GEOGRAPHIC INFORMATION SYSTEM FOR REMOTE INTEGRATION OF DIVERSE UNDER-WATER ACOUSTIC SENSOR DATA

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Maritime and port areas throughout the world are exposed to many different hazards, like pollution, terrorism and natural disasters. Early detection, identification and preparation of appropriate response strategies is especially important in the case of semi-enclosed basins like the Baltic Sea, mainly due to the marine ecosystems' continuous absorption of pollutants including oil, heavy metals and chemicals. Many of those agents are characterised by great toxicity and cause devastation of the natural environment. The huge development in the information technology provides the means and possibilities for much faster and more efficient access to survey data, allowing their remote, nearly real-time management, processing and visualisation. Several approaches and techniques of measurements are available in marine environment monitoring. These consist of direct sampling, airborne and satellite imagery, hydrological measurements using CTD probes, remote sensing with the use of electromagnetic waves, acoustic methods based on the data acquired by multibeam systems, side-scan sonars and singlebeam echosounders.

INTRODUCTION

The problem of efficient methods of monitoring, prediction and visualization of various marine environment processes has been of great importance for many years. This is the reason for development of various research techniques using different approaches and equipment. These techniques include [1]:

- direct sampling,
- hydrological measurements using CTD probes,
- satellite and airborne imagery,
- acoustic methods based on the data acquired by multibeam systems, side-scan sonars and single-beam echosounders (ES).

The acquisition, processing, integration and visualization of various kinds of data constitutes an important problem in the context of numerous applications related to aquatic ecosystems management.

The paper describes a marine GIS system capable of integrating the data from various sources. These include real-time sensors like radar or satellite data receiver, where data is transmitted to the system without relevant delays and presented on the map, dynamic data sources such as results from numerical simulations, e.g. prediction of oil spill behaviour, as well as other data types such as bathymetry, background maps, underwater acoustic sensors' data and others. Comprehensive description of important visualization algorithms is also outlined in the paper.

The data from the investigated marine region can be presented by two separated components of the system, namely the Web-based GIS consisting of GeoServer integrated with Open Layers and standalone GIS application built upon ESRI ArcGIS Engine technology. Each of these modules differs by data visualization algorithms and is characterized by specific capabilities.

This paper presents the design and the application of the newly developed nearly real-time, remotely accessible GIS. The system features like web integration framework, advanced 3D visualizations of underwater acoustic data have been described in the following sections.

1. SUMMARY OF PREVIOUS WORK

The Department of Geoinformatics of Gdansk University of Technology carries out an intensive research in the field of design and creation of marine GIS systems. The recently developed versions of the system have already been presented in [2] and [3]. The basic functionalities of the system are briefly described in this section.

The developed marine GIS enables integration of different kinds of distributed data from various types of sensors and sources, along with the presentation of the data from the investigated marine region in the form of multiple, time-varying 2D and 3D thematic maps. It consists of two basic modules, which provide full functionality to end-users, namely Web-based GIS and standalone application.

The Web-GIS module was developed entirely with the use of Open-Source technology. It utilizes the GeoServer for serving Open Geospatial Consortium's (OGC) Web Map Service (WMS) layers, Apache Web Server as the HTTP proxy, Java 2 Standard Edition with the Tomcat Servlet Engine for data processing, and OpenLayers Javascript library for building the DHTML client. Web-based system is dedicated to provide basic 2D visualization for every user of the system. Due to technological limitations interactivity with the user is limited to basic 2D data management and editing. Also rendering algorithms are less complex and cannot provide 3D information about marine environment.

The standalone application module provides far more complex solutions on integration, analysis and visualization of the spatial data, however it requires ArcGIS license and a good CPU for rendering algorithms. This part of the system was developed in C# language using .NET platform and uses ArcGIS Engine functions as spatial processing and visualization tool. ArcGIS Engine is a set of objects that provides application programming interfaces (APIs) for COM, .NET, Java, and C++. It also includes a series of high-level visual components that makes it fairly easy to build an GIS application. ArcGIS Engine provides well-defined, cross language objects called ArcObjects, the same objects on which the ArcGIS Desktop products are built. Thus ArcGIS Engine is a tool that allows building applications or extending existing applications to provide focused spatial solutions to both GIS and non-GIS users. An important feature of ArcGIS Engine is the form of map presentation that can be either an incidental or a central element in an application. These features make ArcGIS Engine particularly well-suited to specific GIS solutions like marine ecosystems' sensing. Standalone application provides complex mechanisms of 3D visualization of custom spatial objects ranging from MBS bathymetry, side-scan and single-beam echosounder data results to 3D modeling of oil spills or pelagic fish visualization.

To provide common and efficient solution to serve the geospatial data via TCP/IP protocol particular modules of the system are compatible with widely used spatial data serving protocols such as Arc SDE and WMS (Web Map Service). Several open-source and commercial solutions were used to provide the set of basic GIS functionalities like viewing, panning and zooming of the map including ESRI ArcGlobe control for 3D visualization of custom spatial objects in standalone application or open-source Open Layers Javascript library for implementing the WWW client in the Web-based module. The detailed architecture of this marine GIS data is presented in Fig. 1 and it’s comprehensive description is available e.g. in [1] or [2].

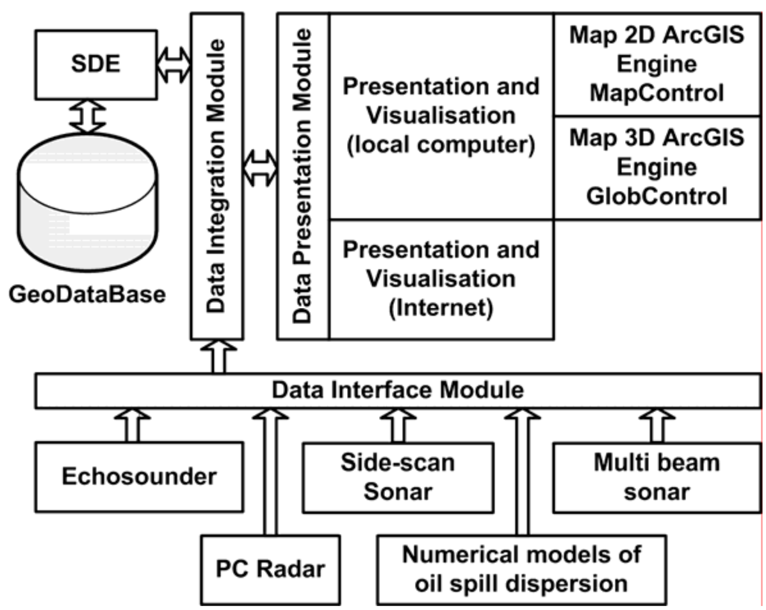


Fig.1. The previous system architecture

Integration and visualization of spatial data is one of the most important objectives of every GIS application. The previous version of the system was capable of analysing, processing and visualisation of marine data acquired from various external sensors, namely Simrad-Kongsberg EM 3002 multibeam sonar, EdgeTech DF 1000 side-scan sonar, Simrad EK 500 single-beam echosounder, Sitex radar and others. These tasks were accomplished by implementing several data processing algorithms responsible for transforming all external sources and sensors data to manageable data types that can be presented by visualization components of the system.

The previously developed system had several features and functionalities that made it quite helpful for marine habitat monitoring. However, many of additional algorithms and functions needed to be implemented to make it more efficient in marine research. New features and functionalities that were implemented in the system are described in following sections.

2. UNDER-WATER ACOUSTIC DATA EXCHANGE

Collecting marine data during research is a complex task which not only consists of measurements but also analysis, validation and interpretation of information acquired by various sensors. Scientists of the Gdansk University of Technology Department of Geoinformatics along with researchers from the Polish Academy of Sciences have made several expeditions on the r/v Oceania where such measurements took place. It became clear that, in this context, it is crucial to provide efficient way of communication between distributed marine data sources and create mechanism of dissemination of the measurement results among other groups of scientists. This task was accomplished by creating additional framework, called GIS Integration Framework (GIS-IF) that is responsible for integration of the metadata in web-based module and distributed users of standalone applications. In this context, metadata is considered to be a description of the information that is analysed and visualized in the main module of the system. The architecture of it's application is presented in Fig. 3.

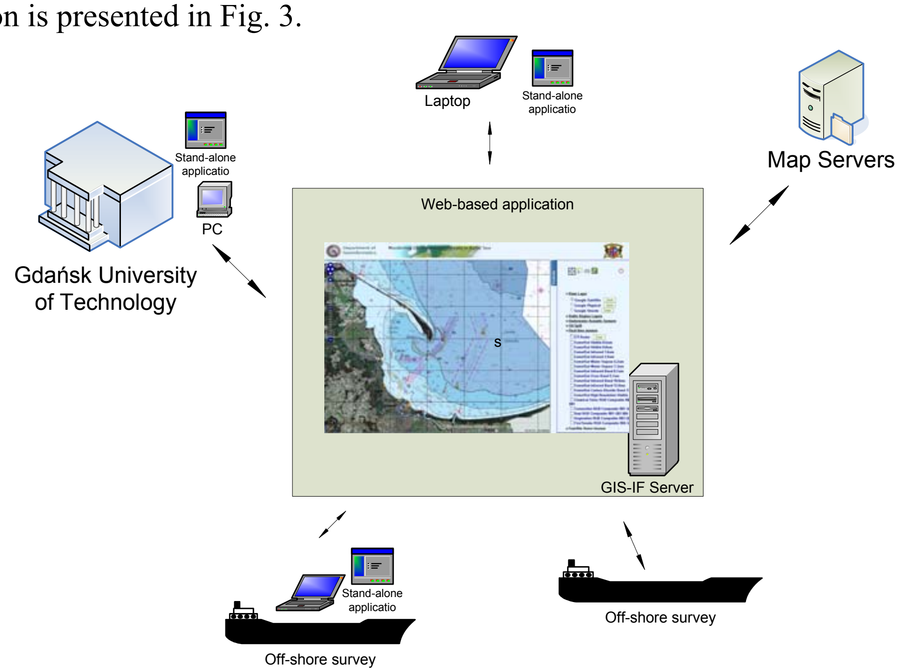


Fig.2. GIS Integration Framework architecture

The presented solution made the system much more flexible and useful as a tool in the research activity. GIS-IF enabled the rest of the developers of the system to consider web-based module and standalone application as two separated modules, where the synchronization of the data is provided. This simplified the application development process and led to significant changes in the structure of the resulting GIS. Most of the system modules responsible for data processing were also separated to provide a wider range of functionality, especially in the web-based part of the system what was shown in Fig. 5.

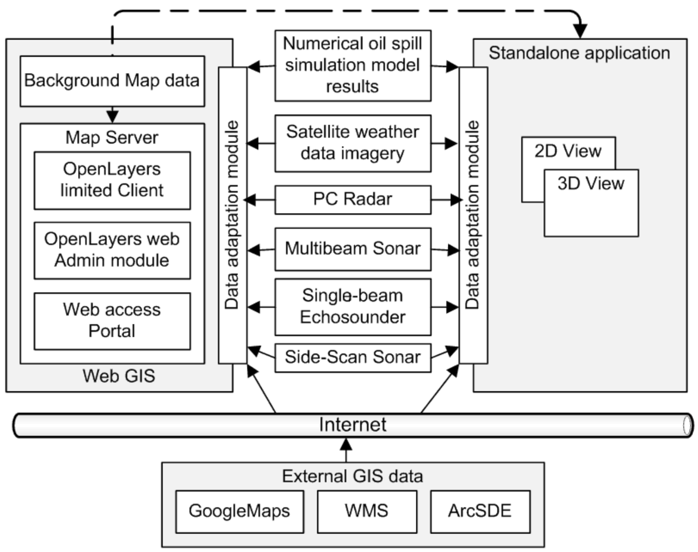


Fig.3. The architecture of the recently developed system

3. SUPPORTED SENSOR TYPES FOR OCEAN MONITORING

The proposed system integrates several types of data coming from various sensors. Many sensors available on the market deliver their measurements along with their respective absolute spatial positions in global coordinated systems. However, providing the data for real-time web-based GIS systems requires special processing depending on the data type. For the purpose of exemplification, the system was tested on data from three kinds of real-time sensors that vastly differed in the sense of collected information, which ranged from radar system echo data, through meteorological data from satellite receiver to marine traffic data from automated identification system (AIS). This data differs not only in structure but also by its hardware and software acquisition interface.

The first sensor delivers data acquired by the portable PC radar located on the roof of the building of Technical University of Gdansk Faculty of Electronic, Telecommunication and Informatics. The radar, manufactured by Sitex, provides a stream of data containing the current radar image every two seconds via usb interface. The maximum 16Nm range covers most of the coastline area of the Gulf of Gdansk. For the purpose of web-based access, this kind of real-time data requires setting up a dedicated software server, which provides geo-referenced imagery on user demand. Depending on the sensor's geographic orientation, each requested image frame needs to be projected for its precise overlaying over the base map of the GIS system. In the actual system the single 240x240 raw raster image headed from North by 11 degrees is fitted to a standard 256x256 tile that is geographically scaled on the map to its actual range setup.

The second sensor system used for testing the developed GIS's performance is used for processing data acquired from EumetSat's Broadcast System for Environmental Data (EumetCast). It is a multi-service dissemination system based on standard Digital Video Broadcast (DVB) technology. It uses commercial telecommunication geostationary satellites to multicast files received from meteorological satellites. Because of limited bandwidth, a full scan is available each 15 minutes after reception by a satellite antenna. The data contains twelve spectral channels spread from visible band centered on 0.6 μm to carbon dioxide band centered on 13.4μm including one broadband high-resolution visible band channel. Data received from all channels is segmented to 8 or 24 (for high-resolution channel) strips, as a 3712x464 raster (5568x464 for high-resolution channel). The received information is stored in the local filesystem, and is available for access through the classic Apache web server. However, georegistered and compressed files in geostational projection require additional processing for presentation in unprojected Plate-Care charts or Mercator projected marine maps. To accomplish this task, the channels are organized in the form of GIS layers, which can be geo-concatenated and reprojected by a dedicated WMS server. The server provides the web-based GIS with near real-time area snapshots which cover nearly the entire northern hemisphere in the form of 256x256 pixel tiles.

The last real-time sensor used during testing is of different computer technology origin. It is based on data already published in the Internet and coming from MarineTraffic.com, a website provided by the University of the Aegean in Greece [4]. The marine traffic web-service manages the radio signals obtained by AIS receivers from all over the world and publishes them in form of dedicated XML files obtained by HTTP queries. In this case the software processing part is moved to the client side by applying Javascript parsing code based on AJAX requests. The code is prepared to be used by many APIs, including Google Maps and Open Layers. According to the data provider, its internal database representing positions of all world-wide AIS equipped ships is updated every five minutes. Therefore the refresh rate of this GIS layer is set up for this time period. Moreover, as the layer represents so called feature information, the data are visualized using earlier prepared icons in the form of ship markers with adequate orientation (rounded to 5 degrees) reflecting ship course. The HTTP queries are map extent and zoom level sensitive in order to be efficiently transferred by global Internet network.

Fig. 6 shows three described real-time sensors layers overlaid on the base map. The layers are refreshed according to software setup timeouts imitating near real-time acquisition. It is worth to note that although the systems allows for multiple selection of many such layers, its heavy usage may lead to performance problems on client machines due to demanding requirements for the part of the application operating in WWW browser environment.

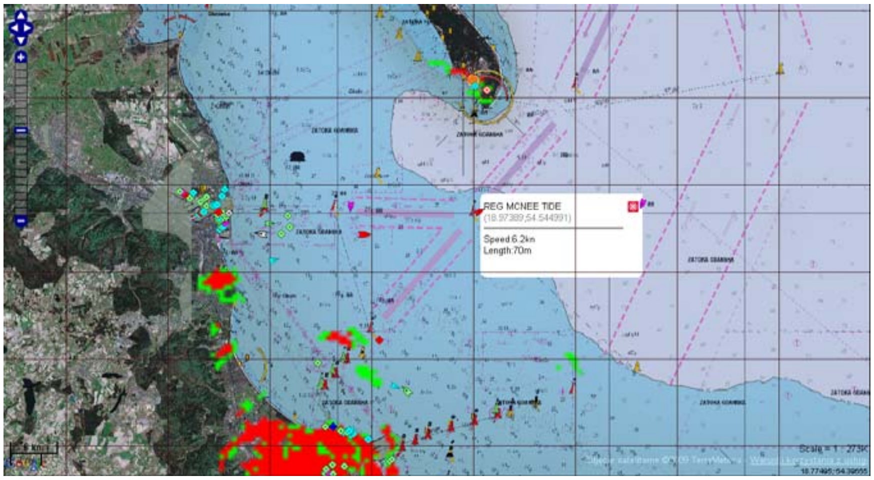
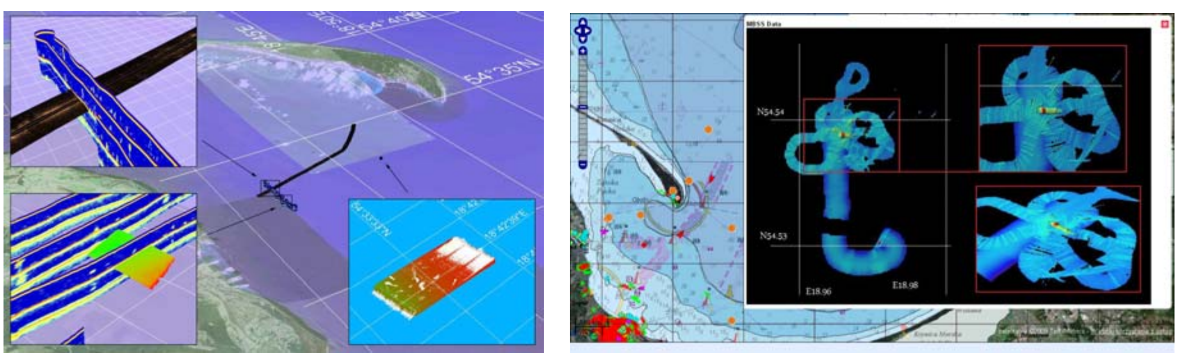


Fig.4. Satellite and radar real-time imagery overlaid on AIS data and ENC maps

In addition to visualizing real-time sensor data, the GIS can be used to display offline data. The standalone application is capable of displaying data from typical online sources (e.g. SDE, WMS) together with custom layers containing results of sonar surveys. The basic functionality, i.e. view management, layer organization and basic geodata import is based on components available from the ArcGIS Engine SDK. However, in order to efficiently visualize custom data, creation of dedicated OpenGL procedures for display of three dimensional views was necessary. Fig. 7 and Fig. 8 show an overview of the Bay of Gdansk with overlaid three detailed views that present data acquired using the echosounder, side-scan sonar, and multibeam sonar. The application allows seamless navigation between data acquired from various sources, at various times.



(A) (B)

Fig.5. A typical overview and three detailed views in the standalone application(A)
And multibeam sonar data visualization (B)

The data from MBS is displayed in two forms, either as a series of points containing bathymetry data, or as a series of two dimensional fan-shaped images that can be used to visualize objects other than the seabed, such as fish or pollution. In order to maintain visibility, signals below a certain threshold can be made completely transparent. Fig. 8 depicts data acquired during one of the aforementioned surveys. This method can be used to clearly show objects floating above the seafloor, which in the case of Fig.8 are pelagic fish schools.

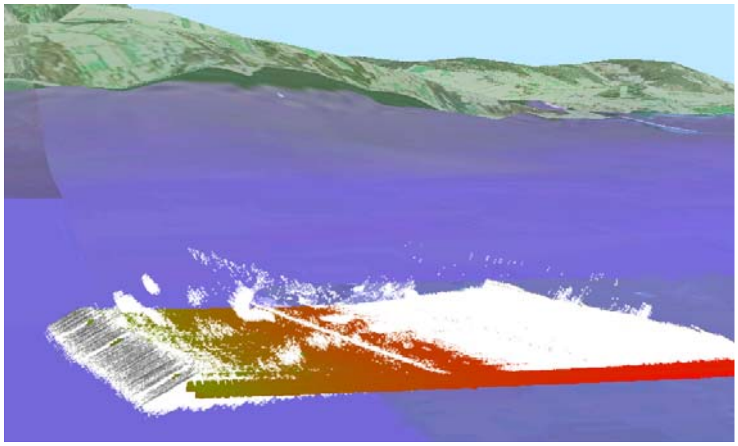


Fig.6. Water column data containing pelagic fish schools

4. SUMMARY

The paper introduces the design and applications of the real-time, remotely accessible marine GIS dedicated for marine environment sensing, monitoring and visualization, developed by the Department of Geoinformatics of Gdansk University of Technology. The system was developed using powerful Open Source and commercial technologies to deliver multi-resolution maps designed for different scale observations of marine environment and various ecosystems components. It is particularly useful for instantaneous integration, processing and imaging of data acquired from different sensors and distributed sources. When integrated with sensors providing current on-line data containing measurement results, the system can be a valuable, intelligent support tool for diverse groups of scientists, authorities and others.

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