WEB-BASED SPATIAL DATA INFRASTRUCTURE: A SOLUTION FOR THE SUSTAINABLE MANAGEMENT OF THEMATIC INFORMATION SUPPORTED BY AERIAL ORTHOPHOTOGRAPHY

INFRAESTRUCTURA WEB DE DATOS ESPACIALES: UNA SOLUCIÓN PARA LA GESTIÓN SOSTENIBLE DE INFORMACIÓN TEMÁTICA APOYADA EN ORTOFOTOGRAFÍA AÉREA

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ABSTRACT: Under the framework of the Spanish National Plan for Aerial Orthophotography in Castilla-La Mancha, a web-based spatial data infrastructure has been developed that allows both the sustainable management of spatial and thematic information and efficient quality control of orthophoto production. The dissemination of thematic cartographic information by means of false-color infrared images and their physical parameters (reflectance and radiance) could allow its use in applications such as the extraction of biophysical parameters, forest coverage evolution and vegetative analysis of species. For wide accessibility, a geoportal that offers all the information related to the project and based on spatial data infrastructure technology has been created (http://ide.jccm.es/pnoa) that incorporates web map services.

KEYWORDS: Photogrammetric flight; False-color infrared images; Thematic information; Geographical Information System; Quality Control, Web Map Service

RESUMEN: En el marco de ejecución del Plan Nacional Español de Ortofotografía Aérea de Castilla-La Mancha se ha desarrollado una infraestructura web de datos espaciales que permite la gestión sostenible de información espacial y temática junto con el cumplimiento del control de calidad de producción de ortofoto de una forma eficiente. En concreto, se ha llevado a cabo una difusión de información cartográfica temática por medio de imágenes infrarrojas y sus parámetros físicos (reflectancia y radiancia), los cuales permiten su explotación en aplicaciones relacionadas con la extracción de parámetros físicos, evolución de la cubierta forestal y análisis agronómico de especies vegetales. Dado que se ha perseguido en todo momento la mayor transparencia posible, se ha creado un geoportal que ofrece toda la información de interés relativa al proyecto basándose en tecnologías de infraestructura de datos espaciales (http://ide.jccm.es/pnoa), incorporando servicios web de mapas.

PALABRAS CLAVE: Vuelo fotogramétrico; Imágenes infrarrojo falso color; Información temática; Sistemas de Información Geográfica; Control de Calidad, Servicios Web de Mapas.

1. INTRODUCTION

The distribution of geoinformation on the web has become increasingly important in an information society, particularly for cartographic production, local planning and public/private participation [1-4]. To disseminate geoinformation through Spatial Data Infrastructure (SDI) and to support the well-known concept of "collect data once, use it many times" it is important to generate information automatically. To this end, web-based SDI, which can be defined as a software component that provides geospatial applications functionality through a web-accessible interface in a programming language- and platform-independent manner [5], constitutes a possible and efficient solution to derive spatial and thematic information. Major initiatives in Geographical Information System (GIS) interoperability are solving new problems by defining sets of standards and by specifying development interfaces [6]. With the aim of providing geoinformation automatically, two important types of geoprocesses should be considered: generalization [7] and schema transformation [8,9]. While the schema transformation processes transform the thematic characteristics of geodata, the generalization processes transform the spatial properties. In this sense, web-based SDI has made it possible to combine both concepts into a web-based process, reducing the cost of data maintenance and capture [10]. A distributed geospatial data storage and processing framework for large-scale web application is fundamental [11,12]. Today's geoportals are focusing on interoperability through the implementation of standards for discovery and the use of geographic data and services. Some interesting implementations that are looking for the interoperation of multi-source environments include the following: remote sensing [13], topography [14], thematic cartography [15], cropland [16], urban and environmental management [17] and emission inventory [18]. Therefore, based on actual successful experiences that have led to the development of community-based portals, possible strategies for the development of the next generation of geoportals are shown [19].

Under this framework, the Spanish National Plan for Aerial Orthophotography in Castilla-La Mancha (PNOA) is one of the most important projects included in the General Spanish National Plan for Territory Observation [20]. This plan is divided in two different phases: (i) capturing and processing the necessary images from aircraft and satellite and (ii) data extraction and dissemination. PNOA is a project co-financed by the Central Government and the Autonomous Regions. In the region of Castilla-La Mancha the agents that take part through agreements of collaboration between civil services, are the following: the Board of Communities of Castilla-La Mancha (Statistical Institute of Castilla-La Mancha) responsible for management at regional level, mainly administrative tasks; the National Geographic project manager at the national level; and the Regional Development Institute at the University of Castilla-La Mancha, which carries out technical management and regional quality control. The company that carries out the photogrammetric project is Tragsatec via commissioned management with the regional administration, so the National Geographical Institute (IGN) staff will be in charge of developing the national-autonomic control. To date, only one aerial photogrammetric flight covering the entire region has been performed. The flight utilized the Digital Mapping Camera (DMC) and was carried out by the Cartographic Institute of Cataluña.

1.1. Goals

First, this project analyzes the importance of exploiting thematic (radiometric) information using false-color infrared images. One of the main challenges of photogrammetry is the automatic extraction of physical measurements by means of reflectance and radiance images. In this way, and similarly to remote sensing images, several approaches and analyses such as the extraction of biophysical parameters, forest coverage evolution and vegetative analysis of species, can be extrapolated. For this purpose, an exhaustive analysis is made of the physical elements present in the area of study in the acquisition phase, of which atmosphere, solar illumination, observation geometry and terrain information are mandatory.

Second is monitoring the status of the project. It is essential to know the actual project status together with its evolution. Questions such as what area of the territory has been expanded , how has the vegetal or forest surface evolved, or how many sheets of the digital elevation model or orthophoto have been made are essential. In this line of work, time is a vital factor because the information varies very quickly. Thus, to have valid monitoring, the information must be constantly updated rapidly and should indicate the date of update. Project monitoring involves reporting the rates of production of the company and the dynamics of quality control. In particular, these projects are made up of several steps of production and quality control which are performed in a sequential fashion and require a considerable workload. That is, the next step cannot be performed until the corresponding quality control step has been validated. For instance, the digital terrain model cannot be generated until the aerotriangulation has not been validated. Therefore, a delay in the quality control step directly affects the production step and vice versa. Because the project is in constant motion, an essential condition of the designed system is to allow rapid updating of information with minimal effort with an easy way to incorporate new content.

Third is the development and implementation of a data model that allows the management of the project in an optimal way and which is scalable according to the needs of the project. To this end, the processes presented are developed using the Open Geospatial Consortium (OGC) Web Processing Service (WPS), [21], which is OGC's interface specifications for Geoprocessing Services.

Last but not least, is the publishing of the results: from the main derived metric and thematic cartographic products to those reports related to the quality control protocols undertaken by the regional technical team. Special emphasis is placed on exploiting the four multispectral bands provided by the DMC digital camera, to obtain thematic information that can be contrasted based on its spatial and temporal resolution. To this end, a radiometric calibration of the camera [22] is performed with the aim of passing from digital levels to real physical magnitudes.

This paper presents a solution for the sustainable thematic management of thematic information and quality control of orthophoto production using a web-based SDI. After this introduction, Section 2 outlines the SDI architecture developed together with its conceptual model; Section 3 describes the project monitoring in each of the phases of production; Section 4 presents the quality control performed to meet the technical specifications of the project; and Section 5 describes the exploitation of thematic information based on reflectance and radiance images. A final section is devoted to the concluding remarks and future perspectives.

2. SPATIAL DATA INFRASTRUCTURE ARCHITECTURE

2.1. System components

The system is based on the conventional model of three layers. The primary level is the data that can be arranged in different formats. At the intermediate level are the application servers and interfaces that allow the third level, comprising the final user, to access the data in a controlled manner.

The following scheme (Fig. 1) briefly outlines the set of components that comprise the system architecture.

In the designed model, the basis is a database with a spatial component that integrates purely geographical and alphanumeric information that remains interrelated at all times. Basic information comes mainly from the following sources:

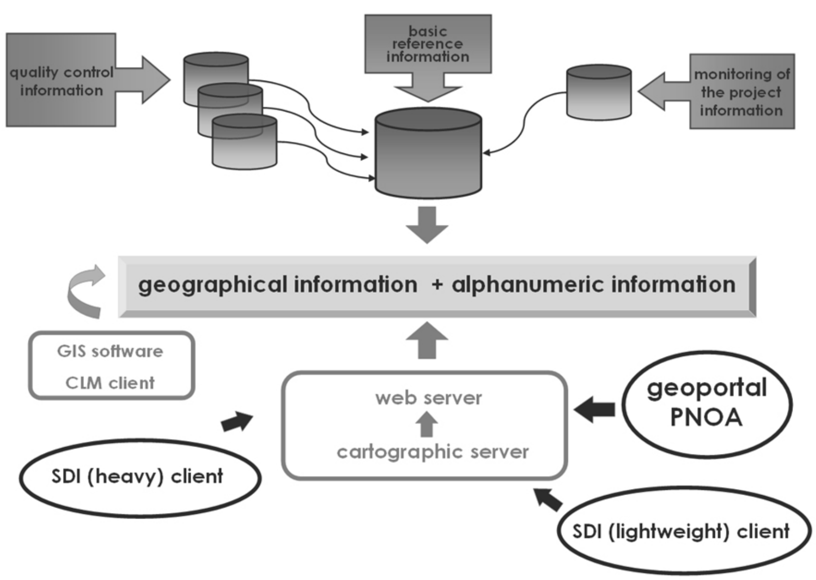

Figure 1. The implemented architecture: system components.

- Information on the results of quality control, which together constitute the largest volume of data.
- Information about the monitoring of the project, whose main characteristic is its constant evolution and constant change, requiring immediate updating of data.
- Basic reference information, whose presence is essential for the management of the geographic information, such as mapping grids and administrative boundaries.

Another essential component is a web server application that enables communication through *http protocol*. In this case, the Apache server (http://www.apache.org/) is used. A mapping server called *Mapserver* is installed on this application to manage and visualize geographic information. These two elements are essential, as they allow access to the information base through various types of requests.

Finally, it is essential to discuss the role of the user as a part of the system component. Depending on the method of accessing the published information, different types of customers can be established:

- The geoportal PNOA, designed for this purpose, is the client that is always connected and constantly evolving.
- Any SDI (lightweight) client, who through other viewers can connect via Web Map Service (WMS) to implement services in a manner analogous to the PNOA geoportal.
- Any SDI (heavy) client that can access data via WMS through local applications.
- A registered Castilla-La Mancha customer who has permission to enter directly into the PNOA database.

2.2. Conceptual model

Among the most important conditions for the implemented infrastructure is that the conceptual model must be agile with information management, updating and adding new elements [23,24].

The region of Castilla-La Mancha is divided into blocks of geographic information (**Block_GI**) that will be, in general, the common unit of work for all phases of this project. To this end, the following structure is defined:

- Block_PF_Plan: Block of the photogrammetric flight in the planning phase, which is composed of an aggregation of images (Image_PF_Planned).
- Block_PF_Execution: Block of the photogrammetric flight at the stage of execution that is constituted by an aggregation of images (Image_PF_Executed).
- Block_CCP: Block of processing of control and check points.
- Block_AT: Block of aerotriangulation calculation.
- Block _DEM: Block of digital elevation models.
- Block_ORT: Block of orthophotos

Block _GI is formed by an aggregation of Geographic Information Units in the form of a map sheet (Sheet _GI), which may belong to the series 1:50.000, 1:25.000 and 1:10.000.

Each unit of geographic information is associated with, in addition to the spatial information, a temporal component which is included in the Sheet_GI, that allows us to know the current state. In this project, the following states of the model are of vital importance:

- State _Production: Reflects the current state of the company executing the project.
- State _CC: Reflects the current state within the process of regional quality control.
- State _Diffusion: Reflects the current state of the process of distribution.

3. PROJECT MONITORING

Due to the dynamics of the project, this type of information varies almost daily. The geoportal provides an overview of the project, which reflects both the production work performed by the contractor and the changes in the quality control process. An established categorization divides the project into the following phases of production:

- Photogrammetric flight
- Control and check points
- Aerial Triangulation
- Digital Elevation Model
- Orthophoto

In each one of these phases, the state of each map sheet is shown. The states that have been defined for the geoportal must be simple and not show ambiguities, so the following states have been established:

- In production: Located in the period of execution by the company, in this case Tragsatec. If we consider the temporal parameter of the process, a product can be found in this state due to two situations:

    - The product has not yet been delivered because it has not completed the task of realization or production.

    - The product has not passed through the regional quality control. This fact has been communicated to the company and, thus, it is in the process of debugging.

- In quality control: The product has completed the production process and has been delivered to the technical team that performs the regional control, in this case the Regional Development Institute (IDR), and it is currently being validated.
- Validated: The product has passed the regional quality control processes and can be delivered to the national quality control (IGN).

Next, samples of the project's progress are outlined (Fig. 2).

4. QUALITY CONTROL

A fundamental aspect of the project is trying to implement efficient quality control methodologies that are appropriate to the technical specifications of the project.

The quality control processes, which take place in different phases of the PNOA project, are intended to ensure that the product meets the technical requirements for its operation. In a project such as this, it is essential not only to ensure the geometric accuracy and thematic quality of the final orthophoto but also to control each stage of production. Such control will avoid misleading results, both in final and intermediate products, meaning that they can all be used in other applications. For this purpose, a quality control suitable for each stage of the implementation of the photogrammetric process is established by coordinating the workflow toward the tasks developed by the company.

Because there has been a unique photogrammetric flight of the entire community, the volume of information that needs to be processed is crucial. To give an idea of the magnitude, the flight covers approximately 8.000.000 hectares. The information consists of approximately 24.000 images, and the area is formed by 2.617 cartographic maps - according to 1:10.000 scale distributions.

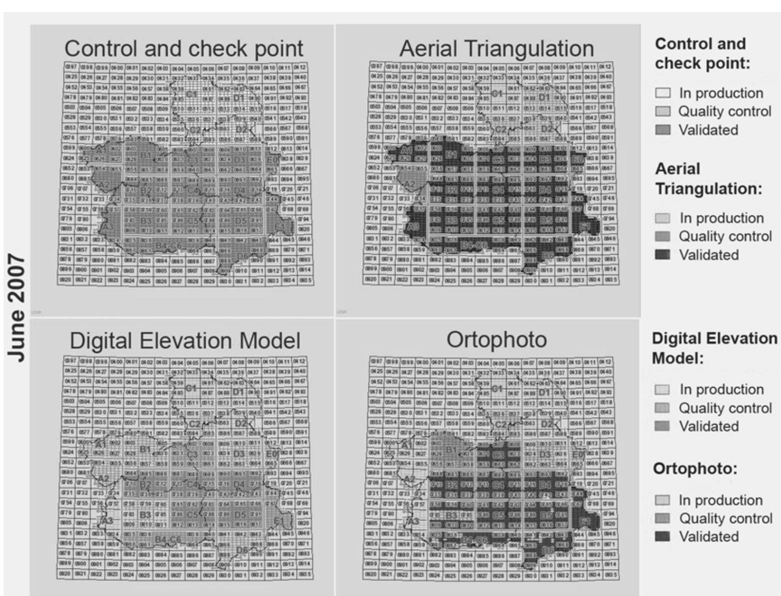

Figure 2. Running state of orthophoto production - June 2007.

With these conditions, automating the processes is an essential step. Specific software has been developed [25] with the aim of automating the quality control of photogrammetric flights.

In particular, the quality control is proposed with a twofold purpose in mind:

- Controlling the geometric parameters, such as geo-referencing between different coordinate systems; controlling blocks, strips and overlaps; controlling vertical image deviation; and controlling scale. This final aspect has been rigorously analyzed based on the digital elevation model (DEM).

- Providing a radiometric calibration based on a vicarious method [22] and validating the thematic parameters obtained.

A paragraph description summarizing the quality controls carried out in each stage is added, making the results more detailed. Another section reports the results of quality control in an alphanumeric form. The results are normally distributed in a table, where each record is identified as the basic unit of control, adding the definition of parameters necessary to establish whether that particular unit exceeds the quality control. As usual, a red color is used to identify those units that failed the quality control.

Finally, a map viewer that allows spatial visualization of the most interesting results of quality control has been included in each of the phases.

To sum up, quality control at different stages of the project is performed as follows (Fig. 3):

- Control of planning and execution of photogrammetric flight.
- Planning and execution of control and check points.
- Control of radiometric properties.
- Calculation and adjustment of aerial triangulation.
- Generation of Digital Elevation Models, including Digital Surface Models (DSM) and Digital Terrain Models (DTM).
- Generation of orthophotos.

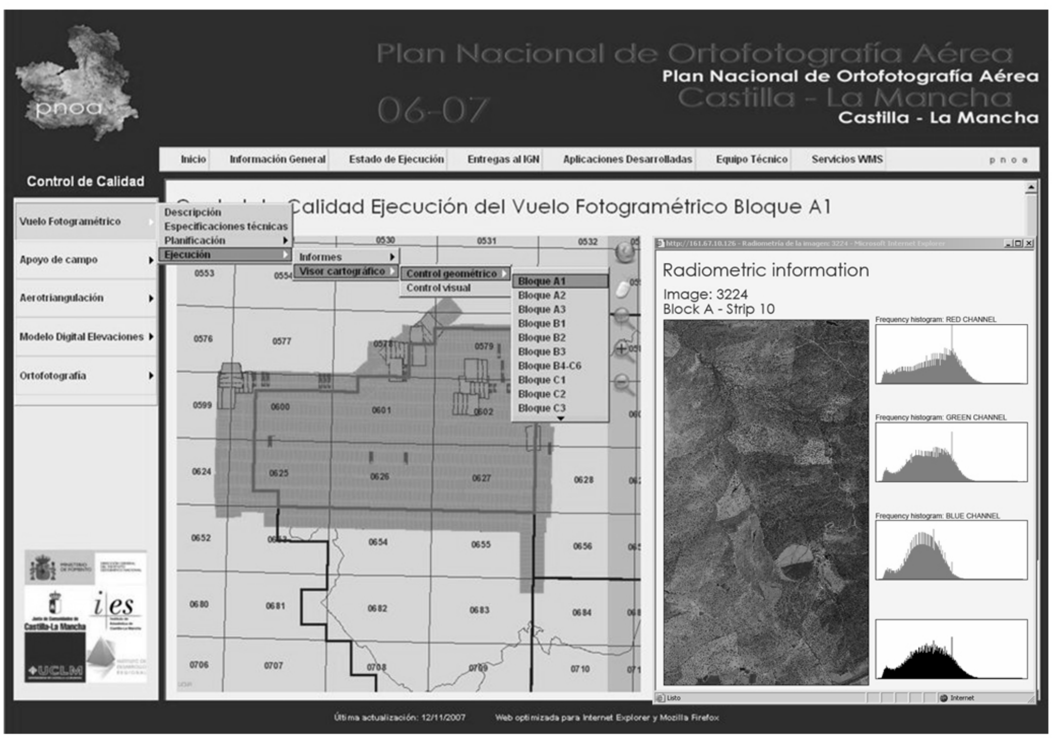

Figure 3. Geometric quality control of execution of photogrammetric flight: longitudinal overlapping (Left). Control of radiometric properties (Right).

5. EXTRACTION OF THEMATIC INFORMATION

Once the aerial images have been oriented and geo-referenced [26], the extraction of thematic information is usually performed, but based on different, non-rigorous and subjective

criteria. The main goal is to provide a final orthophoto with a continuous appearance without gaps or radiometric alterations. To perform an objective and automatic homogenization of images, as well as the extraction of thematic information, radiometric camera calibration should be mandatory. In this project, the method of vicarious calibration based on reflectance, has been applied. In particular, the radiative transfer equation used for implementation and atmospheric characterization is model 6S [27]. In this manner, radiometric calibration parameters and reflectance and radiance images are obtained at the ground level, which could be of great interest for thematic applications. Some analyses were performed to determine whether radiometric measurements can be extrapolated to other spatial locations. This information could be of interest because a public database of radiometric control points could be maintained prior to the photogrammetric flight. The results obtained were promising, given that they range within a 3-5% threshold, depending on the band [22]. The publication of reflectance and radiance images is supported by the Web Coverage Service (WCS), which allows us to exploit the physical magnitudes of images. Fig. 4 shows an RGB orthophoto in natural color and false color infrared (CIR). It can be observed that the first and third images do not provide a continuous transition because the radiometric calibration has not been performed. In contrast, the second (RBG) and fourth (CIR) images present a better transition, with great homogeneity for both images.

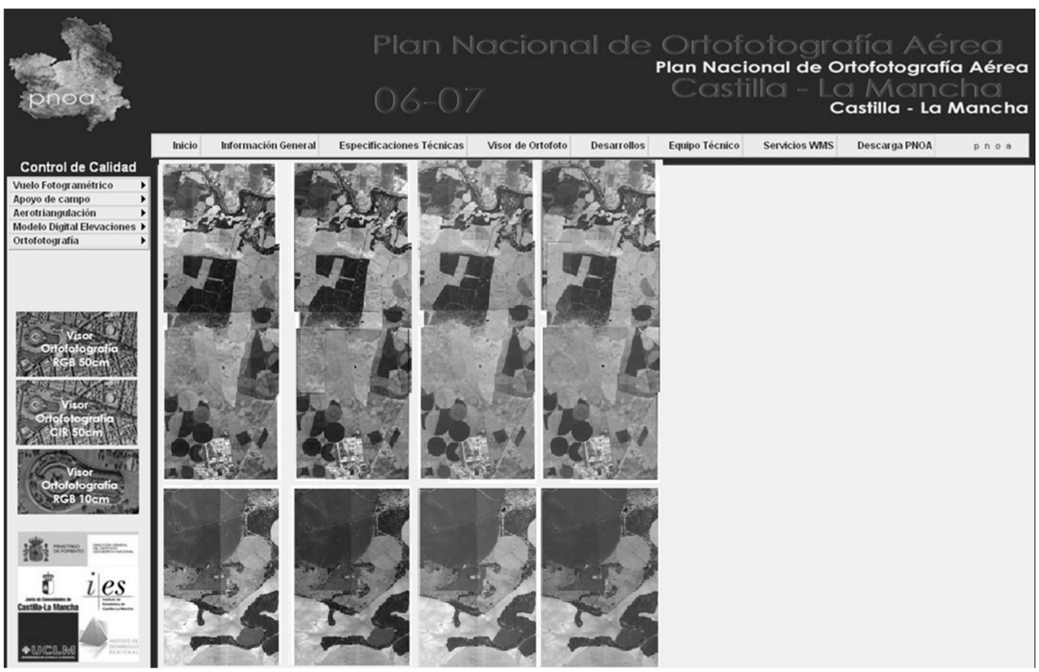

Figure 4. Final RGB and NIR orthophoto viewer based on WCS. (Left) Original and homogenized RGB orthoimages. (Right) Original and homogenized CIR orthoimages.

6. CONCLUDING REMARKS AND FUTURE PERSPECTIVES

Once the project has been accomplished, it can be concluded that the project adheres to the methodology, the system development and the technologies required for efficient project management.

The system's main advantages are the following:

- The ability to adapt to the needs of the project.
- The integration of different elements, which facilitates their independence so that, if necessary, the change of any component will not affect the whole system but only the element to be modified.

- The possibility of updating the spatial and thematic information database with flexibility.
- All the map viewers are based on SDI specifications, most of which are WMS because it follows the OGC standards and, thus, can be used from other applications and platforms. One of the most recent applications is automatic detection based on these services [28].

The proposed system opens new lines of work, such as the incorporation of WFS-Web Feature Services for the management of vector data. Moreover, the recent emergence of new sensors, such as aerial linear cameras and airborne laser systems, which are being used in the PNOA project, will prove that the existing strategies and methods have to be re-implemented to carry out the technical management and quality control. As a result, the Spanish National Aerial Orthophotography program is a dynamic project that requires constant updating to increase its capacities and functionalities.

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