Interactive Access and Processing of Multispectral Imagery: The User in the Loop

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Abstract. Accessing and processing of multispectral imagery in an interactive way is essential to a number of operational scenarios. This paper illustrates their use in the context of forest management and planning, by presenting the results of a system that allows operators to access large repositories of geographical data, including multi-spectral imaging, and to process them in a very user friendly way. The project has seen the involvement of personnel from a local planning authority and it has provided the chance to confront with a number of issues related to today's large availability of airborne and satellite data. This is challenging current technologies, creating a potential information overload. The paper will illustrate how the use of interactive 3D technologies to access and process multi-spectral data within a comprehensive framework capable to manage a large variety of different geographical information, can be beneficial to reduce access time to information and to improve the entire decision-making process.

Keywords: environmental planning, satellite imaging, web-based access, 3D GeoVisual analytics.

1 Introduction

Geographic Information (GI) repositories are constantly growing in size and complexity [1]. Data within these repositories is usually generated by Geographical Information Systems (GIS), Computer-Aided Design software (CAD), image processing systems and by a large number of specifically designed software providing real-time information coming from different sensors (e.g. pollution, traffic etc.).

The field of GI is being also characterized by the success enjoyed by consumer-oriented 3D geobrowsers such as Google™ Earth and Microsoft® Bing™ Maps 3D. These have fundamentally contributed to extend the scope of the GI domain, far

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beyond the exclusive domain of a small elite of experts, with the introduction of 3D interactive visualization systems. In fact although 3D geobrowsers have been designed for consumer use, indeed their widespread success has determined their perhaps inadequate use in professional contexts. Nonetheless this trend, in turn, has contributed to the development of 3D visualization capabilities in other software tools specifically engineered for professional and expert use.

Both professional Geographic Information Systems (GIS) as well as general-purpose geobrowsers are heavily dependent on accurate and up-to-date high-resolution airborne and satellite imagery. Geobrowsers heavily rely on Digital Elevation Models (DEM) acquired by satellites since they require accessing DEM at large if not near-global scale. Within these systems satellite data plays undoubtedly a key role both in that it essential to represent the Earth surface as well as to ensure access to complex information, for instance through multi-spectral data over vast coverage.

However the constantly increasing availability of high resolution airborne and satellite data, is causing a critical "information overload". A remarkable example of this is the recent data centre built by Microsoft for its 3D solution Virtual Earth which has been designed to accommodate up to 15 Petabytes (15*1015 bytes) of satellite imaging or the Earthscope project that expects to generate daily outputs of over 10 terabytes. In order to support the operators' decision making process within several scenarios, including land use and planning, environmental monitoring and management to name but a few, it is necessary to develop efficient software technologies capable to provide intelligent access and filtering of available information through automatic or semi-automatic extraction of thematic information.

Such an information overload is yielding two potential criticalities. The first is related to the difficulty to access, manage and distribute through the network data in an efficient manner. Equally importantly, this growth in data available is challenging interoperability, an essential requirement within the domain of Geographical Information. In fact, today's enterprise-wide, network-based, GIS infrastructures heavily relay on standards and protocols which appear increasingly unfit to cope with such a fast expanding data growth.

Additionally, along with this information explosion, operators are facing an increasing difficulty to assess the accuracy of a particular dataset and its suitability for a given task. In fact a number of domain-specific scenarios require frequent update of large operational geographical datasets, often relying on complex enterprise-wide GIS systems, referred to as Spatial Data Infrastructures (SDI), where the traditional process of review and update of Geographical Information (GI), typically based on field survey, can be extremely time consuming and costly, if not impracticable. It has became necessary to develop methods for supporting, through automatic or semi-automatic processes the management of huge, complex and high dimensional datasets.

This paper presents the results of a project dealing with the aforementioned issues, where operators from the Forest Department of the Autonomous Province of Trento in Italy, needed to be able to assess, very efficiently and in a very user-friendly way, three dimensional distribution of the different vegetation species over relatively large forested areas. To do so operators needed a be able to access interactively different bands of multispectral imagery and to render them interactively over a 3D representation of a digital terrain (both as DSM – Digital Surface Model and DTM – Digital Terrain Model) created from satellite or airborne high resolution LIDAR data.

This first assessment was essential to quickly identify specific portions of forest where further onsite in-depth survey needed to be scheduled. The availability of an interactive tool capable of ensuring interactive access and processing to the variety of information available ranging from LIDAR, to multispectral imaging, to standard GIS information, has significantly improved their operational efficiency. Due to the nature of the application, it was required that operators could access a very user-friendly fast responding interface, whose use would require short training time.

2 Outlook

In the case of the project described within this paper, the Forest and Fauna Unit of the Province of Trento, Italy, together with the local university had started a project to assess the use of remote sensing data in the context of forest management. A first feasibility study had highlighted the potential, in terms of assessment of dendrologic features, of using LIDAR and hyper spectral data.

The process includes the identification of a number of macro-tasks such as analysis of the main requirements and pre-processing of data, classification and identification of different species, assessment of forest density, assessment of forest structure, assessment of biomass height within the forest, assessment of scalability of the project to the entire Provincial territory.

For this reason a first set of LIDAR and hyper spectral data were acquired within three sample areas representatives of the most important forest pattern in the area ranging from coppice to alpine spruce forests. These sample areas were chose in Val di Sella (Sella valley) in the area of Padergnone and within the Paneveggio Forest for a total surface of about 1500 hectares.

As far as the LIDAR data were concerned, a point cloud was retrieved as a tuple {x, y, z, I} (I being the intensity of laser) and with a density not lower than 5 points per square meter. As far as hyper spectral data were concerned these included 64 bands within the 400 and 100 nm range. All the information have undergone a geo-referencing and radiometric correction process, both on single passes and on the entire mosaic, at the spatial resolution of 1 meter.

Concurrently, within the same areas, onsite surveys were conducted with the aim of assessing precision of remote sensing procedures according to the different forest layouts. The onsite surveys were planned to collect two specific datasets, respectively to create an assessment model and for its validation.

More precisely 165 sample areas were identified, all localized within the different forest types, ranging from beechwood, norway spruce to holm oak forests. Through the use of LIDAR and hyper spectral data it was possible to assess, with high precision, the following parameters: plant height, forest species, horizontal and vertical structure, density and biomass.

From this experience it become clear that forest classification, also within most complex forest configurations such as mixed forest, yielded good results. For this reason it was chosen to develop a technology that could be used by forest expert during the editing of forest plans. For this reason it was decided to create a 3D tool that could enable interactive manipulation of:

- LIDAR data, with the possibility to create real-time cross section to detect forest structures (e.g. single plane, multiple plane, irregular etc.).
- Hyper spectral data with the possibility to visualize, in false color (RGB), three different bands among the 64 available, in order to highlight the different species on the basis of the hyper spectral characteristic triad of the species of interest.

3 State of the Art

In the past, the domain of 3D scientific visualization has explored several techniques to ensure access to complex data patterns in an interactive way through the use of 3D visualization that could support the understanding of an evolving phenomenon.

3D visualization can be extremely effective to ensure reasoning over such a vast range of n-dimensional information. With the correct design in terms of interface layout and information items, large amount of data can be quickly and easily comprehended by a human observer through the use of 3D graphics [2]. In fact it is well acknowledged that visualization provides an additional cognitive support that improves context awareness [3]. When information is presented visually, efficient innate human capabilities can be used to perceive and process data. Information visualization techniques amplify cognition by increasing human mental resources, reducing search times, improving recognition of patterns, increasing inference making, and increasing monitoring scope [3] [4] all essential elements of environmental management process [5] [6] [7] [8].

However visualization alone often does not suffice to support analysis, to provide model and hypothesis-making. In recent years scientists have developed a discipline that combines the benefits of data mining and information visualization within a geospatial context, which is referred to as GeoVisual Analytics (GVA) [9]. GVA is capable to provide integrated visualization, filtering and reasoning solutions to better support operators looking for design decision support [4]. Through GVA tools, users can typical acquire visual cues that can help them formulate a set of viable models.

An ideal environment for GVA in fact should provide seamless integration of computational and visual techniques. For instance, the visual overview may be based on some preliminary data transformations appropriate to the data and task. Interactive focusing, selecting, and filtering could be used to isolate data associated with a hypothesis, which could then be passed to an analysis engine with informed parameter settings. Results could be superimposed on the original information to show the differences between the raw data and the computed model, with errors highlighted in a visual manner. This process could be iterated if the resulting model did not match the data with sufficient accuracy, or the analyst could refocus on a different subspace of information [10]. For this reason GVA is essential in contexts such as understanding of complex spatial relationships among information spaces and different datasets, for instance to define the most appropriate evacuation routes or to plot an emergency plan [11] [12] [13].

In the specific context of forest cover management and analysis, several authors [14] agree on the fact that concurrent access to satellite and GIS data is essential to create maps and to assess indicators such as cover changes, forest recolonization dynamics, forest structures evolution to name but a few.

Furthermore providing web-based access to forest-related data is an essential priority as acknowledged by experts operating in the field of forest management. Works such as [15] and [16] clearly indicate how the possibility to concurrently access different information including satellite imaging, cartography and alphanumerical data through web-based repositories is key to their operational activities.

Last but not least within the wider European context, the European Commission has clearly acknowledge the importance of providing standardized access geospatial information related to the environment. In fact The EC is promoting the creation of a Infrastructure for Spatial Information in Europe (INSPIRE) (http://inspire.jrc.it/home.html) to improve utilization of geographic information of environmental interest on a European level. The INSPIRE directive [17] together with GMES (Global Monitoring for Environment and Security) [18] programme based on data received from Earth Observation satellites whose results will converge into GEOSS - Global Earth Observation System of Systems [19] by Group on Earth Observations (GEO), SEIS - Shared Environmental Information System [21] [22] all clearly testify the great attention paid by the international community to this issue.

4 The System Developed

The application developed has been engineered to provide strong support to operators looking for decision support in the context of forest planning, monitoring and management. Typically operators have to refer to an extremely wide range of heterogeneous multi-source, multi-dimensional, time-varying information sources, including GIS maps, morphology of the terrain and forest canopy through LIDAR data (Digital Terrain Model - DTM or Digital Surface Model – DSM). The very nature of the processes, which are intrinsically cooperative -as diverse operators may be involved- underlines the importance of developing user-friendly universal interfaces. Navigation and data access must be complemented with functions that enable operators to analyze interrelations between spatial information, data patterns and environmental effects through interactive processing of a range of satellite and airborne data.

Within this scenario the complexity of most standard Geographical Information Systems (GIS) and 3D GIS [22] [23] [24] in fact is far too complex for decision makers. For this reason a Geo-Visual Analytical approach was preferred. The goal was to deliver a web-based 3D solution capable to provide interoperable access to geographical information and satellite imaging that was able to provide strong links between data transformation and visualization to better support analysis. The tool should also provide the capability to define customized processing functionalities, for instance to cross-relate data from multi-spectral datasets, in a very user friendly manner. For this reason it was imperative to provide alternative visual and user friendly solutions to traditional programming of simulation procedures, which notably require extensive training and time.

The system developed has been engineered as an articulated enterprise level Service-Oriented Architecture designed to provide all the functionalities required to access, manage and process large sets of multi-dimensional GIS and satellite data through OGC – OpenGIS Consortium compliant web services. The entire infrastructure has been designed to benefit from the web services abstract model to provide access to complex operational workflows and simulations which are essential to complex daily analysis, yet retaining high usability and fast response.

At client level, operators can benefit of a very user-friendly 3D interface, which allows them for instance to navigate within the 3D territory, to visualize and compose images from different bands of multispectral datasets and perform complex processing functionalities in a very visual way.

4.1 Client Side

The client application developed is capable to render a 3D scene of a large scale environment containing a multitude of different data sets ranging from satellite imaging, to multi-spectral data, to vector-based geographical information. Altimetry information on the terrain are streamed, via web service, from a server to the client as raw height maps at variable level of resolutions, built from SRTM30Plus (Shuttle Radar Topography Mission) dataset generated during the Space Shuttle Endeavour mission in 2000. This publicly available dataset ensures near global scale coverage at convenient resolutions ranging from 30 to 90 meters. The use of relatively low precision data allows fast rendering with standard computing hardware, while retaining the overall morphology of the terrain. Moreover this allows saving bandwidth to the benefit of high resolution airborne of satellite imaging.

As illustrated in Figure 1, operators can conveniently access cartographies, sensor data, multi-band datasets and overly them within the same scene to perform analyses and studies. Most relevantly, as it will be illustrated in a later section, the client can also be used to easily configure simulations over a variety of data. This is done in a visual way following a visual programming approach where operators can drag and drop processing unit, represented as icons, and connect them to create a meaningful processing sequence. The computations requested for the processing are then performed at server level, in a completely transparent manner and results of simulation are sent back to the client in an interoperable format. This ensures high scalability and allows the creation of very lightweight client applications.

Additional information on interoperable access to processing functionalities is beyond the scope of this paper. Full details on the technology developed can be read from previous works of the authors [25] [26] [1].

The application has been developed on Java extending the World Wind APIs [27] with regard to 3D geo-visualization and it makes use of Java Web Start [28] technology to assist the deployment of client applications.

Following the architecture described in Figure 2, the client application has been engineered with the goal of delivering a web-based 3D access to data exposed on the network via a number of OpenGIS Consortium (OGC) standards. This in fact was considered essential to ensure access to the variety of geographical information and satellite imagery available within enterprise-level infrastructures. Specifically interoperability is enforced through support of a number of OGC standards including Web Map Service (WMS) for raster cartography and airborne or satellite imaging [29],

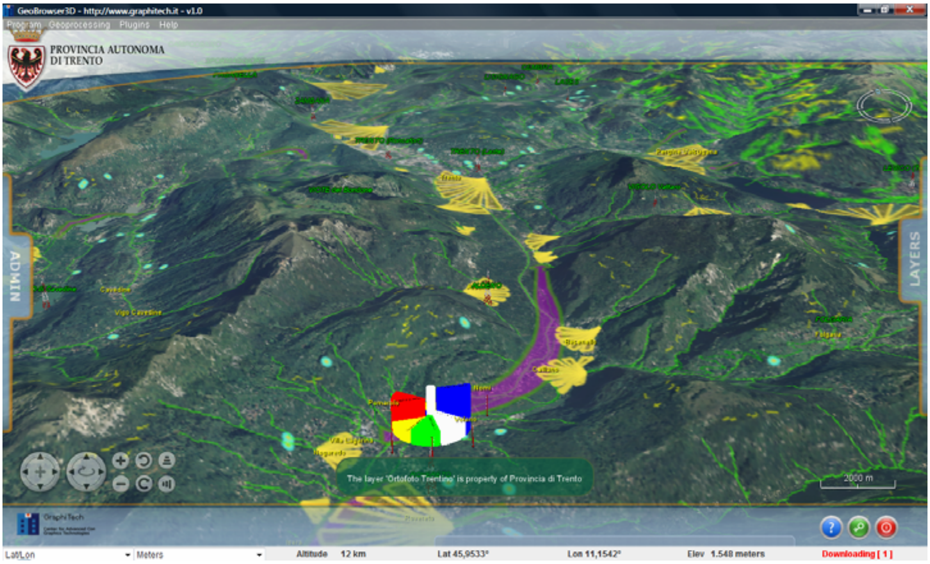

Fig. 1. The image of the system where the user concurrently accesses satellite imaging, real-time sensor information, GIS vector layer within a single environment

Web Feature Service (WFS) [30] for vector based information, Web Coverage Service (WCS) [31] for time-varying data related to coverages of portions of territory and Web Processing Service (WPS) [32] essential to expose processing functionalities via the web through a standard interoperable format. All these services are exposed by a federation of server geographically distributed.

As illustrated in Figure 2 this architecture enables the client software to make use of data and services coming from multiple sources in multiple formats and process them, if necessary, by using distributed processing [1] providing strong support to operators looking for decision support through an ideal environment for analysis that integrates computational and visual techniques.

Furthermore processing of complex and large dataset, typical of Earth Observation data, takes place between components at server level where computing performance is highest and bandwidth can be very high. We shall see how this feature, in the scenario analyzed, has brought to considerable advantages in terms of computing and networking resources optimization.

As a matter of fact this approach requires dealing with scalability at the server side as these becomes responsible for the processing of work load from all the client applications [1]. Furthermore this architecture can easily be extended to benefit from the potential of cloud computing for any processing activity. Following this approach, the operator can pay for temporarily computing resources, if they are only necessary for some peek period. These resources are then transparently accessed from clients applications, optimizing investments and resource allocation.

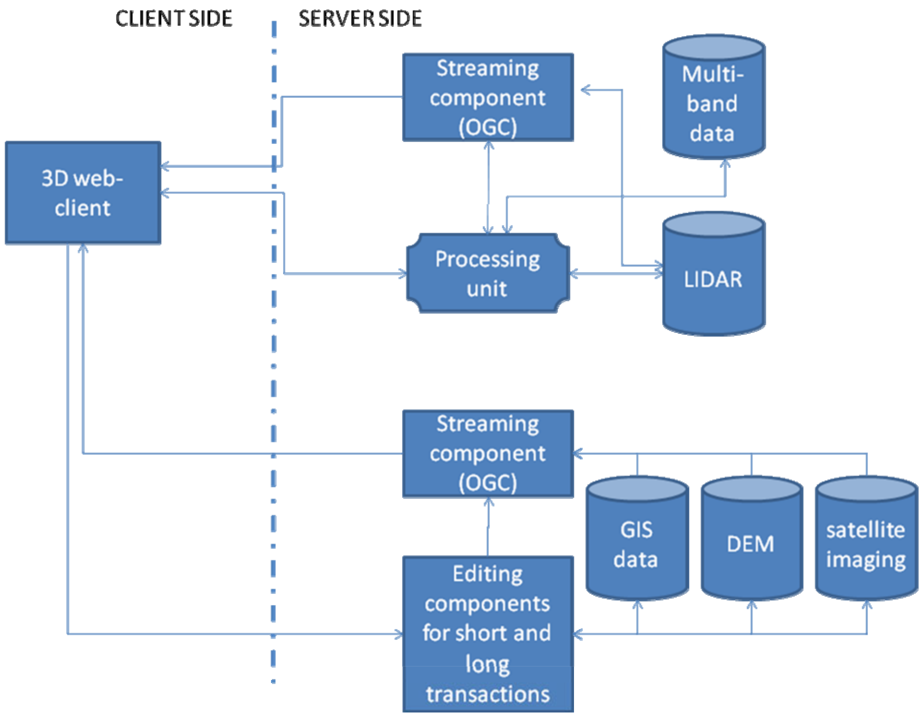

Fig. 2. The overview of the architecture

4.2 Processing of Multi-spectral Data

As mentioned in the previous section the approach followed allows to distribute the processing capabilities over a federation of servers each exposing its processing capabilities through a standardized communication interface. With such a distributed infrastructure it becomes possible to develop lightweight client applications which are only required to interact with processing parameters and to show the final results, once these are received from the network. The client is also responsible for ensuring orchestration of services when services (processes) chains are composed.

An example will help us illustrate the benefits of this approach when the user has to perform some processing over a very high-resolution dataset. The datasets used for the test were 32 multi-band imagery each containing 63 or 126 bands (from approximately 400 to 1000 Mhz) each represented by raw 256 color grayscale image. If the user wants to see the content of each band of the multispectral dataset this is sent from the server to the clients, as compressed image (PNG) through the WMS protocol, where each band is visualized as a gray image. The operator can use several tools available at the client side to visualize and process this data. Additionally operators needed, within the same environment, to visualise and overlay the multi-band imagery to LIDAR datasets (both DTM and DSM) with a resolution of 1x1 meter. The areas covered by the different datasets, i.e. muti-spectral imaging and LIDAR, did not coincide although they overlapped for most of the areas covered.

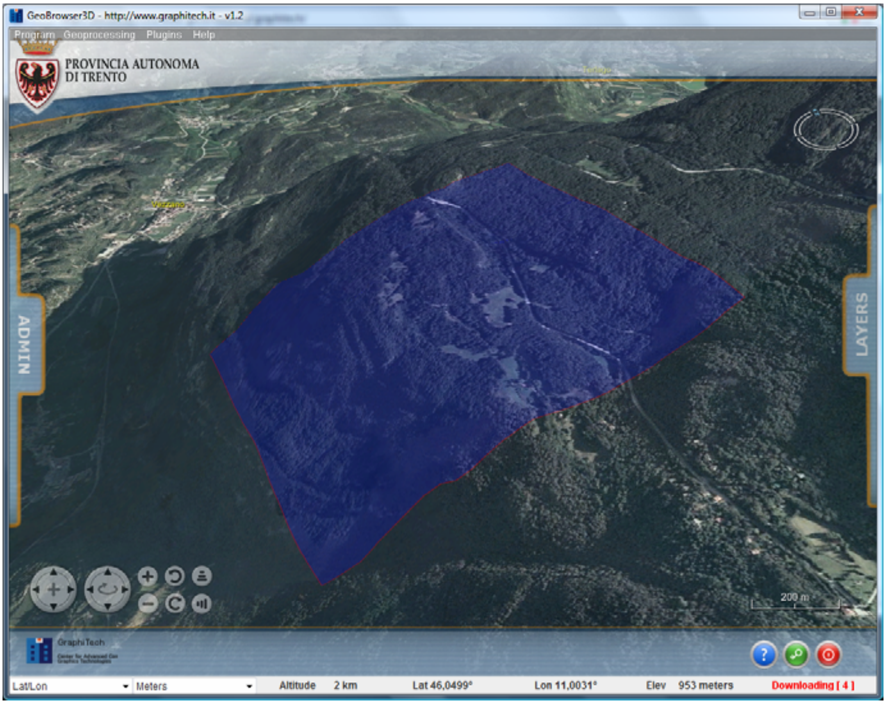

Fig. 3. The area identifying high-resolution multi-spectral data is available

The client software shows automatically all the areas containing multispectral or LIDAR data available from the servers, which are identified by a blue bounding box as shown in Figure 3. These bounding boxes are retrieved automatically from the server at run-time, enabling in this way the operator to be aware of any high-resolution data available on one or more servers prior to visualising. Due this approach the client initially only needs to render bounding boxes and it requests the full dataset only when required.

Once the operator decides to see the multi-spectral data he/she can seamlessly integrate his other airborne or satellite imagery, combine them with several maps, all retrieved through standard Web Map Services (WMS) within the same virtual environment. When a multi-spectral dataset is received for the first time, it is cached locally, at the client side, and re-used, if static, on following requests, thus further improving performances and reducing bandwidth usage. The transparency of each of these datasets, dealt with by the client as a different information layer, can also be adjusted in real time for better analysis and visualization. Furthermore the different datasets can be superimposed at wish by selecting the proper stacking order. This for instance was considered an essential requirement for the operators to be able to provide better support to decisions.

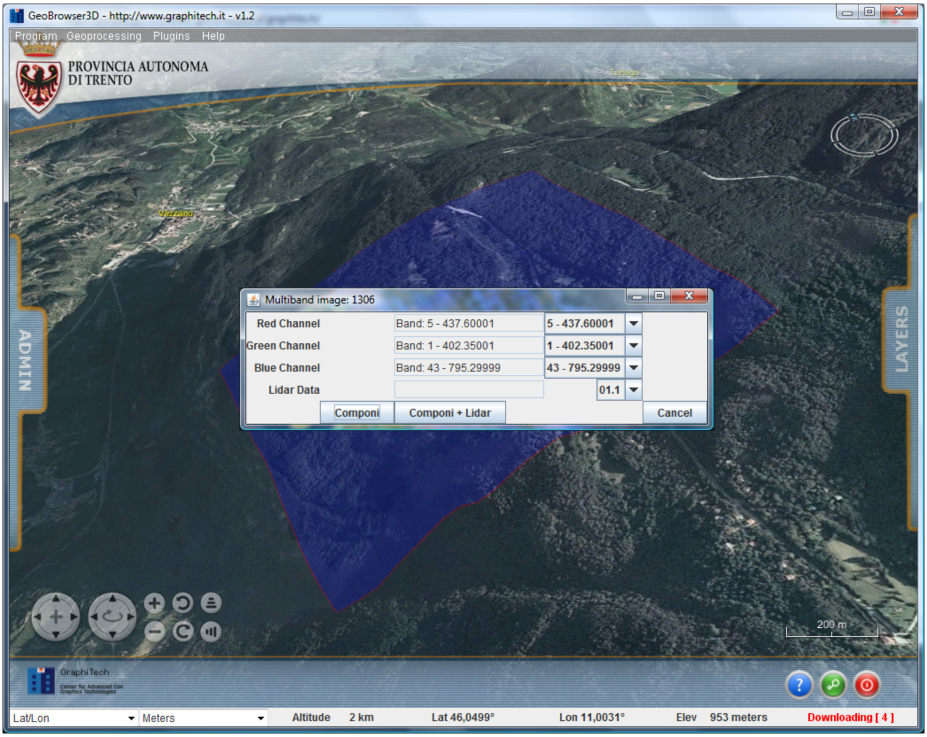

Fig. 4. Selection of bands available for a given dataset

One important aspect during operational activities is the concurrent visualization of different bands, to be used for interpretation. Photo-interpretation of different combinations of bands allows the operators to determine regions of interest and important features in the forest identifying areas which require further analysis or on site survey.

To visualize multispectral images, a Red-Green-Blue (RGB) composite image is usually generated from the data through a number of statistical methods. As a data compression algorithm, this approach provides a n:1 image compression ratio, while preserving edge feature information. For remote sensing community, this application provides a visualization tool for realizing the full edge information content in hyperspectral images, such as those obtained through satellite imaging. Such high-dimensional photometric data is not easily tractable by traditional geobrowsers [33].

When the user wants to compose a RGB image from three bands of a given multispectral dataset then he/she only needs to click on the corresponding bounding box. As shown in Figure 4, a new windows will appear where he/she can select the desired bands to compose the image. When the operator confirms the operation, the request is sent to the server for processing and the resulting composed RGB image is returned through the WMS service and located at the proper location within the virtual scene as shown in Figure 5. The process is very fast, since only the final composed image is sent over the network and since the merging process is performed by a dedicated server. A further advantage is that if a new, more efficient version of the service is

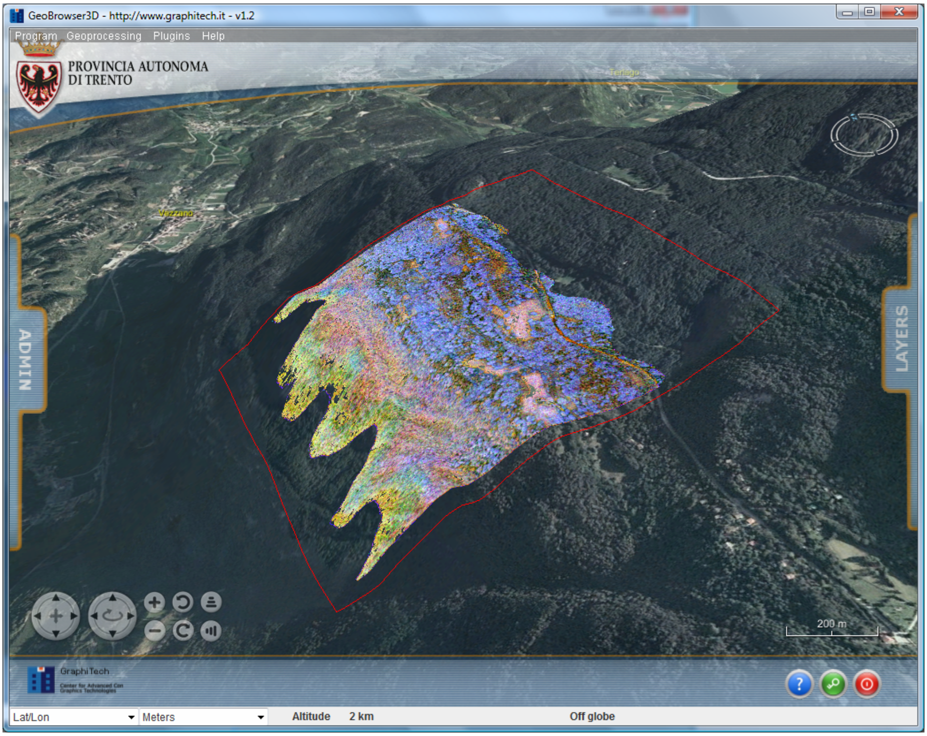

Fig. 5. The final composed RGB image with the selected bands

available, all the user can immediately benefit from it in a completely automatic and transparent manner.

As mentioned previously, in order to maximise rendering performance at the client level and to reduce network traffic, information on the altimetry of the terrain is sent to the client by default at low resolution based on the SRTM30Plus (Shuttle Radar Topology Mission) dataset. However this type of information, although suitable for general-purpose large-scale navigation falls short when detailed analysis of a specific area are needed. In this case, when the standard Digital Elevation Model (DEM) resolution provided by the client application does not suffice, the operator can also use a high resolution sub-metric LIDAR dataset. This high-resolution datasets can be acquired through airborne LIDAR (Laser Imaging Detection and Ranging) technology, can easily scale up in order of Gigabytes just for some thousands of km2.

Sending this information by default would be unsustainable for the client (it would require extremely performing graphical hardware) and for the network, instead keeping this information at server side thus optimizing the overall system's performances.

When the operator needs to perform a more detailed analysis he can opt to combine the LIDAR dataset with the multispectral information available in order to have more accurate results. If the operator confirms this option, the LIDAR data (DSM or DTM) is then used to create a very high-resolution scene covering a limited area, as selected by the user, comprising the processed multi-band data superimposed to the high resolution

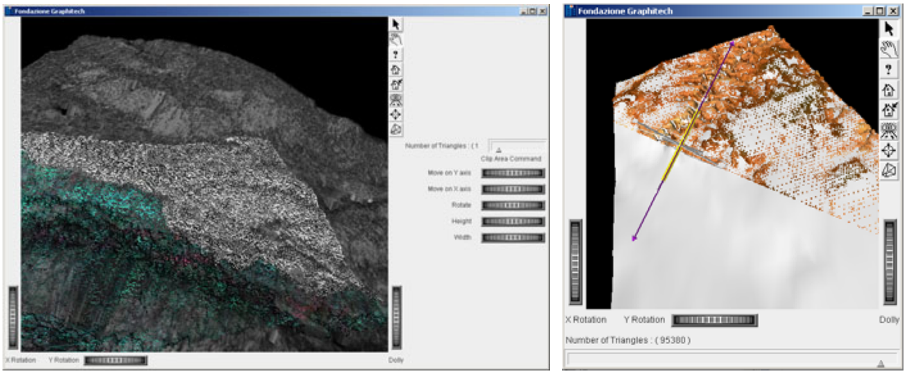

Fig. 6. The high resolution scene built combining LIDAR data with multi-spectral information

terrain. This information is prepared by the server, compressed and sent to the client that renders it on a new window together with a set of tools necessary to perform real-time cross sections and other analysis necessary to the operator as visible in Fig. 6.

4.3 Additional Processing Capabilities

Additionally to the processing illustrated in the previous section the operator can potentially perform any other processing task from his/her client if this is made available on the network through the interoperable WPS standard. The client in fact can be used by the operator to combine different elementary processing functionalities to create complex simulations in a very user friendly way. The operator, through their 3D client, can access the different processing functionalities made available through the network by a federation of processing services.

As illustrated in Figure 7, at the client side each processing unit is represented by a black box that receives data and provides an output as a result of its computing. These components are accessible within a menu of the graphical user interface. Each black box provides access, in an interoperable way, to processing functionalities through web services as presented in previous works of the authors [34] using the Web Processing Service(WPS) protocol.

Such black boxes can dragged and dropped within the 3D scene and the operator can create complex graphs representing articulated simulation routines by composing graphs whose nodes represent an elementary processing unit.

For instance, in order to perform further and more complex multispectral data processing, the operator could use the WPS interface to retrieve specific multispectral bands, pass them as input to another web process, in order to perform some image analysis and then retrieve the final result for presentation at client level. It should be noted that the operator can create an arbitrarily complex process chain without the need to download them to the client software since the code is being run at the server level.

Through this approach client applications not only avoid heavy computational workloads, but the entire system save network bandwidth, since all necessary data for processing is transferred directly between servers where connection can be assumed to be much higher.

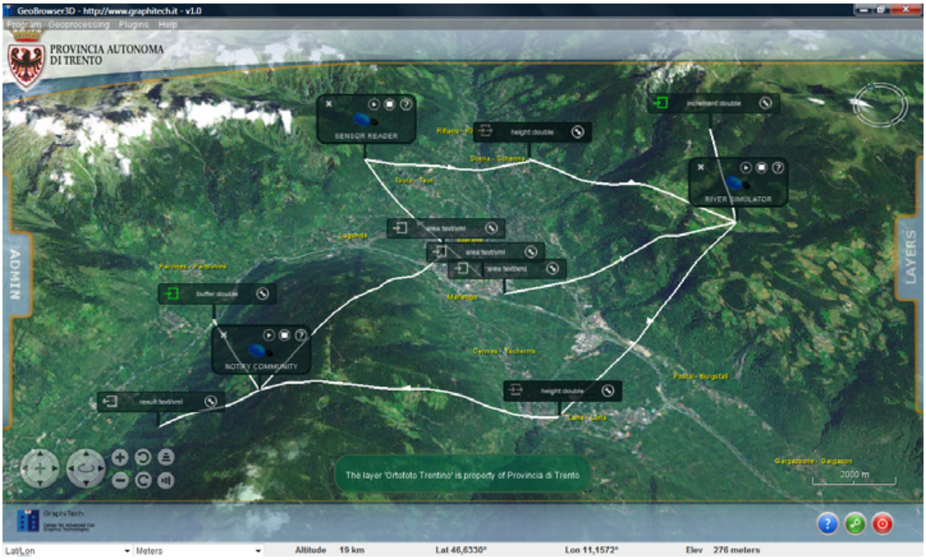

Fig. 7. An image showing a chain of process being created within the 3D scene

5 Conclusions

This paper presents the result of a system developed around the specific requirement of a user who needs to access large airborne and satellite data within an environment capable to render them together with other GIS data of relevance. Additionally the paper presents how the system developed has answer to the need of providing analysis feature, by allowing operators to perform specific processing tasks required for their operational activities.

The entire system has been engineered to benefit from a distributed Service Oriented Architecture where functionalities, including streaming of data, editing of dataset as well as processing features, are all available through interoperable open standards from the OGC – OpenGIS Consortium. This approach brings a considerable advantage in that it allows using services from a number of other applications complying with those standards. Additionally, as discussed throughout the paper, this has allowed a number of optimisations especially during the access and processing of large dataset since transactions requiring very high bandwidth can be reduced considerably.

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