

PROCESSING OF MARINE SATELLITE DATA IN A WEB-BASED GIS

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Geographic Information Systems (GIS) are an excellent tool for integrating various types of spatial information. They provide functionalities which allow for quick analysis and correlation of various types of data in a geographical context. The paper presents a Web-based GIS dedicated for integration and analysis of marine data from satellite imagery. The system operates with the use of automatic image processing procedures, which allow for detection of several different characteristics such as surface temperature or the existence and location of blooming algae. The system correlates the processing results with information from other sources, including vessel movement acquired from the Automatic Identification System, as well as results of oil spill simulation. The paper presents the architecture of the system as well as sample layers produced by the employed algorithms.

INTRODUCTION

Monitoring and analysis of the marine environment with the aid of Geographical Information Systems has been a subject of intensive research for many years. The potential of Web mapping in application to environmental modelling has been known for more than a decade [1], [2], [3], however the potential of integrating a Web GIS in online remote sensing facilities for environmental monitoring and management has only been demonstrated more recently [4]. At the same time, it has been shown that a common geographical coordinate space is an excellent place to combine many types of information concerning the environment [5]. Since then a Web GIS Decision Support System (DSS) has been applied for use in resource management and assessment of environmental quality [6], as well as for monitoring, integration and dissemination of marine pollution data collected from multiple sensors by means of non-proprietary technologies [7]. A Web GIS portal has also been dedicated to integration and dissemination of multi-source data for the purpose of environmental risk management in marine and coastal areas of Europe [8]. More recently, successful attempts at dynamic presentation of marine data collected from a variety of sensors by means of Web GIS have been presented [9]. Currently, Web GIS is being applied in marine monitoring

primarily for the purposes of data presentation and analysis. In consequence, the collected data is delivered to the GIS irregularly and with long delays, during which the information is extracted from raw format of the source sensors and processed into thematic layers of spatial data. Presentation of calibrated satellite sensor measurements of marine data in semi-real time via a Web GIS is still to be achieved. This paper presents a system for online acquisition, processing, analysis and dissemination of satellite images within a Web based Geographic Information System.

1. MATERIALS AND METHODS

The presented system builds upon several years of experience in designing Web based Geographic Information Systems [10]. It consists of three main elements, including the Web GIS Server, the Web GIS client and a set of modules for spatial analysis and data management. The latter include satellite data integration module and a Spatial Analysis component. Data from satellite services as well as simulations produced by the system are stored in the Geodatabase. The stored data may be further processed by the Spatial Analysis Module. The resulting spatial data is disseminated to authorized users of the Web GIS client in the form of thematic layers by the Web GIS Server.

Satellite Data Adaptation module

The Satellite Data Adaptation Module is responsible for the integration of the GIS system with data acquired from the 1.5 m HRPT/MetOp satellite ground station. Since 2009 the Gdansk University of Technology Geoinformatics Department operates a satellite ground station capable of receiving the High Resolution Picture Transmission (HRPT) from polar orbiting satellites. The ground station consists of the antenna, localized on the roof of the WETI Faculty Building (Fig. 1) and the indoor part consisting the receiver and acquisition-storage-control computer unit.



Fig.1. Antenna of the 1.5m HRPT/MetOp ground station.

The groundstation is capable of obtaining data from the Advanced Very High Resolution Radiometer (AVHRR) which is a major sensor onboard of NOAA-* and MetOp-A/B satellites.

The geometry of the AVHRR sensor is of the whisk broom type, as presented in Fig. 2.

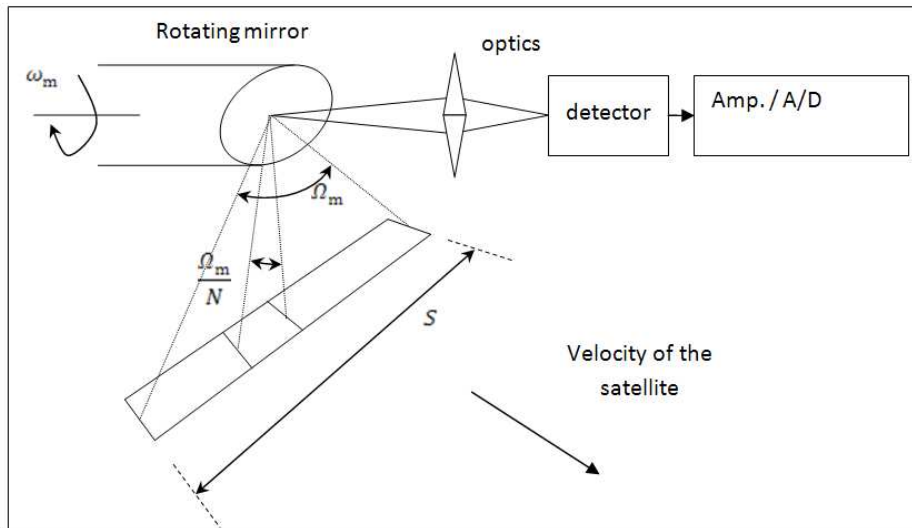


Fig.2. AVHRR sensor geometry.

Due to the localization of the ground station (N54° 22' 15.60", E18° 36' 45.48") and the sensor geometry constraints, the geographical areas addressed with the service will mostly cover Poland, Southern Baltic (including the Gulf of Gdansk) and eventually some adjacent regions. The typical footprint of the registered and received scene is presented in Fig. 3.

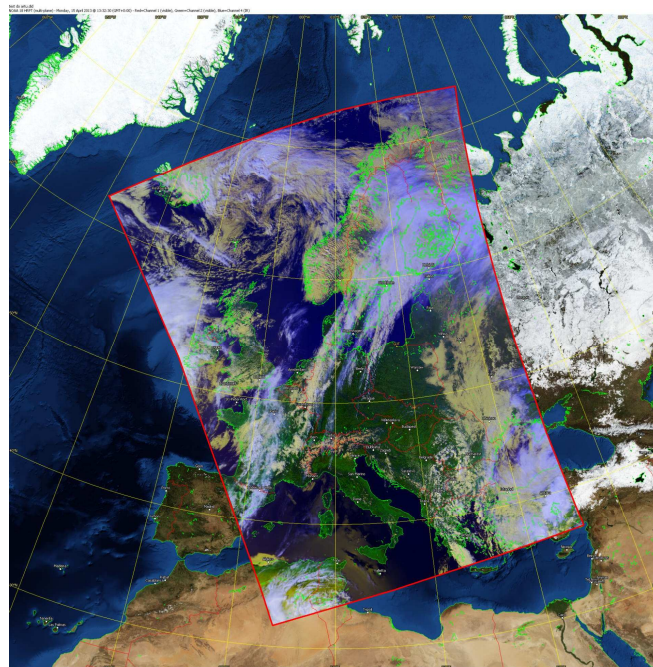


Fig.3. Typical footprint of the AVHRR scene received with the satellite ground station.

The satellite data acquired with use of ground station may be processed by the satellite data adaptation module. Processing capabilities are implemented as separate routines and may be also used with other sources of data. The module consists of a range of services which use

dedicated routines and may be executed directly inside the Web GIS. One of them is the GUT_AVHRR service, which is dedicated for dissemination of AVHRR data. The module provides a complete set of data (raw, calibrated and additional information i.e., solar zenith angle, satellite inclination, nadir to pixel angle) from the AVHRR sensor onboard the meteorological satellites (NOAA-15 – NOAA-19, MetOp-A and MetOp-B). The AVHRR data is processed and provided by the GUT_AVHRR service in the form of GeoTiff or HDF file formats. The files provided by the service may also be automatically registered in the database of the Web GIS system. Since the GUT_AVHRR service is compatible with the European Space Agency's Service Support Environment, its results may be chained in the process flow (e.g., included in a request to an external service - in the form of input data to ESA SSE SOMAFID).

The service provides the system with both unprocessed satellite images (e.g. AVHRR based True Color maps), as well as thematic layers obtained by processing the AVHRR data with dedicated detection routines. The routines which enable satellite-based analysis of marine environment include:

1. AVHRR/chlorophyll algal bloom detection,
2. Sea surface temperature estimation.

The results are accessible in from the Web GIS Server in through the Web Map Service (WMS) protocol. This guarantees their good integration with the Web GIS client.

AIS data integration module

The Automatic Identification System is used for automatic recognition and tracking of marine vessels. It works by electronically exchanging data such as vessel name, position, speed and course with other nearby ships and Vessel Traffic Service (VTS) stations. By requirement of the International Maritime Organization (IMO), AIS is mandatory on all passenger ships as well as other vessels which exceed gross tonnage (GT) of 299 tons. In addition to vessel tracking, AIS may be used to assist the crew and port operators in traffic monitoring and avoidance of collisions. Collecting AIS data requires a dedicated receiver, however several institutions have made it available in semi real-time over the Internet. An example of such a service is www.vesselfinder.com, a website affiliated with the AIS Hub data sharing center. The Web service collects radio signals obtained by AIS receivers from all over the world and makes them available through HTTP queries in the form of XML files.

Because AIS data is provided by an independent Web service, it isn't readily compatible with the Web GIS coordinate system. Because of this, it needs to be pre-processed on the client side before it can be displayed. Thus, the data returned by AJAX requests to the VesselFinder Web service is parsed and transformed through Javascript methods. It is then visualized using simple icons representing ship markers, with adequate size and orientation (rounded to 5 degrees) reflecting ship course. The HTTP queries are map extent and zoom level sensitive in order to conserve bandwidth. The layer is periodically refreshed in an automatic manner in order to properly represent the ever-changing state of ships.

Oil Spill simulation module

The oil spill simulation module uses the oil spill simulation model of Computer Aided Rescue and Oil Combating System (CAROCS), designed and developed by the Maritime Institute in Gdansk (MIG) for the Baltic Sea. From among the processes influencing oil spill dispersion, this particular model considers 1) advection caused by sea currents and wind, 2) wave height and direction, 3) vertical and horizontal diffusion of oil spill droplets and 4) vaporization and dispersion. The model also utilizes the High Resolution Operational Model



for the Baltic Sea (HIROMB) as well as WAM4 wave forecast model as input [11]. The model generates consecutive spill layers with a spatial resolution of 3 NM at one hour intervals.

The Geodatabase

The Geodatabase module is responsible for storing the thematic layers of spatial data created in response to various user queries, like results of oil spill simulations or retrieved satellite images. It is involved in optimized and integrated storage, maintenance and updating of the various kinds of data, e.g. with spatial data layers of satellite observations, background data, and spatial analysis results. Geodatabase implementation is based on relational model extended by spatial data types. It allows to analyse data already on database level. Vector data from various sources can be combined together by many queries and views types using spatial operators, i.e. correlating ship positions with well known marine routes. Raster data is stored in a separate file system. These data is read by GeoServer send via WMS to client.

The Geodatabase Management Module

The main functionality of the Geodatabase Management Module is to enable the user to manage layers stored within the system. A diagram of the module is shown in Fig. 4.

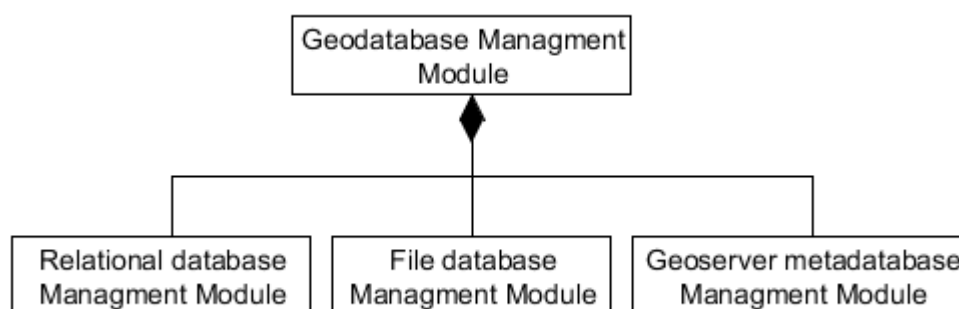


Fig.4. A diagram of the Geodatabase Management Module.

Data generated by the Analysis Modules is mainly stored in vector form, while data produced by the EO Data Adaptation module is stored in raster form. The Management module processes both these types of data, and enables their registration in the geodatabase along with a set of metadata which describe the layers with a unified set of attributes. As a result, both raster and vector data in the geodatabase is processed in the form of datasets accompanied by the following attributes:

- Name
- Title
- Abstract (a full text description)
- Keywords (for advanced queries)
- a default Coordinate Reference System
- a Bounding Box
- Feature Type Details, including a list of attributes for vector data

Due to the applied extensive metadata descriptors, the module enables querying and sorting of the stored data. The data may be searched and sorted against any of the attributes listed above. Finally, the module also allows for automatic layer removal of unnecessary or

outdated data. The listed functionalities of the module may be executed automatically by software, as well as accessed manually from a user-friendly DHTML interface, depending on user authorization level.

Spatial Analysis module

The Spatial Analysis Module performs several processing and analysis functions on spatial data. The sample possible analysis tasks include both basic geoprocessing as well as advanced spatial analysis.

Basic geoprocessing tools can prove to be a useful aid in analysis of marine environment. The example here may be calculating the proximity of well known marine routes to discovered oil spill locations. Another example might be the selection of an area where detected underwater waste intersects fish reservoirs.

Advanced spatial analysis tools operate on both vector and raster data as their input or output. An example may be the creation of a thematic (raster) layer with the values of water temperature (or phytoplankton) defined only for areas of fish reservoirs. The result can be presented in the form of a layer overlaid on the source data. Another example could be the interpolation of vector point data, such as the locations of underwater waste, over the area of an investigated basin.

All of the applied algorithms adhere to the paradigms of Geovisual Analytics, which involves the support of human abilities of vision and cognition with computer-based visual interfaces that provide flexible connections to relevant data and are specifically designed to provide support for analytical reasoning [12].

The Web GIS Server

The Web GIS Server is responsible for providing the authorized Web GIS client users with layers of satellite observations, background data, analysis results and other contents of the Geodatabase. This module is implemented with the use of GeoServer, a dynamically developing Open Source JEE servlet-based GIS server. GeoServer fully supports OGC standards of geographic data exchange such as Web Map Service, Web Coverage Service, Web Feature Service and Web Feature Service Transactional (WFS-T) protocols. It also offers support for a broad range of standard data sources as well as custom data formats which can be defined through its DataStore plugin system, based on the Open Source GeoTools package. An embedded EPSG database allows for real-time data reprojection between hundreds of existing as well as user-defined projections. This allows for easy import of existing data into the GeoServer, as well as integration of layers served by GeoServer with other geographic information [13]. In addition, the presentation of every layer stored in the GeoServer database can be individually customized using Styled Layer Descriptor (SLD) files, which can be dynamically swapped and altered during web queries.

Web Access Portal

The functionality of the Web Access Portal will be twofold. First of all, the portal contains basic information about the project, its outcome and benefits. The main role of the Portal, however, is to provide a secure access to the inner GIS modules, in particular to the Web GIS client. Thus the Portal will allow the users to log in, authenticating them and providing them access to the Web GIS client and other GIS subsystems. The Portal is built in a modular way, which will allow to expand and reconfigure its functionalities as needed.



Web GIS client

The Web GIS client is responsible for presenting the contents of the system Geodatabase in a dynamic manner through an intuitive, user-friendly Web-based interface. The functionalities of the WebGIS client encompass:

1. basic map viewing tools like scrolling, zooming, panning etc.,
2. tools for easy map object information retrieval, including non-spatial attributes like ship name, hull length etc,
3. creation of queries for selection of object subsets using both spatial and non-spatial criteria,
4. execution of the geoprocessing and spatial analysis procedures and definition of their parameters,
5. customisation of map appearance.
6. Presentation of data using open standards (OGC WMS and WFS)

The client is realized with the use of DHTML and Javascript, basing on the Open Source OpenLayers Javascript library for displaying map data in most modern web browsers, with no server-side dependencies. The library implements a constantly developing Javascript Application Programming Interface (API) for building rich web-based geographic applications with many readily available and fully customizable components for easy construction of GIS client solutions which can be embedded into any Web page. As a framework, OpenLayers is intended to separate map tools from map data so that all the tools can operate on all the data sources by means of industry-standard methods, such as the OGC WMS and WFS protocols [14].

Mobile Web GIS client

The mobile client of the Web GIS offers a limited subset of the functionality delivered by the full client. It has been implemented with the use of the mobile version of the OpenLayers library, which allows the client to run on any mobile system equipped with a modern Web browser. Naturally, the ability to run on mobile devices puts some considerable constraints on the available functionalities due to the limited amounts of memory available on those platforms, as well as restrictions stemming from the rules of conserving energy and network usage. Regardless, the mobile client allows remote users to view and categorically browse the data contained in the system geodatabase.

2. RESULTS

The presented system enables seamless integration of data from various marine sources in the context of a single two-dimensional map. The Web GIS client allows the end users to view multilayered visualizations of processed and analysed data in semi-real-time. Figure 5 exemplifies the system's capability of multi-source data integration by consolidating information produced by the CAROCS oil spill model with real-time vessel movement acquired from the Automatic Identification System.



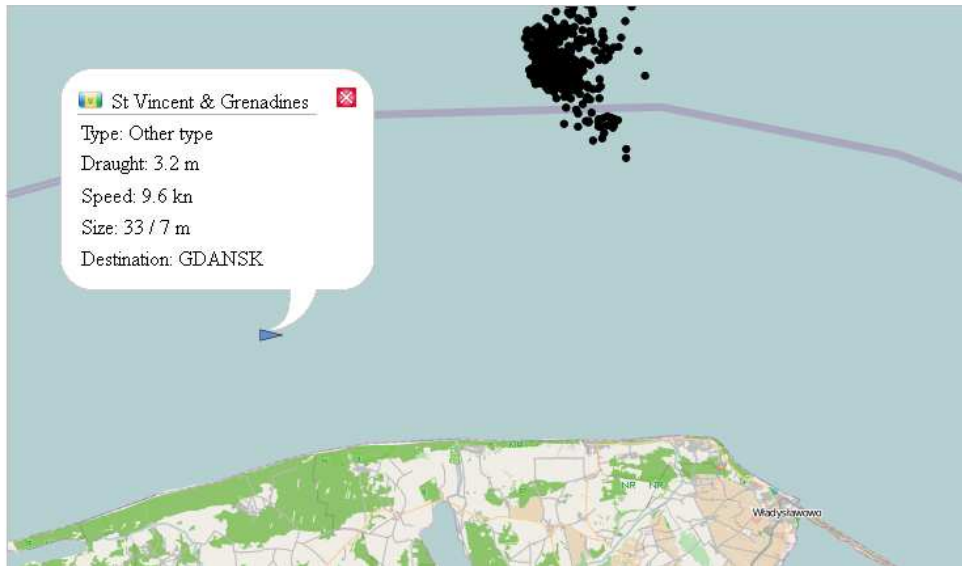


Fig.5. Images from AIS and Oil Spill sensors integrated in geographical context.

The application of Geovisual Analytics to online data processing and presentation allows for a much more thorough investigation of researched characteristics. An example in Figure 6 shows the temperature of the Baltic Sea on a scale from -0.7 to 0.7. As per the paradigms of Geovisual Analytics, the applied colour scale represents the lowest temperatures in blue and the highest ones in red.

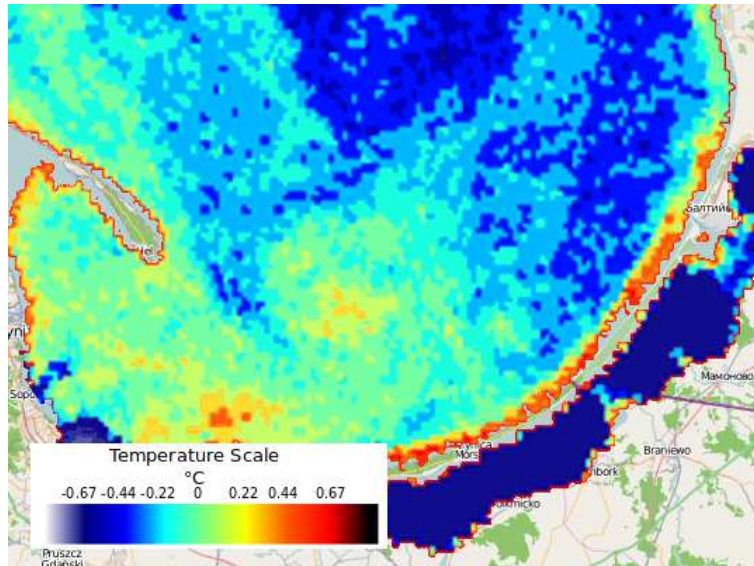


Fig.6. Temperature of the Baltic sea extracted from the AVHRR satellite sensor.

Another example of employing Geovisual Analytics for the purpose of remote sensing is algal bloom detection. The SABI index was calculated on data obtained from NOAA19 in order to identify probable algal clusters on the Baltic Sea and the Gulf of Gdansk. The formula used for computing SABI is as follows: $(B_{NIR} - B_R)/(B_B + B_G)$ [15]. Results of this analysis are shown at Fig. 7.



Fig.7. Geovisual analysis of surface algal bloom detection results.

3. DISCUSSION

The paper presents a system for automatic semi-real-time processing and analysis of marine data in geographical context via a Web based GIS. The system was developed using powerful Open Source technologies to deliver multi-resolution, multi-scale dynamical mapping of marine environment and its various components.

The system uses Server-side data processing and an interactive DHTML client for visualization. The system is directly connected to several real-time sensors, such as a satellite ground station. The collected data is processed with accordance to the paradigms of Geovisual Analytics, which enhances the rate of the users cognitive apprehension of even the more complex data structures.

This, along with features like real-time monitoring of vessel positions via AIS, constitutes a unique platform for numerous research activities related to marine environment sensing and monitoring.

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