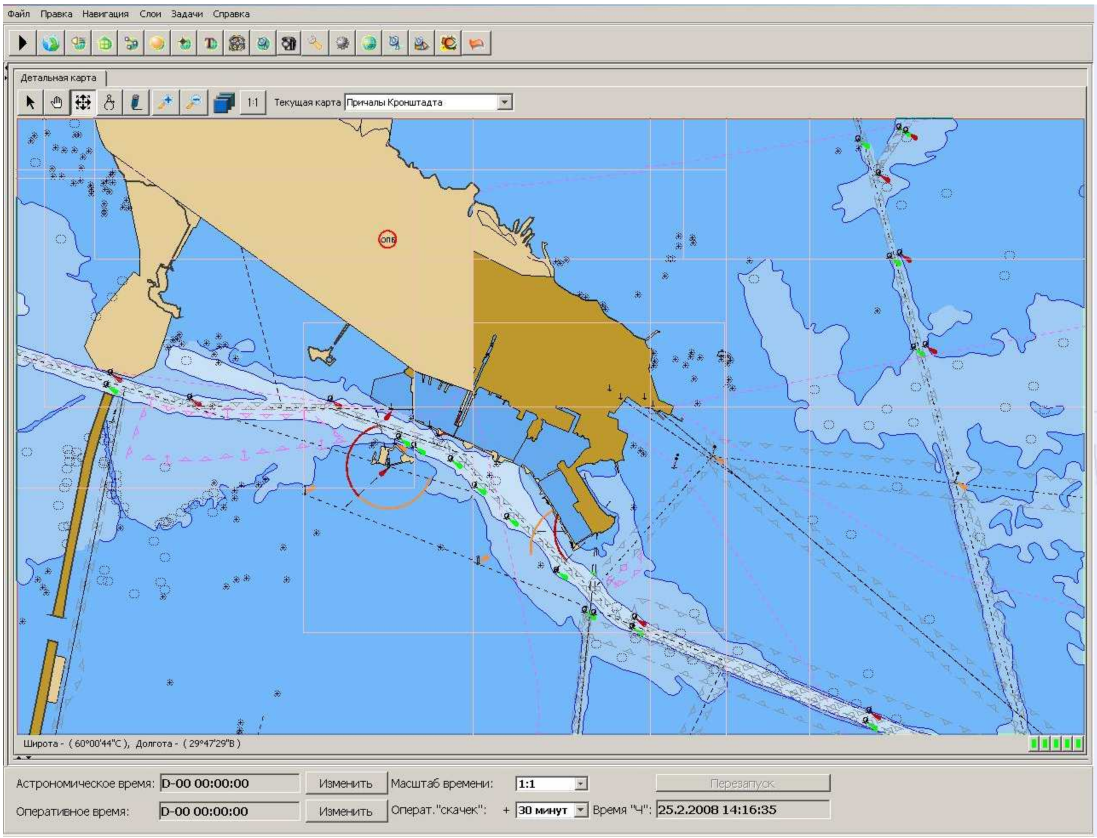


Fig. 3: A typical interface of VTCS

A window for search operation modelling is presented on Figures 4 and 5.

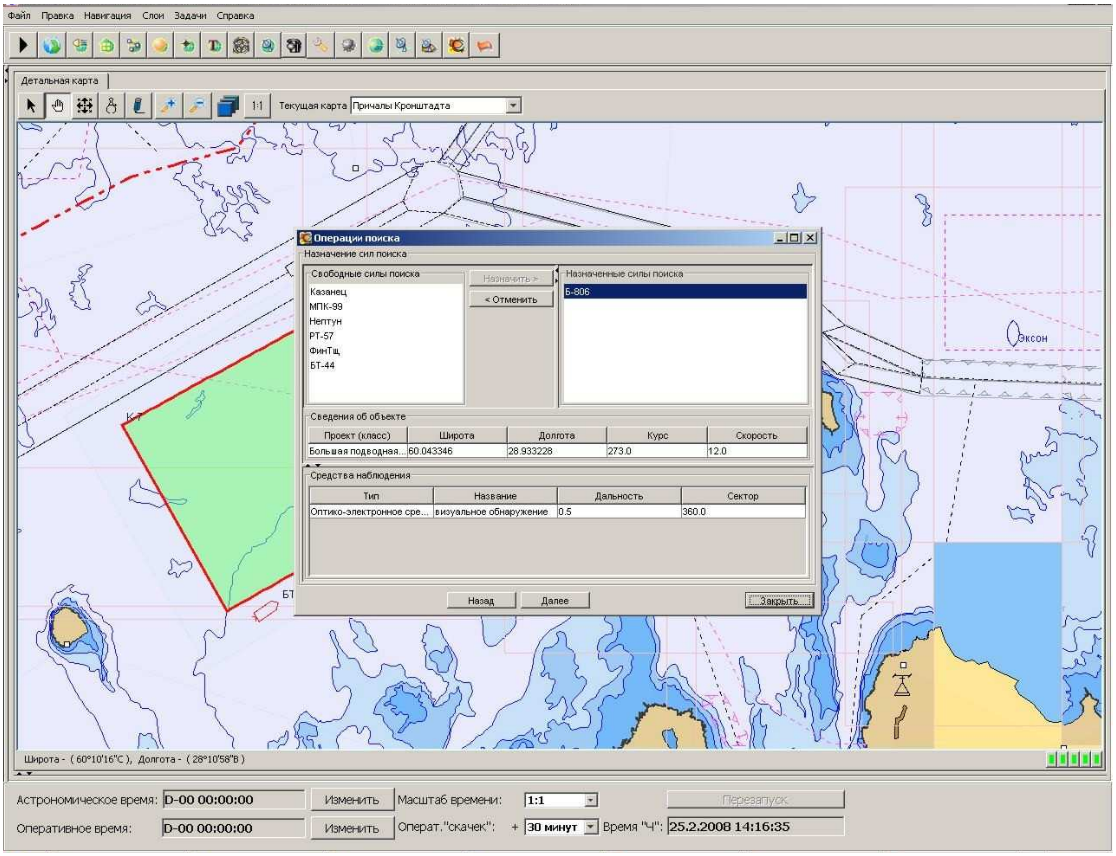


Fig. 4: Search effort allocation and region of search detection

Customers have the possibility to change global input data and estimate effectiveness of search operations (Figure 5).

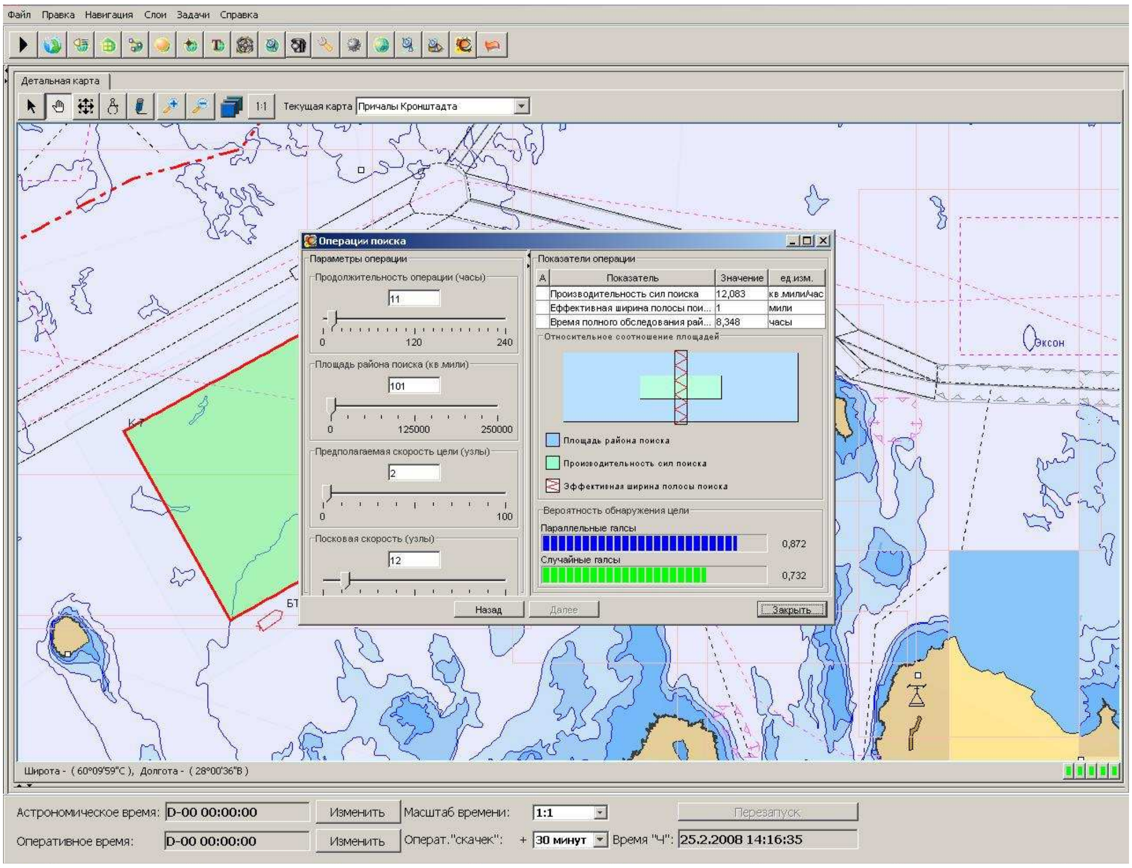


Fig. 5: Search operation modelling

5.2 Vessel docking to a berth

Another TS (vessel docking to a berth) is shown on Figure 6. There is a common picture of situation near the berths of a harbour. In the very beginning of SA customer can receive a list of available berths. A variant of preferable way of docking is presented. Many factors during SA can be taken in mind as follows:

- Berth particular properties;
- depth around the berth;
- presence of other vessels and their properties;
- harbour rules;
- weather conditions.

The visual interface of control over this situation is shown on Figure 7.

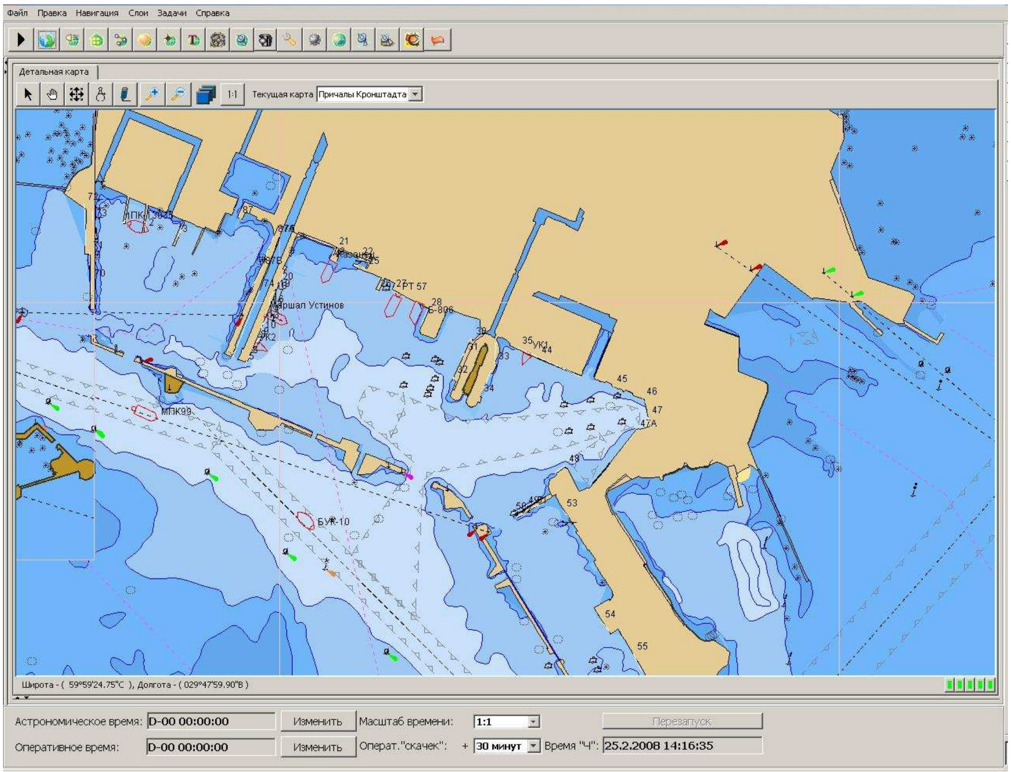


Fig. 6: Current situation in a harbour

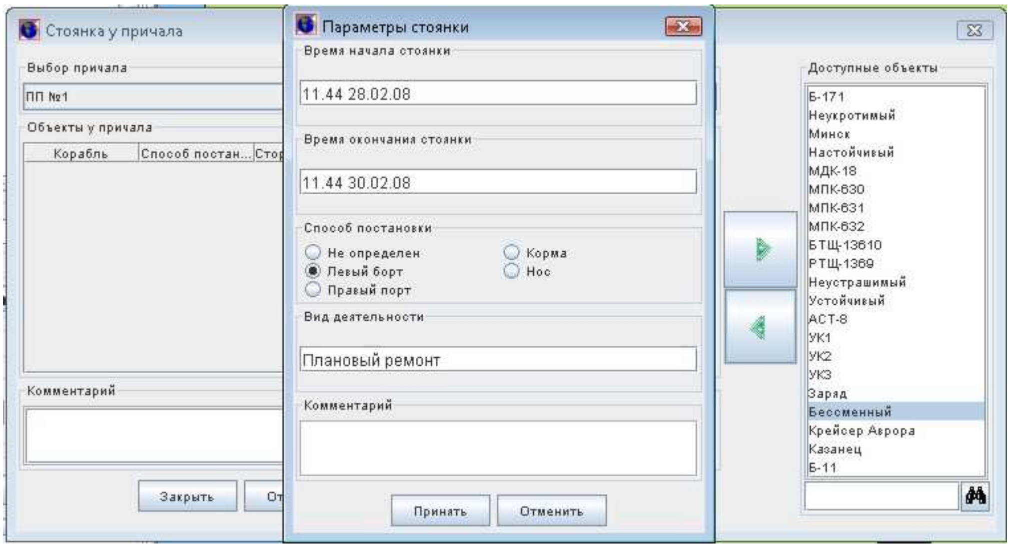


Fig. 7: Visual interface of control over “vessel docking to a berth” situation

5.3 Navigation estimation

For navigation safety of every type of vessel, appropriate data is used as follows: bathymetry, fairway marking, navigation risks, and other moving objects allocation as well. An important problem of SA is the vessel’s location estimation. If the location of vessel contradicts the current conditions the system should take appropriate decisions to prevent such situation. A typical common visual interface for the TS is presented in Figure 8.

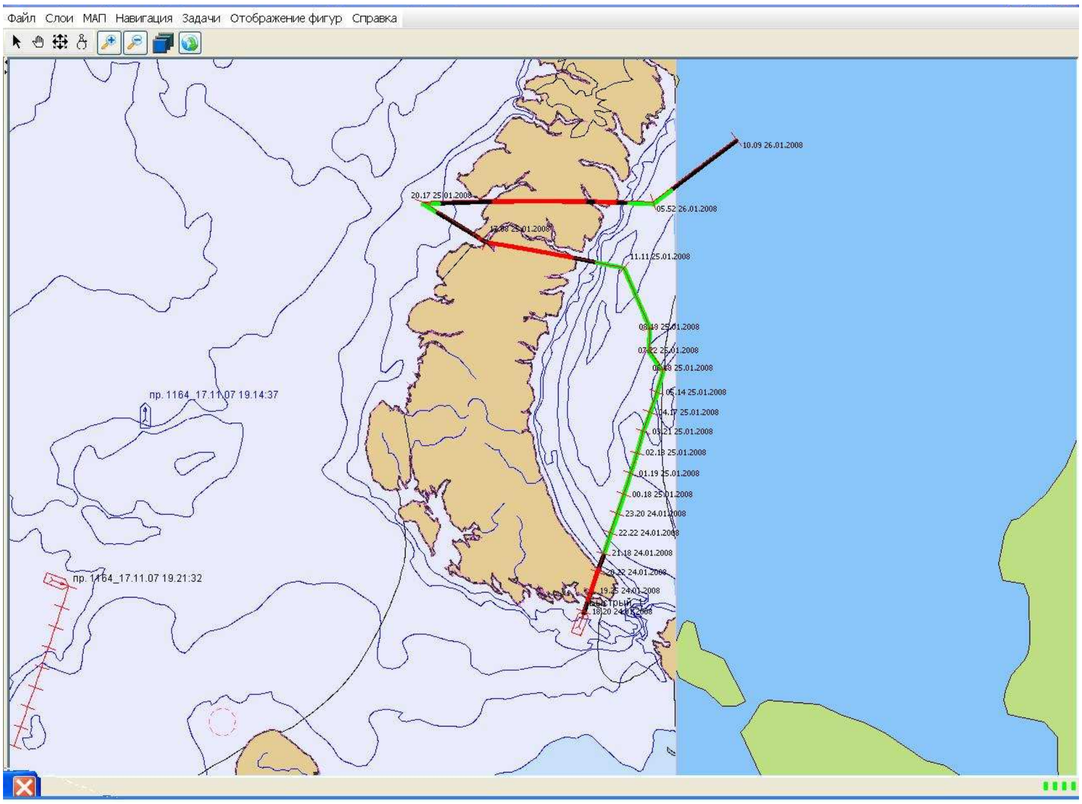


Fig. 8: Visual interface for TS "Navigation estimation"

Repository of TS covers practically a full set of VTCS problems. Decisions and collisions during SA process are illustrated by visual features and voice support.

6 CASE STUDY FOR BREST AREA AND THE ATLANTIC OCEAN

Beyond the interest of Tactical Situations (TS) that occur in harbours such as the ones presented in the previous section, vessel traffic control might also take advantages of GIS capabilities to analyse and extrapolate maritime traffic at different levels of granularity : from coastal to worldwide levels.

Over the past years, the Geographical Information Systems research group of the Naval Academy Research Institute (IRENav) has developed a wide range of projects in the development of automated monitoring and management systems for the integration and manipulation of maritime navigation data [6]. Main current and on-going achievements include the development of mobile solutions for the delivery of additional situation-aware services [13] to end-users in coastal environments, design and implementation of data models and query languages, and autonomous trajectory prediction subsystems [14]. An information system has been also designed to illustrate needs and benefits of intelligent GIS for Vessel Traffic Control Systems (VTCS). This information system acts as a located-based service able to integrate, store, model, analyze and visualize spatially related data in real-time. These dynamic data to locate and display are ships (e.g. cargos, passenger ships) moving in coastal and port areas [7]. The platform developed so far has been designed with four tiers client-server architecture and organized through a distributed data and processing model. The objective of the platform is to provide an integrated and flexible system for the monitoring and tracking of different types of mobile objects in real-time.

These developments offer new opportunities to analyse behaviours and patterns that emerge from large navigational databases. As navigation data is available in almost real-time, intelligent inference mechanisms might help to observe and understand maritime traffic at different levels of granularity (e.g. locally, regionally, global). Several exploratory projects have been recently conducted in application of mechanisms for the data mining of navigational data, and maritime information systems in order to analyse incoming navigation data either from AIS (local traffic) system or International public databases (worldwide traffic).

6.1 Local traffic: Basic trajectory output

Based on existing standards and recommendations of the Open Geospatial Consortium (OGC) and the W3C for the design of Web services, the approach proposed for the real-time following of maritime traffics has been designed as a Web-based visualisation tool that can report dynamic location-based information on maps. It has been designed with a PHP-based generator of Keyhole Markup Language (KML) files (KML is an OGC standard) to apprehend the diversity of Geoweb applications. This favours integration of the location-based information on existing GIS software (e.g. ESRI tools, Google Earth) or GeoWeb-based applications (e.g., GeoServer, Google Maps and Mobile).

Figure 9 shows an example of Web interface output where additional information on a given vessel is presented to the user (e.g., latitude, longitude, speed, direction, and time of last position). The example presented in figure 9 shows the trajectories of a passenger within the Brest bay, and additional contextual traffic information.

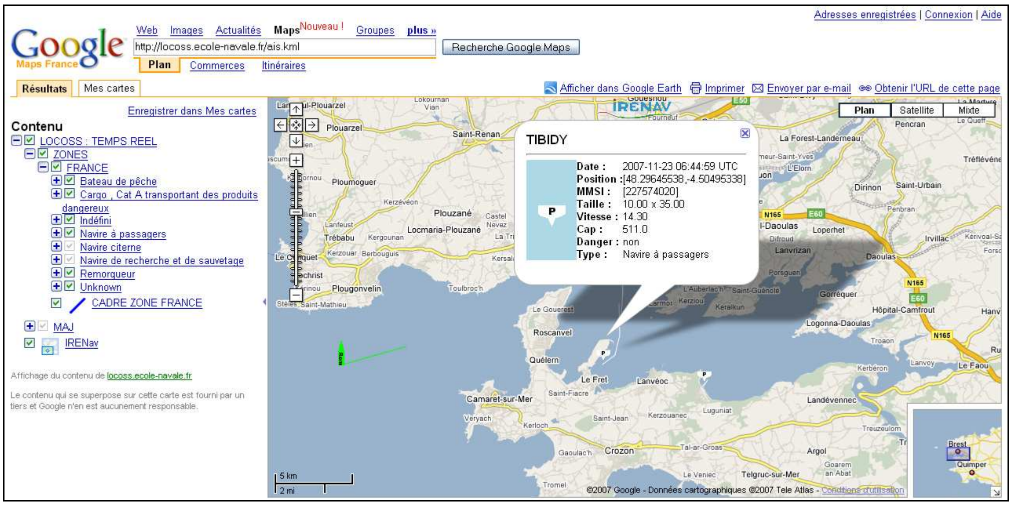


Fig. 9: Web-based visualisation interface

6.2 Trajectories behaviours

Additional contextual objects predefined by end users can be integrated at the interface level (e.g., waiting area, access channel, dangerous zones). Figure 10 shows the example of a vessel on a waiting area (displayed as a square), a vessel that leaves an access channel (to the left), and a vessel leaves abnormally the same channel at it goes out of the limit of that channel (to the top). Intelligent GIS can help users of Vessel Traffic Control Systems with automatic notifications of such events.

Fig. 10: Trajectories behaviours

6.3 Long-term analysis of maritime trajectories

Other services provided by this information system are oriented towards the manipulation and visualisation of historical trajectory data. Figure 11 presents a visualisation of long-term maritime navigation between Brest harbours. This figure shows several trajectories of passengers' ships correlated in time. Aggregation of these trajectories provides typical routes that are useful for the analysis of navigation traffic as patterns and trends [8]. This is particularly useful for safety purpose, and the study of specific events and incidents in a given maritime area.

Fig. 11: Illustration of trajectory analysis between Brest harbours

Trajectory analysis can be also useful to more erratic behaviours such as the ones provided by pleasance ships. Figure 12 shows for instance trajectories of sailing ships in a championship event. This figure illustrates that understanding sailing races without intelligent GIS support can be a real challenge for users.

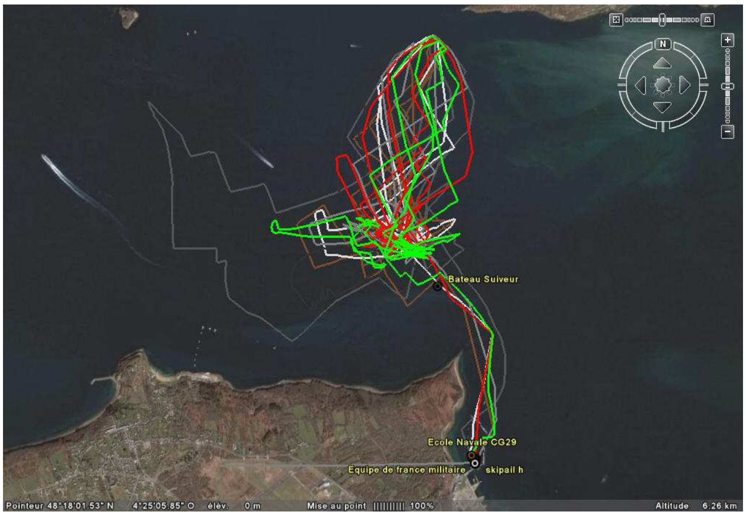


Fig. 12: Illustration of combined trajectories of sailing ships

6.4 Global traffic: Analysis of worldwide traffic

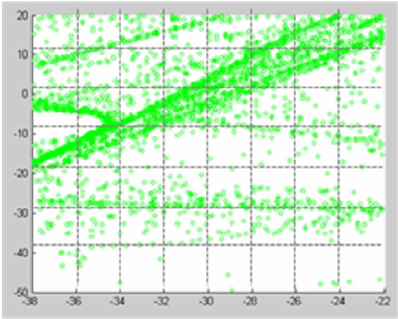
Modelling and analysis of maritime trajectories trends and patterns at a global level is an emerging demand of maritime authorities. The aim is to provide homeland security, location-based information regarding worldwide traffic density, routes analysis according to periods and weather conditions for optimal and economic trajectories and to analyse piracy activities compared to maritime routes. Figure 13 shows a global view example of maritime traffic in the Atlantic Ocean.

Fig. 13: Worldwide maritime traffic

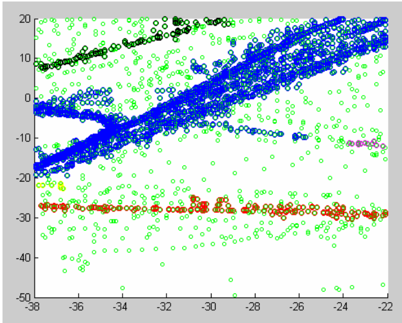
The route detection method can be designed to search for all the possible routes between the different ports of a given list. The ways maritime routes can be identified are varied. Regarding the worldwide maritime data illustrated in Figure 13, a challenging issue relies in the identification of emerging trajectories and routes on the basis on anonymous data (public databases provide only anonymous information). The approach studied to solve this issue relies on a clustering technique.

The objective of clustering is to group observations that are "similar" based on predefined criteria, that is, classification of objects into different groups, or more precisely, the partitioning of a data set into subsets (clusters), so that the data in each subset (ideally) share some common trait - often proximity according to some defined distance measures. The computational task of classifying the data set into k clusters is often referred to as k-means clustering [9]. Beside the term data clustering, or in short clustering, there are a number of terms with similar meaning, including cluster analysis, automatic classification, numerical taxonomy and typological analysis [10, 11, 12].

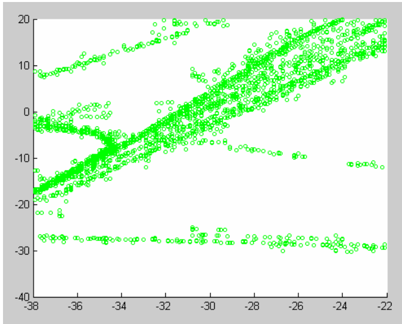
The route detection method, illustrated in Figure 14, has been designed to search for all the possible routes between the different ports of a user-defined list. The areas where routes have to be detected and the list of ports these routes could link should be parameterised. Therefore, the computing process is automatised and processed using several steps (Figure 14). Firstly, the zone is squared in order to delete isolated points (1, 2, 3). Then a clustering method is applied to keep relevant groups of points, that is, clusters (4). A method based on a Dijkstra algorithm is then applied in order to find the shortest path (i.e., a polyline) between two ports within each cluster (5, red dots). Finally, a data mining and clustering algorithm is applied to determine the route's border polylines (6, red dots).



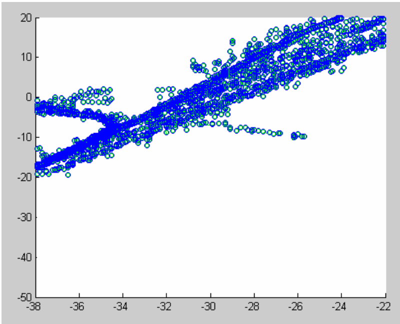
1. Squaring the zone of initial dataset



2. Detected relevant clusters

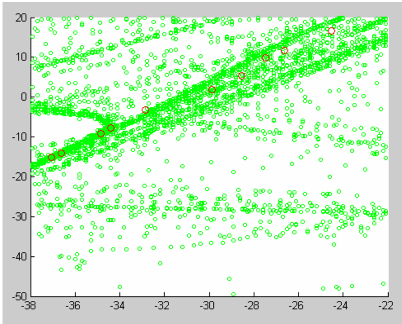


3. Remove the noise

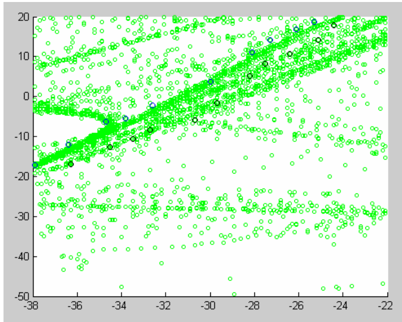


4. Kept cluster

(between origin and destination)



5. Determining the central poly line (shortest path)



6. Determining border poly lines of the trajectory

Fig. 14: Detecting maritime routes

Such analysis provides a valuable source of knowledge to optimise maritime shipping and traffic security in high density areas. Figure 15 shows an example of relevant points of the route identified between the ports of Dubai and Le Havre.

Fig. 15: Route from Dubai to the North of France

7 CONCLUSION

The researches and experiences presented in this paper have shown that embedding Intelligent GIS (IGIS) into Vessel Traffic Control Systems (VTCS) provide several functionalities of interest for maritime users, from local to global authorities to navigation users. Close integration between VTCS and IGIS can provide accurate and fast decision-aid support in comparison with usual VTCS. This is particularly reinforced when vessel traffic is rather high, and demands for decision time important. Considering IGIS as an analysis and self-learning subsystem also provides several research opportunities. This is closely related to the concept of

Tactical Situation (TS) that gives another functional dimension to VTCS. A variant of VTCS has been used for navigation control in St. Petersburg Harbour and Golf of Finland over the past few years, and maritime navigation systems in North West France. Further work concerns the development of joint models and platforms between the research teams involved in this research.

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