Maritime GIS: From Monitoring to Simulation Systems

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Abstract. Combined research in the fields of Geographical Information Systems (GIS) and maritime systems has finally reached the point where paths should overlap and continue in better unison. This paper introduces methodological and experimental results of several marine-related GIS projects whose objectives are to develop spatial data models and computing architectures that favour the development of monitoring and decision-aid systems. The computing architectures developed integrate agent-based reasoning and distributed systems for the real-time monitoring, manipulation and simulation of maritime transportation systems.

1 Introduction

Recent advances in telecommunication and positioning systems, client-server and distributed architectures, and mobile devices offer new perspectives and challenges to maritime GIS and transportation research. However, there is still a need for data management and communication protocols, graphic and exploration interfaces that support the development of integrated maritime GIS. Such systems will be of great interest for many maritime applications oriented to the monitoring and analysis of maritime traffic and transportation.

One of the current limitation to the development on integrated maritime and GIS systems relies in the fact that current GIS models, software and interfaces do not yet provide the functionalities to make this technology compatible with maritime transportation, particularly when considering the telecommunication and navigation-based systems available in maritime transportation. This poor level of integration 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 lead to the development of automated monitoring systems such as the AIS (Automatic Identification System) and the ECDIS (Electronic Chart Display and Information System) as a support of electronic mapping services. However, officers on the watch and monitoring authorities still require the development of additional and advanced decision-aid solutions that will take advantage of these communication and cartographical systems and thus improve their benefits.

Amongst several technological solutions that might contribute to the emergence of maritime-based decision-aid systems, integration of Geographical Information Systems (GIS) with maritime navigation systems appears as one of the promising directions to explore. The projects presented in this paper present several contributions to such a field of maritime GIS: from the real-time monitoring of navigations for a local authority and maritime clients (Section 2), to the diffusion of maritime data to mobile interfaces (Section 3), and the development of a relative-based model and visualisation system for maritime trajectories (Section 4). Finally Section 5 draws some conclusions and perspectives.

2 Real-time Traffic Monitoring

Nowadays, Automatic Identification Systems (AIS) used to detect and warn about possible maritime navigation collisions are a suitable solution for well equipped ships, but are unfortunately relatively expensive and difficult to maintain for small ships and pleasure boats. The Share-Loc project (fig. 1) purpose is to design and implement a flexible maritime navigation system for small ships and boats [1][3].

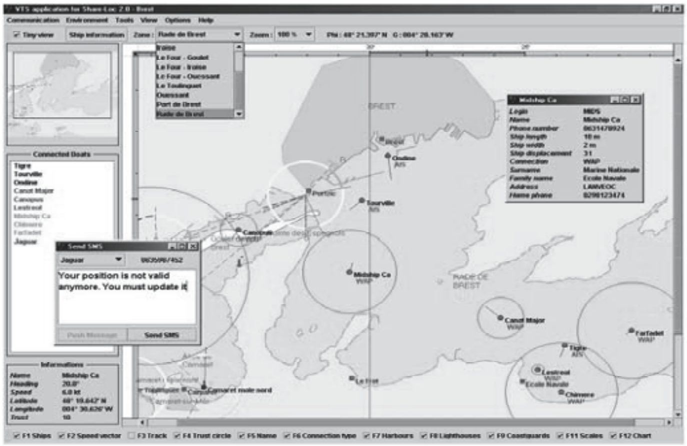

Fig. 1. VTS application

The Share-Loc system is based on a distributed architecture and real-time services for the diffusion of maritime geographical information, at different levels from the global monitoring of the maritime traffic of a given area, to individual services on request. The Share-Loc system is made of a navigation database server and mobile navigation clients. It is based on a client-server architecture that maintains a global view of a given navigation area on the server side, and a WAP-based solution that provides location-based data on the clients side. The server is a web-based program running on an Internet connected computer. Each client is a WAP-enabled mobile phone device that accesses the WEB server data through a WAP gateway program running on the server computer. Mobile clients are connected to Internet service providers according to their choice of telephone handset and mobile telephone network. Subsequently each authorized client is able to request the appropriate address on the server and to start the navigation-based application. The project provides a solution for the monitoring of small ships, and is oriented towards Vessel Traffic Services (VTS). A VTS is a marine traffic monitoring system established by harbour or port authorities, similar to solutions used in air traffic control. VTS are based on radar systems and AIS to keep track of vessel movements, and improve navigation safety in a given maritime area.

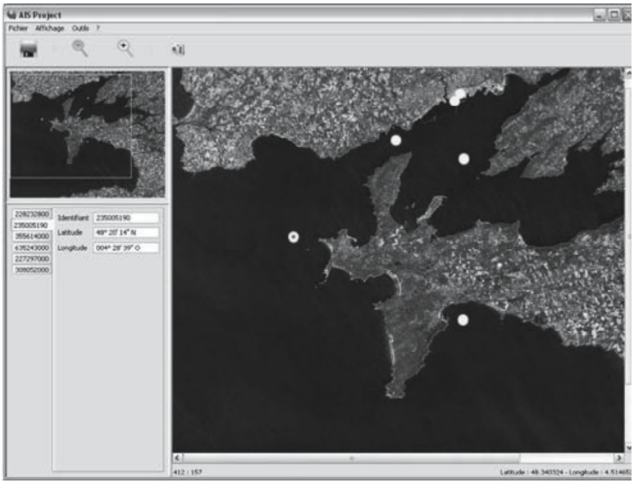

Fig. 2. Real-time AIS monitoring

This system is completed by a monitoring-based project whose purpose is a management and visualization system for positional data coming from an Automatic Identification System (AIS) that uses a VHF ad-hoc network to broadcast data over large distances. The aim is to provide a generated view of a real-time maritime situation of the Brest maritime neighbourhood. Thanks to a three-tiers application, AIS messages are received from ships and stored on the server side. Clients access information using a Web interface written in Java. This constitutes a sort of abstraction of the appliance level. The application is designed to run on every device that can browse the Web and execute a Java runtime. AIS messages provide additional information on the ships manipulated (fig. 2). Figure 2 shows a maritime configuration where each spot represents a vessel location. Attribute values of the selected vessel are displayed on the left part of the interface.

A second development that extends the functional objectives of the Share-Loc prototype relies in a real-time monitoring system developed in the context of an international sailing race. This event has a large audience, and requires appropriate solutions to diffuse real-time information, from the coastal maritime area to the users located in the ground. This generates different needs in term of geographical information usage and appliance. The experimental prototype is composed of two parts: a wireless network and an experimental adaptive GIS. Ships locations during the race are acquired through a real-time infrastructure. The implementation of the geographical context into different views and an appliance context divided into several classes of devices are considered by the adaptive process.

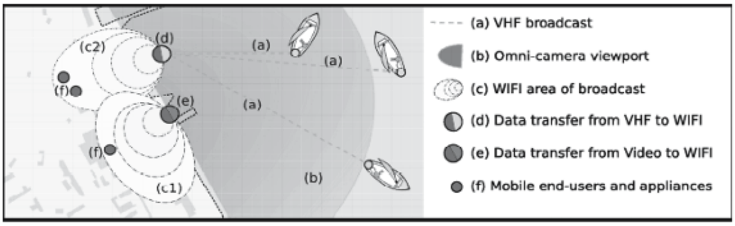

Fig. 3. Real-time communication infrastructure

The user context is modelled by a generic concept of user group that aggregate user behaviours. An important aspect of the adaptation process is its ability to integrate real-time geolocalisation information that delivers GIS data and influences the geographical context and related services. A localization system has been developed and allows for real-time reception of ship's positions and a continuous video stream of the race (fig. 3). Locations are provided by an embedded system available on ships. This system includes a GPS, a configurable modem, a VHF transmitter and fulfills several constraints: light weight (less than a kg), long range (5 to 10 km), high autonomy (8 to 10 hours). This module collects and diffuses the real-time locations of the ships to the ground station (fig. 3-(d)). The transmission to the ground station is a VHF communication (fig. 3-(a)) based on APRS frames (Automatic Position Reporting System). The ground station is composed by a VHF receiver and a VHF-to-WiFi bridge that broadcasts real-time data to a given area (fig. 3-(c2)). Mobile end-users (fig. 3-(f)) located in this broadcast area can access ships data, whatever the form of their appliance.

A general drawback of coastal sailing races is the lack of visibility on the ground, because of the distance to the coast. As real-time positions are crucial, video streams are provided and offer a concrete service of the geographical data. The installed video system presented in fig. 3-(e) broadcasts a video stream of the race (fig. 3-(b)) to a given WiFi deserved region (fig. 3-(c1)).

Complementary geographical data views, each associated to a particular service, are presented to the user. The "2D mapping" service delivers ships location information. Different levels of zoom are automatically computed several times per minute to provide detailed views on the race activity. The "3D mapping" service displays similar data, but in a 3D view of the region of interest. Basic displacement and zooming functions in the scene are available using keyboard combinations. The "Video" service provides a real-time view of the race region. Zooming and camera movements are also allowed.

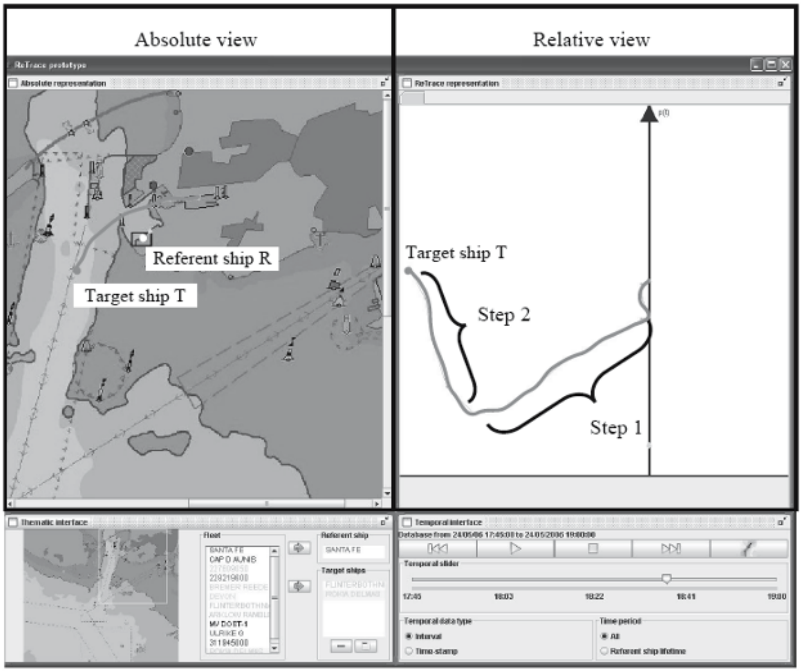

Fig. 4. ReTrace prototype

Despite the interest of modelling and visualisation functionalities, there is still a need for additional prediction mechanisms that should improve the monitoring and planning of navigation decisions. Cognitive studies have showed that the conventional absolute vision of space does not completely reflect the human perception of the environment [10][11]. Observer-based properties such as the relative position and relative velocity of an object with respect to an observer are difficult to evaluate visually when using an absolute frame of trajectory representation. The relative view of space provides a human-oriented vision of space to model closer to the way it is perceived from a mobile observer acting in the environment [12]. We made the assumption that it might be possible with a relative frame of reference to offer a different view of the way a mobile object behaves in space and time. This should offer a direction to explore for the study of maritime trajectory interactions, particularly when the objective is to analyse the behaviour of one or several moving objects (i.e. ships) with respect to an observer also acting in the environment (i.e. either a ship or an observer acting in the environment).

This leads us to explore and design a relative-based trajectory data model: the ReTrace data model (Relative-based Trajectory data model) [13], where relative position and relative velocity of a mobile object with respect to an observer acting in the environment are modelled over time. One of the research objectives is to explore to which degree such a model completes the conventional absolute view of a spatial trajectory. The model is supported by formally-defined process primitives that are also qualified at the cognitive level [13]. A prototype implements the ReTrace data model with a dual visualisation frame that integrates the absolute and relative representations (fig. 4). The figure shows a target object T that gets closer the referent object R and accelerates during the time interval Step 1, and moves away from the referent object R and accelerates during the time interval Step 2. This dual representation provides complementary views that favour the understanding of trajectory behaviours in space and time, thus favouring the analysis of the emerging processes and patterns.

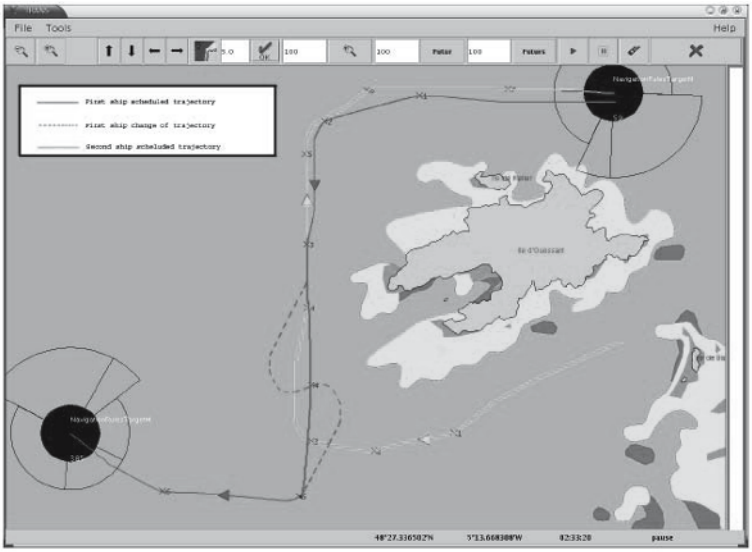

Fig. 5. TRANS scenario example

Simulation capabilities are also required to predict future vessel positions. The TRANS prototype (Tractable Role-based Agent Prototype for Concurrent Navigation Systems) develops a multi-agent spatial decision support system that supports micro-simulation capabilities, and where ships are modelled as autonomous agents acting in their environment (fig. 5) [5]. Several modelling concepts enhance the semantics of this meta-model. In particular, they allow an agent to be part of a group and to act according to the roles defined at the group level. Role priorities and constraints give additional flexibility to the meta-model. Simulation objectives of the TRANS prototype are to model and anticipate ship behaviors and trajectories in order to avoid collisions and running aground. The figure 5 illustrates the TRANS interface and displays two ship trajectories and show a case where one ship avoids the other by the application of navigation rules. This ship then returns to its initial trajectory. These changes of behaviours are supported by the role mechanisms. The aim is to develop a realistic simulation environment that can be used either for monitoring purposes or as educational software for training purpose. Further work concerns progressive interoperability of the TRANS prototype with simulation systems that integrate the modelling of continuous phenomena such as ship trajectories, tides, streams and winds.

3 Towards Adaptive Interaction Techniques

These navigation-based systems illustrate the variety of methods and research issues that support exchange of geographical data between a centralised system and mobile users. Although they make a basic usage of the geographical context taking into account ships location and characteristics, no flexible automated adaptation is provided to the users at the interface level. These elements are not new when studied individually, but less considered as a whole. For instance, previous work in the field of adaptive GIS introduces a technology-driven approach for an hardware-based interaction medium [8]. Adaptation of an open GIS layer descriptor to specific user needs and contexts has been also studied in [7]. A context-sensitive model for mobile cartography that emphasizes different levels of data adaptation and presentation has been proposed in [9].

Another on-going project introduces an adaptive GIS defined as a generic and context-aware GIS that can be automatically adapted according to several contexts defined by (1) the properties and location of the geographical data manipulated, (2) the underlying categories that reflect different user profiles and (3) the characteristics of the computing systems, supporting web and wireless techniques [4]. This classification has been inspired by a previous work done by Calvary et al. [2]. These contexts cover the components of the diffusion of geographical data in wireless environments. The dimensions identified are of different nature as they involve data, computing processes and interfaces, and categories of users.

In order to consider the problem from a global point of view, this project develops an integrated contextual-based architecture that considers these different factors and interrelationships. The framework is developed and applied to maritime navigation (fig. 6) and combines mobility and distributed services. From a maritime point of view, heavy and even increasing maritime traffic need very low human response time in order to prevent accident. The use of adaptive GIS as a decision-aid system for end-users appears as a useful approach for maritime transportation systems.

Fig. 6. Adaptive interaction

4 Conclusion

The development of integrated maritime and GIS systems still requires the integration of different geographical information sources to be combined, adapted and shared in real-time between different levels of users acting in the maritime environment. The development of information and telecommunication technologies brings new and often unexpected possibilities for integrating, analyzing and delivering maritime traffic data within GIS. Integrating GIS information architectures and services with maritime information systems should improve the economical and technological benefits of transportation information by allowing the diffusion of traffic information to a larger community of decision-makers, engineers and final end-users.

Research challenges are varied: development of cross-domain protocols and exchange standards for the transmission and interoperability of traffic data. Conventional statistical, geographical data analysis and visualization methods should also be adapted to the specific nature of traffic information often associated with large volumes of data. At the implementation level, there is a need for the development of GIS-based distributed computing environment, computational and processing capabilities as traffic data and applications are usually physically allocated in different geographical locations and computationally expensive in terms of the data volumes generated. The diversity of projects presented in this paper illustrates the range of opportunities of the integration of GIS and Intelligent Transportation Systems (ITS) for maritime navigation. We believe that all these application domains should benefit for this information integration and those methodological findings should be shared and cross-fertilized amongst the research communities active in these fields.

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