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Hyperspectral proximal sensing of a marshy area: data acquisition methods and image processing

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I. Introduction

In recent years, among the modern techniques useful for the analysis of territory, the application of hyperspectral sensors has become more and more important. Hyperspectral remote sensing is a technology that merges two sensing approaches belonging to the world of science and engineering, imaging and spectrometry [1]. The purpose of the research presented in this paper, conducted at the Centre of GeoTechnologies of Siena University (Italy), is to test the potential use of a proximal airborne hyperspectral imaging system in performing the analysis and monitoring of both natural and anthropogenic contexts. The analysed marshy area is located near to the city of Viareggio (Lucca, Italy) in a coastal plain delimited North-eastward by the Apuan Alps and the Pisan Mountains. Alluvial cones, built up in a multi-step process throughout Pleistocene and Holocene [2], connect plain and mountain areas. The swamplands, characterized by a thick layer of peat, includes both the Massaciuccoli Lake (7 km^2 wide) and the "Padule of Massaciuccoli" (13 km^2 wide) representing the palustrine residues of a large marsh which was reclaimed and used for intensive cultivation [3].

II. Materials and methods

By means of a prototypal aircraft (an aerodyne with rotary wing [4]) equipped with a pushbroom hyperspectral scanner, a flight was carried out over the test site on March 1st, 2017. The aircraft (Figure 1), able to fly with more than 100 kg of scientific payload, is named "RadGyro", from "Radioactivity Gyro" as it was initially developed for the detection of natural radioactivity [5]. Several tools compose the technical equipment: five L1 GPS (Global Positioning System) receivers; an Inertial Navigation System (INS) which allow associating every scan line of pushbroom sensors or scanners to its spatial position and attitude; a radar system, useful to compensate possible GPS signal cycle slips, and a Windows based data recorder [4]. Moreover, also the following sensors are available on-board: a pair of non-metric digital cameras (full frame sensors with 35 mm equivalent focal length), which operate in the visible region (VIS) of the electromagnetic spectrum; a thermal imaging camera recording in the 7,500–13,000 nm wavelength range; a SOC710-GX (Surface Optics Corporation, USA) hyperspectral camera [5] that constitutes the object of this study. This last (Figure 1), a hyperspectral pushbroom imaging scanner, can acquire imagery at a rate of 40 Megabytes per second, in 120 spectral bands at 12-bit of radiometric resolution, 640 pixels per row, up to 260 lines per second.

Figure 1: a) The RadGryro during a flight; b) The SOC710-GX in grey and a digital camera located in one of the two lateral compartments of the aircraft.

The spectral response of the system covers the VNIR (Visible-Near Infrared) spectral range (from 400 nm to 1,000 nm) and can be used in normal lighting conditions with automatic and manual exposure settings.

The main characteristics of the executed flight can be synthetized as it follows: aircraft speed about 80 km/h; nominal distance at ground between the flight strips about 100 m; scanning speed 90 Hz; nominal flight altitude 200 m above the ground level. Defining a focal length of 4.8 mm, a GSD (Ground Sampling Distance) of about 0.41 m has been achieved. After data acquisition, the hyperspectral image processing has been executed in several stages and using different consecutive software.

First, the raw hyperspectral datacubes were synchronized with the corresponding INS and GPS information through a software specially developed by Enformatic Sp. z o.o.. The main goal while developing the software was to merge INS and GPS data into one sensors datafile, which has to correspond to the hyperspectral camera datafile. The sensors datafile was created in a structure (format) enabling further orthorectification process. In this case, all necessary sensors' readings were defined: longitude, latitude, altitude, roll, pitch and yaw. Then, data density was analysed. Since the camera's hyperspectral datafile had the highest acquisition frequency, an algorithm was implemented to interpolate the sensors' data. At the end, the software was developed by using the C# language according to data mapping. Afterwards, another software (i.e. PARGE® - ReSe Applications Schläpfer Company, CH) based on the parametric geocoding procedure [6], allowed the orthorectification of the hyperspectral imagery through the following main steps.

- Data preparation and loading: hyperspectral imagery, sensor model, GPS/INS data, Ground

Control Points (GCPs) and Digital Elevation Model (DEM) of the zone. In particular, GCPs have been identified on available orthophotos of the test area. Both the orthophotos and the used DEM, 1m x 1 m cell size from an aerial LIDAR (Light Detection And Ranging) survey, were made available from the Tuscany Region open data WebGIS service.

- Calculation of the Image Geometry Map (IGM) allowing to create a reference map based on DEM geometry.
- IGM Cube Rectification for creating a geocoded cube (i.e. an orthorectified hyperspectral imagery in ENVI® format - Harris Geospatial Solutions).

Finally, the atmospheric correction of the orthorectified imagery allowed removing the effects of the atmosphere on the pixel reflectance values; atmospheric correction was performed by applying the QUAC (Quick Atmospheric Correction) algorithm provided by ENVI® software [7]. This is a semi-empirical correction method, which determines the atmospheric compensation parameters directly from the information contained within the scene using the observed pixel spectra.

III. RESULTS

Figure 2 shows an example of the orthorectified hyperspectral image acquired near the Massaciuccoli Lake and the manufacturing zone of Torre del Lago. It is possible to notice, in addition to a landfill, the swamps and the channels that characterize the area. The geometric distortion of the right-most part of the image is due to the turn of the aircraft in that section.

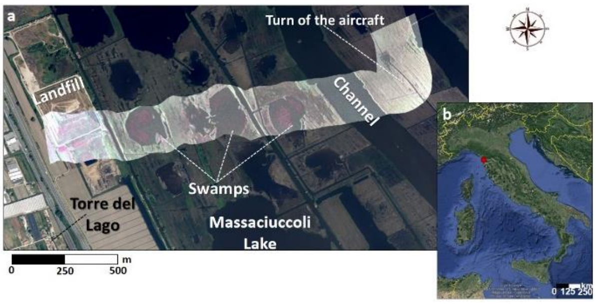

Figure 2: a) Example of an orthorectified hyperspectral image of the marshy area superimposed to the Tuscany Region orthophoto.
The image is visualized in the following false colour composite: Red = band nr. 65 (725.9 nm); Green = band nr. 50 (643.4 nm); Blue = band nr. 33 (550.7 nm). b) Red dot indicates the location of the Massaciuccoli marshy area in the Italian territory.

A qualitative analysis of the data firstly suggests that the obtained GSD (0.41 m) is a good result for hyperspectral analyses. Secondly, the total RMSE (Root-Mean-Square Error) lower than 2 m is also a good result in terms of spatial accuracy even if, for the future, it is better to plan a GPS survey of GCPs instead of using points from the regional topography.
The spectral signatures of two Regions of Interest (ROIs) covered by vegetation and soil, were compared with those provided by the Johns Hopkins University ECOSTRESS Spectral Library, showing also a good matching (Figure 3).

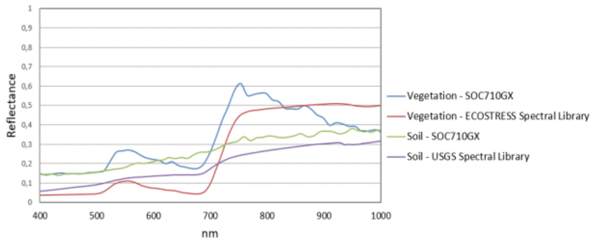

Figure 3: Comparison between spectral signatures from hyperspectral imagery and a spectral library.

IV. CONCLUSIONS AND FUTURE WORK

The described research shows the definition of a very useful and accessible workflow for the acquisition, processing and orthorectification of airborne hyperspectral images acquired with a hardware configuration supported through specialized software suite. Future developments of the work will consist of improving the spatial georeferencing through GPS surveys and determining the spectral signatures of natural and artificial targets in a way to map the reflectance variations with respect to the incident wavelengths. The characteristics of the marshy area will be investigated by analysing the spectral response given by ROIs identified on the basis of the orthocorrected and atmospherically corrected images. In particular, the ROIs will be represented by samples of different matrices, as soil, vegetation and swampy water. The reflectance graphs will be compared with spectral signatures obtained through an ASD Fieldspec 3 portable spectroradiometer, available to the Authors, and reference spectral libraries (i.e. Johns Hopkins University and U.S. Geological Survey). The spectral analysis will provide a better aid for the identification of the ecological and territorial properties of the marshy area.

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