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RECOGNIZING LANDSCAPES: CAN WE CHANGE THE POINT OF VIEW OF GEOGRAPHIC DATA?

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This paper presents a methodology able to handle georeferenced panoramas (GeoPans) projected on 3D models for the integration of landscapes into digital environments. This is not a simple task because the typical visualization (say vertical point of view) through geographic data and GIS software does not fulfil a fundamental request: the virtual reproduction of the human eye at head height. This means that a transition from aerial images to ground (terrestrial) data is mandatory. In addition, an improvement of SDI able to generate innovative typologies of representation is needed. In this work a methodological approach aimed at rediscovering and correlating 3D reconstructions of landscapes with the typical human vision is illustrated. This contribution investigates the potential of panoramic view reconstruction and simulation from images acquired by RC/UAV and by multi-sensor terrestrial platforms (photoGPS) along with existing cartographic data. The main aim is the generation of multiple visual models able to simulate real scenarios at head height (or low altitude above ground). Examples and case studies are illustrated and discussed to prove the complexity of the problem, which requires not only new algorithms and procedures for data acquisition and processing, but also a modification of the traditional 2.5D representation of geographic data.

Key words: historical map, landscape, panorama, SDI, spatial data, UAV

1 Introduction

The main aim of this research is to enhance the comprehension of landscapes introducing innovative representations for different users (planners, public administrations, and citizens). This complex task requires a modification of standard 2.5D geographic data (e.g. orthoimages, digital terrain models, spatial databases, etc.) towards models able to reproduce the realistic perception of the human eye at head height.

As mentioned, the problem is not trivial and can be considered as a new paradigm with a growing interest in scientific disciplines such as digital cartography and photogrammetry [1] where the 2.5D representation is still the final format of most real applications. On the other hand, it is clear that the world is not a height-map and new methodologies able to handle the 3D shape of the objects are becoming more popular. For instance, 3D GIS or new techniques and software for 3D dense image matching (e.g. Acute3D) and texture mapping from aerial data are today available on the commercial market. The obtained results proved that reconstructions of the fully 3D shape of the photographed elements are feasible and can improve the typical outputs of mapping applications.

The work presented in this paper focuses on a particular category of "objects" where the standard 2.5D digital representation is not enough for a comprehensive inspection. Basically, the problem of landscape reconstruction is addressed. It requires new methods able to simulate real scenarios from a different point of view: the height of the observer (or ground level) or low altitude above ground.

An example if shown in Fig. 1. The aerial orthophoto available in the area does not contain information about vertical objects (e.g. building facades). In addition some interesting terraced areas are hidden in the aerial view, whereas they are clearly visible in pictures acquired from the ground. The problem can be intended as the development of optimal procedures to combine a visualization at head height with aerial or satellite data.

The developed strategy is based on *georeferenced panoramas* (*GeoPans*), i.e. images created with stitching techniques and then georeferenced. Shown in Fig. 1 are 4 GeoPans of some municipalities of the area termed "Unione dei Comuni della Tremezzina" (Lombardy Region, Italy), which were acquired with a special calibrated head with georeferencing tools based on GPS technology (more details are given in section 2.2). Images feature a very large resolution and are extremely useful to highlight objects invisible in aerial images.

On the other hand, such detailed visualization is still incomplete from a geometric point of view and can be intended as a preliminary step towards quantitative landscape analysis. Indeed, panoramas are mainly used for visualization purposes whereas metric data cannot be extracted. A possible solution will be illustrated in section 3, where the use of these particular images along with geographic data such as spatial databases, digital terrain models, and texture mapping procedures is described. The final result of this work is a textured 3D model of the landscape that can be used to formulate general application principles, along with strategies and guidelines for the protection, management and planning of landscapes.

It is important to mentioned that a landscape includes historical, monumental and natural characteristics of the territory considered as part of the cultural heritage. Landscape recognition becomes a key feature of the landscape quality. The landscape becomes a resource for sustainable development and the whole territory must be considered in planning policies and programs to improve its preservation with a particular attention not only for "exceptional area", but also for "common and degraded landscapes".

In this context, the development of innovative representations thorough panoramic views and 3D texturing of the landscape is needed to improve the traditional 2.5D maps. Landscape heritage analysis can benefit from the integration of new spatial data, such as terrestrial images and models, rediscovering privileged points of view. Here, the "photographic documentation and representation" of the landscape context must be taken from "accessible places and/or scenic routes", as specified by the Scottish Natural Heritage for EIA (Environmental Impact Assessment), and "it must include fronts, skylines and visual perspective from which the transformation is visible, with particular reference to high visibility areas (e.g. slopes, coasts)".

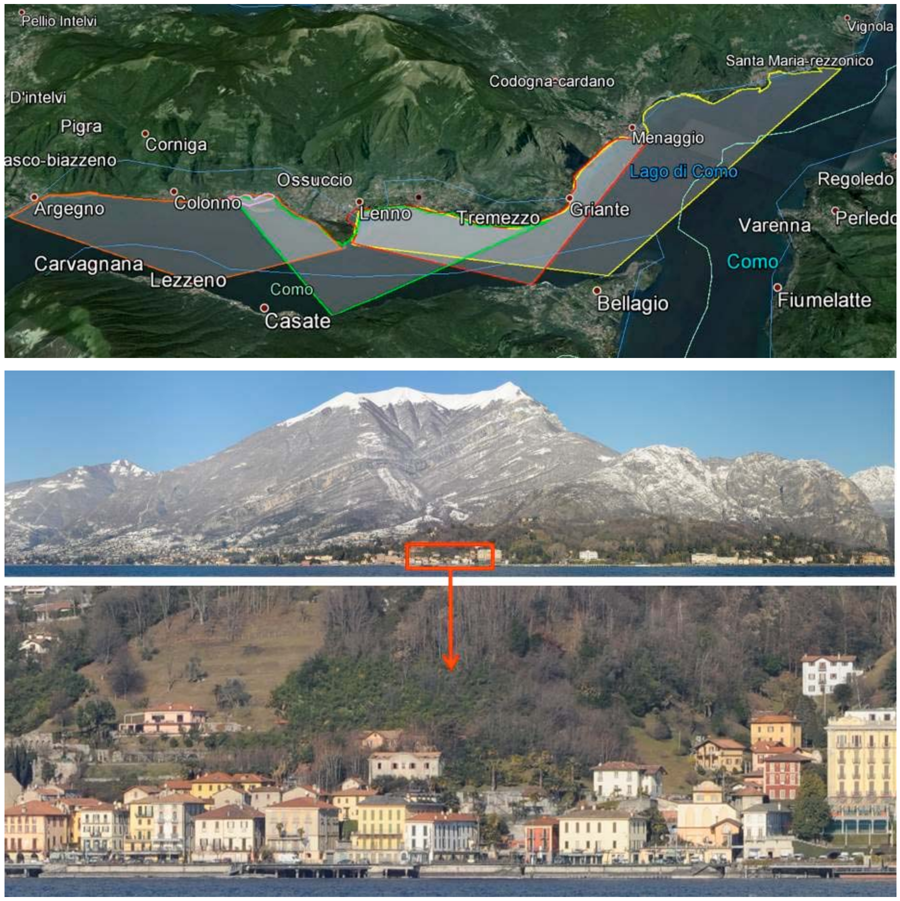

Figure 1 The visualization of panoramas from georeferenced panoramic view can be a preliminary step towards a better visualization and inspection of the area.

Another important aspect is the assessment of the compatibility of the transformation proposed. Synthetic analyses of the state of the art and information about the project are recommended. They must include not only descriptions along with modern (or historical) maps or pictures, but detailed simulations are needed and must rely on a "realistic photo-modelling that includes an appropriate area around the project, calculated from the ratio of existing intervisibility".

According to landscape policies in an EU framework the necessity to develop instrument for landscape simulation and planning will be a fundamental tool for planning policies. For instance, landscapes of water paths and coastal areas have a great strategic importance: INSPIRE directive [2] together with Shared Environment Information System (SEIS) are identified as main tools to facilitate the use of spatial information in these areas.

It is clear that disciplines such as photogrammetry and computer vision can give a significant contribution to landscape reconstruction and representation. Researches carried out on the use of digital cartographic heritage for landscape analysis making proved the potential of the correlation between historical maps and current maps [3], [4]. Open access to historical maps or different sources of information and related services for landscape analysis [5] provided a valid reason to investigate and compare the current landscape with multi-temporal stratified historical layers: Web Map Services (WMS) and Web Feature Services (WFS) can be easily generated from georeferenced ancient cadastral maps and current maps available on the Internet (e.g. Google imagery) or technical orthophotos and true-orthophotos, technical maps, as well as multispectral satellite images and other remotely sensed data.

This paper is divided into two principal sections. Some instruments and products for landscape image processing are illustrated in section 2. They include UAV platforms and photoGPS (a calibrated camera [6] installed on a special rotating head) images for panoramic view reconstruction (section 2).

Finally (section 3) the possibility to combine ground image sequences and existing 3D models derived from spatial databases will be discussed showing its potential in supporting planners with more realistic instruments in the Environmental Impact Assessment. At the same time, such representations can improve knowledge transfer to citizens, towards a volunteered image data acquisition process through mobile applications.

2 Recognizing landscapes

2.1 Overview

Most researches carried out on landscape analysis have underlined the need of new instruments able to support EIA in complex landscape scenarios (such as in the case of wind farm) through photomontages, panoramic images, three-dimensional maps, and historical representations (see Fig. 2 for an example). In addition, they have underlined the lack of realistic models for (3D) GIS simulation: series of good practices devoted to the visual analysis are progressively recognizing the high value of the photos within the simulation process [6]. Problems in the current intervisibility map have been progressively faced in many fields of application [7]. In general, the need of integration of traditional photos within the planning process requires new image data processing algorithms.

This aspect requires a modification of the aerial view towards complex terrestrial visualizations by considering different planes of interest depending on the structural elements orientation in space: vertical fronts (i.e. facades), horizontal planes (i.e. mosaic floors), wooden slabs and 3D covering systems (i.e. domes and vaults [8]), for which advanced 3D object representation [9] and 3D texturing algorithms [10] are mandatory. For this reason, landscape representation is progressively trying to overcome the unique traditional aerial point of view represented by aerial/satellite images acquired for mapping applications. The main idea is a progressive integration of variable points of view, as in the case of 3D city navigation. For example, Street View allows an interactive navigation of the area from an unconventional point of view and gives a perception at ground level of city scenarios. On the other hand, the system is quite rigid as it does not allow the user to change the point of views outside camera path.

In the next sections two methodologies for landscape image acquisition and simultaneous georeferencing are illustrated and discussed. This is the first step in the pipeline for the creation of a detailed 3D model that allows the user to move in the whole environment.

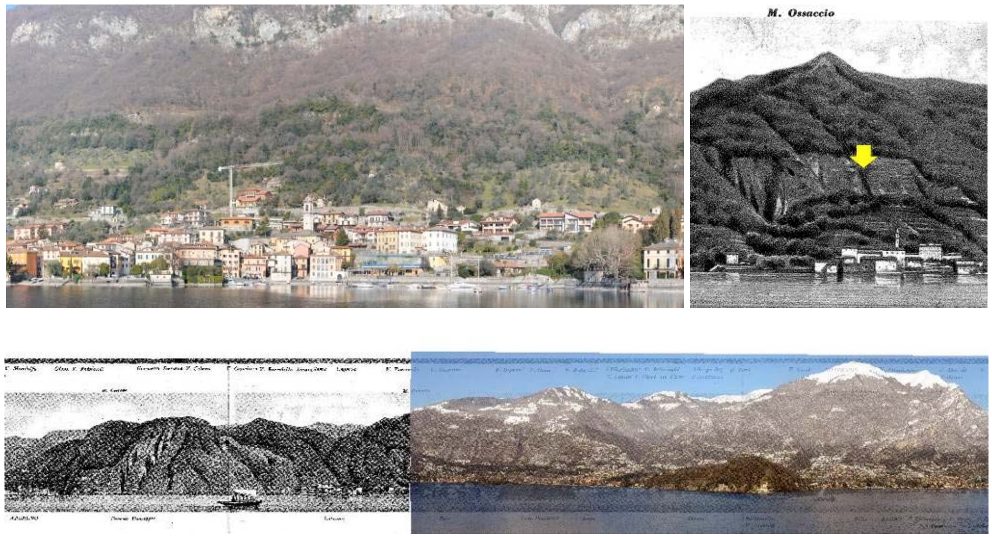

Figure 2 Past and present can be aligned to understand land changes.

2.2 Capturing landscapes from the ground

Nowadays, automatic panoramic image stitching from multiple views is becoming very popular [11] and can be a valid support for landscape analysis.

This kind of visual documentation of real objects is already implemented in many visual applications (e.g. Google Street View) and provides an interactive immersion in the area. The interactive exploration of panoramas allows accurate documentations and is therefore receiving significant attention due to their high-resolution content, large field of view, low-cost, simplicity, and completeness. Several commercial packages (Realviz Stitcher, PTgui, Autopano GIGA, etc.) are currently available for the automatic creation of panoramic images. A sequence of photographs is automatically processed without user's interaction, obtaining different projections (e.g. spherical, cylindrical, gnomonic, etc.) that are a 2D representation of the scene around the camera.

The mathematical formulation behind panoramic images relies on projective geometry [12]. Indeed, the transformation between two pinhole images acquired by a rotating camera (such as the PhotoGPS system used in this work) is a homography. Multiple images are matched in order to determine the mapping parameters of the images through bundle adjustment. Panoramic images, produced by stitching single frame images, allow for the generation of gigapixel images with a very high resolution content and a large field of view. Stitching software are currently highly automated, and the use of lenses with a large field of view (e.g. fisheye lenses) simplifies the generation of 360° panoramas.

In the case of landscape representation, a calibrated head with a digital camera was developed to automate the image acquisition, processing, and georeferencing phases. The final product obtainable with this technique is coined *Georeferenced Panorama* (*GeoPan*), i.e. a gnomonic projection with its interior, additional (distortion), and exterior orientation parameters (position and attitude).

The panoramic head consists of a cardan joint that is able to rotate the camera around the perspective center of the images (Fig. 3). A fast and simple calibration of the head is needed to find the perspective center for a generic lens mounted on the camera. This can be carried out by using two vertical wires. The ruler of the head should be adjusted in order to find a good alignment between the camera-wire system when the sensor is rotated and can be performed with a few tries. The camera can be correctly aligned by using a theodolite, which is then removed to mount the head on the tribrach. Some experiments have demonstrated that this quick procedure gives a good alignment, with a residual error better than 3 mm (less than the resolution of geographic data).

Once the head is calibrated, parallax errors can be removed from the final mosaic, that is a distortion-free gnomonic projection. In addition, the perspective center is aligned with a pole on top of the head. Here, a prism or a GNSS receiver can be placed in order to georeference the image. The coordinates are measured with these external sensors (theodolite or GNSS) to give the location of the perspective center of the pinhole image (which is also the center of the panorama). The vertical shift between the pole and the camera can be easily estimated with a calibration project, and can be assumed as being constant for all images. Finally, an Inertial Measurement Unit (IMU) can be fixed on the ruler of the head to determine the attitude of the camera. This is used to derive three angles (azimuth, elevation, roll) suitable for data processing in the cartographic plane.

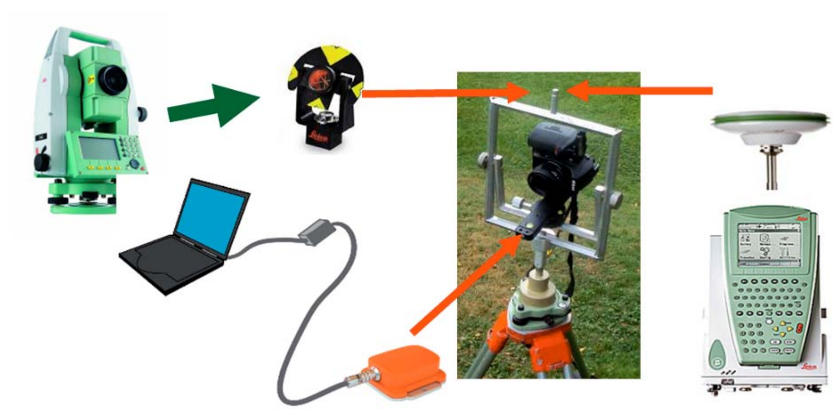

Figure 3 The calibrated head used for georeferenced panorama acquisition.

Shown in Fig. 4 is an example. The dataset illustrated in Fig. 1 (Unione dei Comuni della Tremezzina) was integrated with two additional GeoPans acquired from Isola Comacina (Fig. 4). The whole dataset is made up of 6 gnomonic projections whose projection centers were measured with GPS surveying techniques. The instrumentation includes a Nikon D700 equipped with a 90 mm lens mounted on the rotating head. Gnomonic projections 1, 2, 3 and 4 cover an area of about 20 km (from Menaggio/Santa Maria Rezzonico up to Argegno), whereas the additional projections give a better view of the municipalities of Sala Comacina and Ossuccio (Fig. 4).

Figure 4 The additional gnomonic projections acquired from Isola Comacina. They feature a better image resolution than the previous images as the camera-object distance is shorter.

	Station point	Left	Middle	Right
GeoPan 1	Bellagio	from Tremezzo to Punta Balbianello	Cadenabbia di Griante	from Menaggio up to S. Maria Rezzonico
f = 90mm	distance (m)	4600	1700	9500
	GSD (m)	0.43	0.16	0.89
	scale factor (0.1 mm)	2147	793	4433
GeoPan 2	Bellagio San Giovanni	from Tremezzo to Lenno/Punta Balbianello	Tremezzo	Cadenabbia-Menaggio
f = 90mm	distance (m)	3400	1800	5000
	GSD (m)	0.32	0.17	0.47
	scale factor (0.1 mm)	1587	840	2333
GeoPan 3	Casate	Sala Comacina-Ossuccio-Lenno	Punta Balbianello	Cadenabbia
f = 90mm	distance (m)	3800	1700	4600
	GSD (m)	0.35	0.16	0.43
	scale factor (0.1 mm)	1773	793	2147
GeoPan 4	Lezzeno	Argegno	Colonno	Balbianello
f = 90mm	distance (m)	4300	2400	2600
	GSD (m)	0.40	0.22	0.24
	scale factor (0.1 mm)	2007	1120	1213
GeoPan 5	Isola Comacina-1	Sala Comacina	Villa Beccaria	Ossuccio
f = 90mm	distance (m)	300	200	500
	GSD (m)	0.03	0.02	0.05
	scale factor (0.1 mm)	140	93	233
GeoPan 6	Isola Comacina-2	Villa Beccaria	Ossuccio	Ossuccio-Church of S. Maria Maddalena
f = 90mm	distance (m)	250	430	570
	GSD (m)	0.02	0.04	0.05
	scale factor (0.1 mm)	117	201	266

Table 1 Some parameters of the gnomonic projections.

As the perspective centers are known from static GPS, the nominal scale factor of these images can be estimated with a map, like in aerial photogrammetric projects. Obviously, the configuration of such images is different than typical aerial blocks and a single scale factor for the image cannot be estimated. For this reason, the scale factor was evaluated in three image points (left, middle, right) in order to provide a more significant description of the geometric resolution obtained (Table 1).

As can be seen, the average scale number (it is important to mentioned that the scale factor was evaluated by using a factor 0.1 mm instead of 0.2 mm in the image plane) is quite similar to that achievable with aerial images taken with analogue or digital cameras. On the other hand, the geometric resolution increases for the last two images that have scale factors of about 1:100-1:300. This means that GeoPan resolution is similar or even better than aerial/satellite image resolution.

2.2 Recognizing landscapes from UAV platforms

The rapid development of radio controlled UAV sensors able to acquire images for documentation, inspection and surveying is a field only partially explored in the landscape and environmental heritage domains. Different problems have to be investigated in photogrammetric RC/UAV applications, mainly regarding image acquisition and orientation for 3D image reconstruction and representation of landscapes with a complex morphology, starting from data collected with unconventional assets including vertical and oblique images.

The need of an accurate result requires a proper flight plan and control/navigation systems in order to perform data acquisition following a regular path. Indeed, photogrammetric surveys need regular set of images (blocks) taken from different points of view with good baselines. The integration with GPS/IMU sensors allows one to obtain satisfying results during image acquisition and approximated values able to initialize the adjustment process. Georeferencing and integration of standard images, video imagery [13] and research work on fully automatic image orientation [14] open new opportunities in this particular context.

Nowadays, the calibration and orientation phases of UAV data have reached a high level of automation. This avoids manual (interactive) measurements and reduces CPU time, notwithstanding user's interaction is still mandatory for precise mapping applications.

New marker-less algorithms allows the extraction of tie-points for convergent image sets, with a variable scale and irregular baselines (the opposite case of standard aerial photogrammetry, say images with normal configuration). After image calibration and orientation, dense image matching algorithms can extracted a 3D model (usually a mesh) that can be textured to obtain a photorealist visualization [15]. These methods include not only photogrammetric approaches, but also new powerful algorithms coming from the computer vision area, such as methods for image orientation from several images (thousands) and new 3D texture-mapping algorithms.

This section illustrates (i) the creation of GeoPans by means of a radio-controlled UAV without sensors for direct georeferencing and (ii) another example carried out with an autonomous mini-drone. The first experiment concerns GeoPan created from an UAV platform starting from a preliminary block of 25 images acquired in the area over the municipality of Oggiono (Lombardy, Italy), on top of a small hill with a dominant horizontal extension. The UAV platform is a RC helicopter Vario Benzin-Trainer (mini-UAV with an overall pay-load 7 kg). This UAV gives the opportunity to mount different cameras (according to the aim of each specific survey). In this case, a calibrated Nikon D90 (4288×2848 pix) equipped with a 20mm Sigma lens was employed.

The photogrammetric block of the area was needed to estimate the orientation parameters of the final GeoPan that was included in data processing. Network geometry includes images with short baselines and high overlaps. Some of these images were also quite convergent in order to obtain a better reconstruction of some vertical elements and strengthen block geometry.

Image orientation was carried out in a semi-automated way. A set of tie-points was automatically extracted with the procedure proposed by [16], that uses SIFT features. Then some GCPs (targets made up of white circles on a black background) were measured with the LSM algorithm. GCPs were distributed in the area to obtain a geo-referenced result from theodolite and GPS data (indeed, targets were measured with a combined total station/GPS survey and a geodetic network). 9 points were employed as GCPs in bundle adjustment, while the remaining ones were used to inspect the quality of the estimated exterior orientation parameters. After image triangulation the estimated average height above ground during the flight was about 14 m, and the RMSE values were 5 mm in the horizontal plane (N-E) and 17 mm along the vertical direction (h). Some results and a view of both geodetic network and camera poses are shown in Fig. 5. Then a 360° flight was realized to acquire 32 images for panoramic image generation. These images were combined with the previous survey (already geo-referenced) in order to determine the position and attitude of the final GeoPan.

As the UAV was not very stable (images should be taken with a rotating camera, i.e. the perspective center remains fixed during image acquisition) a precision of about σ_{NE}= ±0.24 m, σ_H= ±0.32 m was derived (UTM-WGS84 coordinates). These values are better than the accuracy of the cartographic products (1:2000) available in the considered area.

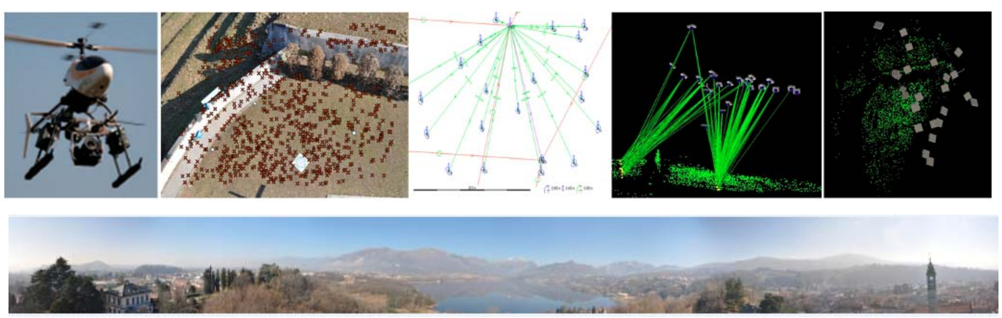

Figure 5 Some phases of the creation of the georeferenced UAV panorama (top) and the final GeoPan (bottom).

The second case was carried out with an UAV platform equipped with GPS/IMU sensors that can simplify the georeferencing phase. The second survey was carried out with the mini-drone Falcon 8 (AscTec) and a sequence of images acquired from the municipality of Galbiate (Italy). The system is equipped with a RGB camera Sony NEX-5N (focal length 16 mm, 4912×3264 pix, pixel size 4.88 µm) and is able to fly up to 20 minutes with a single battery (Fig. 6). The electronic equipment includes a GPS antenna and a system of accelerometers determining the system roll, pitch and yaw. The communication system allows the ground station to receive telemetry data and video signals from the onboard sensors.

The system has an integrated flight planning software (Autopilot Control) and can acquire a sequence of images with a rotation on a fixed position. These images are suitable for photo mosaicking into a single GeoPan, although some misregistration errors (parallax) can be found for objects close to the camera. As the goal is the mapping of the local landscape (distance of about 1 km), the camera-object distance increases and there is a reduction of these effect.

The Falcon 8 has real time navigation sensors and can record position and attitude of the different images. From this point of view, the first block of images (for image orientation with ground control point measurements) presented in the previous example with the Vario Benzin-Trainer is not needed. Data processing becomes faster because the final GeoPan can be directly georeferenced with navigation data. However, navigation data recorded by on-board GPS/IMU sensors are not very accurate and rarely provide sub-meter precision. This has a direct impact on the georeferencing phase of the panorama, where errors can be accumulated and result in a poor image-to-object alignment (see next section for more details about the texture mapping step). In the case of high-precision applications the measurements of some ground truths (e.g. points from a map or additional GPS measurements) remain mandatory to remove this error that mainly affects GeoPan attitude.

Figure 6 The Falcon 8 and the ground station (top). The GeoPan from image stitching (bottom).

3 Virtual reproduction of the human eye (at head height) from geographic data

Aerial orthophotos combines photorealist and metric information. How can we obtain a similar result for landscapes photographed at head height? The first solution could be an orthophoto derived from the GeoPan projected on the DTM. This operation is surely feasible and requires a preliminary identification of the normal direction to the local object plane. However, the result still follows the same 2.5D approach of aerial data, where the reference system is progressively rotated in order to match the local characteristics of the different landscapes.

Obviously, this is not a convenient choice, as the work requires different choices of the reference system for different landscapes. The problem could be completely solved in the case of data processing carried out in a 3D space instead of a simplified 2.5D. The main idea is the re-use of existing information (DTM and spatial database) along with the new GeoPans in a workflow able to handle 3D processing algorithms for the typical problems of close-range image processing (e.g. convergent images, occlusions, and multiple depth values). The landscape is therefore assumed as a 3D object to be textured with terrestrial data, where there is a transition from a "static" point of view towards a "dynamic" visualization. Such new models can be inspected in interactive mode and a series of sub-products (such as 2.D representations) can be automatically derived. This approach is becoming common in close-range photogrammetry where new software packages (e.g. Agisoft PhotoScan, 3DF Zephyr) allow the generation of textured 3D models and the extraction of orthoimages by setting different planes of projection.

The case study presented in this section is the real 3D texture-mapping project of the municipality of Malgrate with a set of three GeoPans acquired from Lecco (Italy – see Fig. 7). The camera installed on the PhotoGPS system is a full-frame Nikon D700 (4256×2832 pixels) and camera-object distance is about 900 m. The ground sampling distance is approximately 10 cm and allows a cartographic representation with a scale of 1:1000. The spatial database, from which the building layer was extracted, has instead a nominal scale 1:2000, that is worse than GeoPan resolution.

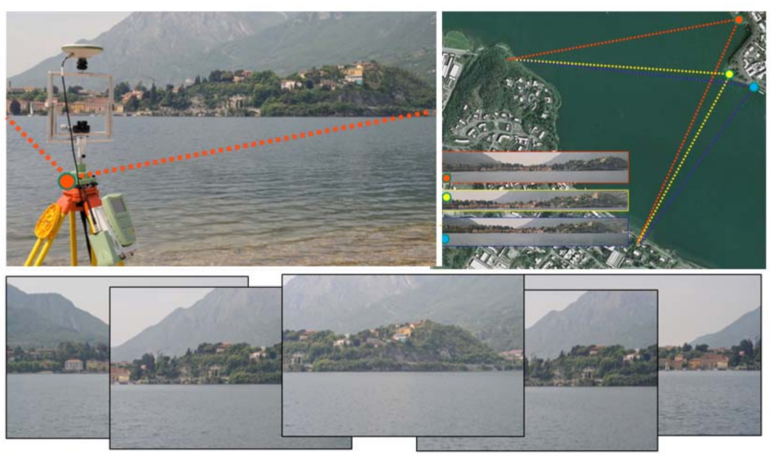

Figure 7 The creation of the GeoPans with the PhotoGPS system.

The used texture mapping algorithm is able to project different gnomonic projections on a 3D mesh and can handle large resolution images. It considers the self-occlusions given by multiple objects (triangle in the mesh occluded because of the three dimensional object used in this case study) along the ray connecting image and object points (collinearity equations). The georeferenced GeoPans can be therefore used to generate a texture for a model derived from an existing DTM combined with the building layer of the municipality.

Overall, this model considers two categories of objects (ground and building) and is a first approximation for 3D texturing (Fig. 8). It should be mentioned that it is rather difficult to obtain a detailed 3D model of the whole object and its different elements, as this requires a new photogrammetric projects with a higher level of detail. The solution proposed in this work is a the first step towards a methodology able to change the point of view of the observer with a reasonable data processing time, avoiding data processing of additional raw images and LiDAR data. The reuse of geographic information already available is fundamental to achieve this result and makes the method feasible in different scenarios where a DTM and a building layer (with height data) are available.

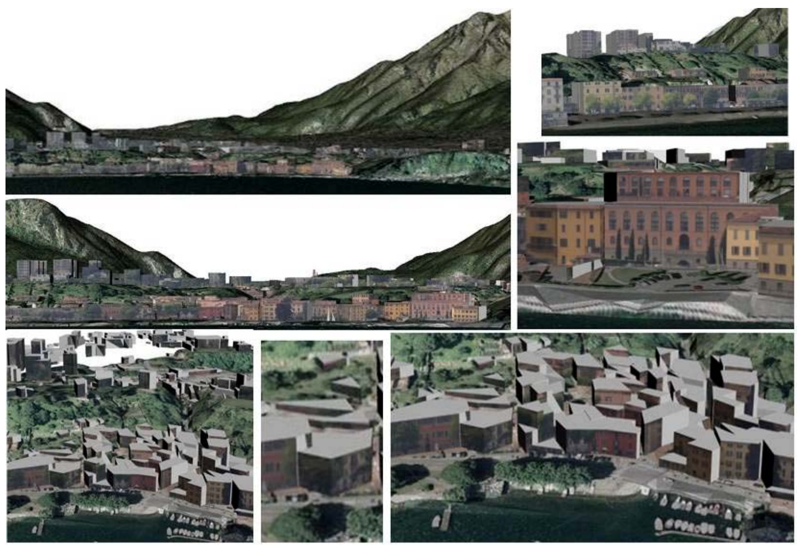

Figure 8 3D texture mapping of DTM and spatial database (building layer) from multiple GeoPans.

Several critical aspects, like occlusions and wrong projections for local inconsistencies between DTM and spatial database (e.g. new buildings) are still inevitable (especially for automated data processing) and need further investigations or manual corrections. More 3D information is needed to overcome the lack of roofs, stairs, walls, or other elements of the natural and built environment that are not modelled by this techniques but are visible in the GeoPan sequence.

4 Conclusion

The paper described a methodology for landscape modeling and inspection starting from existing cartographic products (spatial database, DTM) and new georeferenced panoramas (GeoPans). Images are projected on a 3D model with texture mapping algorithms able to manage gnomonic projections and typical problems of photogrammetric close-range blocks, such as convergent images, occlusions, and multiple texture assignments.

The final product is a 3D model made up of ground information (DTM) and buildings (spatial database with height data) with a photorealistic texture determined from one or multiple GeoPans. This model can be handled in 3D processing environments obtaining a variable user's point of view. This means that the static 2.5D visualization of cartographic data made up of aerial and satellite products is substituted by a dynamic conception with a virtual reproduction of the human vision at head height. The model is a valid tool able to support the creation of realistic intervisibility maps and environmental assessment evaluations. It introduces some elements of the real perception of human observers and improves the role of human perception in landscape interpretation.

Although the case studies presented in this paper were analyzed with ad-hoc instruments (PhotoGPS and UAV platforms equipped with navigation tools) the method can also benefit from volunteered information (VI) gathered by means of consumer-grade cameras, smartphones, and tablets. The creation of apps and databases able to integrated rigorous cartographic products with VI (validated GeoPans created with stitching procedure) is currently in progress. The final aim is the creation of geo-portals not only for experts in the field of landscape planning or image analysis, but also for citizens that can support the preservation process with their own data.

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