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Repeatable and scalable Image Acquisition from Drone equipped with Multispectral and Thermal Sensor for proximal sensing processing of Nature Based Solutions

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Abstract

Hydro-meteorological hazards, such as floods and storm surges, are responsible for severe socio-economic disruptions and the risks associated are projected to increase due to the climate changes, whilst traditional measures (*e.g.*, dykes, seawalls) could not be able to cope with the expected intensifications of these events. For this reason, Nature Based Solutions (NBS) are measures encouraged by global summits in order to address environmental problems caused by climate change. The concept of Open-Air Laboratory (OAL) has been recently implemented by the H2020 project OPERANDUM, in order to demonstrate the applicability of the NBS for this kind of hazards. Monitoring of the impacts of OALs is generally done by using a combination of remote sensing at multiple scale and in situ data, including socio – economic variables aimed to acquire new insights on the bio – geophysical processes determining the impacts and vulnerability of NBS. In this work, a repeatable and scalable image acquisition method over an artificial dune built in OAL Italy is presented. The dune is aimed to reduce storm surge and consequent coastal erosion. For this purpose, a suitably equipped drone is used. Multispectral camera and an advanced drone autopilot need. High resolution spatial and temporal image sequences have been acquired in visible (RGB), red edge, near infrared and thermal infrared (LWIR) bands. Image processing allows to evaluate the surface of NBS, vegetation status and terrain temperature: based on these acquisitions, selected indicators have been computed to evaluate the NBS effectiveness e.g. NDVI (Normalized Difference Vegetation Index), GNDVI (Green Normalized Difference Vegetation Index), NIRE (Normalized Index Red Edge) based on the fact that the reflectance changes significantly between stressed and healthy vegetation. A methodology to use these indicators in other NBS of the same type, but with different dimensions and put in different locations is also discussed and analysed.

1. Introduction

Severe hydro-meteorological phenomena (i.e., extreme weather in terms of precipitation, heat waves and wind storms), causing severe impacts in terms of injuries, casualties, and socio-economic losses, are being reported more and more frequently globally as well as in European territories. The increasing frequency and severity of hydro-meteorological events such as hurricanes, intense cyclones, or destructive thunderstorms appear to be associated with climate change and an increasing number of people is exposed to this hazards each year. The massive deforestation, over-building of rural and coastal areas, modification of natural watersheds has made territories more prone to hazards. Major disasters in the past twenty years have shown the role that nature plays in reducing risks to natural hazards. For example, a specific study by the Swiss Reinsurance demonstrated that for each dollar invested in the protection of the Folkestone Marine National Park (Barbados) would save about 20 million dollars of annual damages from hurricanes [10].
The science behind these phenomena is complex, but advancement in evidence-based knowledge, together with progress in technology and data-driven measurement systems, allow more detailed monitoring and forecasting availability to target interventions at the appropriate time-scale.

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2. Natural Based Solutions

According to the universally agreed definition by the United Nations Environment Assembly (UNEP/EA5/L9/REV.1), Nature Based Solutions (NBS) are defined as “actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits.” The NBS concept, as defined in environmental sciences, has emerged within the last two decades, since international organizations searched new ways to work with ecosystems instead of relying on conventional engineering solutions (e.g. seawalls), in order to adapt and mitigate climate change effects and to improve sustainable livelihoods.
NBS are adopted for Disaster Risk Reduction considering that healthy ecosystems can better overcome occurring hazards and reduce the magnitude, duration and frequency of hazards [1]. NBS are also aimed to tackle other societal challenges, such as, biodiversity loss, health and well-being. NBSs have the potential to provide multiple co-benefits for the human-health, the economy, society and the environment, and thus they can represent more efficient and cost-effective solutions than the traditional engineering approach [2]).
NBS aim to use nature to mitigate natural hazard risks and boost societal resilience, for example, by reducing challenges such as climate change, food security, water resources or risks driven by the other natural hazards [3] In fact, NBSs can give a powerful contribution against climate change by preventing the degradation and loss of natural ecosystems, for example deforestation release about 4,4 Gt of CO2 per year into the atmosphere, corresponding to 12% of anthropogenic CO2 emissions [11].
NBS approaches are often cost-effective, have multiple benefits and can become increasingly valuable in the face of more frequent and severe extreme events such as flooding, coastal erosion and storm surge, increase nutrients and sediment loading, drought, heatwaves and landslides. Other possible applications are the usage or restoration of floodplains and upland areas to decrease flood risk in downstream areas, green and blue infrastructures in landscape areas to reduce run-off during high-intensity precipitation events and forest management aiming to reduce heatwaves or landslides [4].
NBS are aimed to modify many geo-biophysical processes, so it is necessary to implement various measurement techniques to assess atmospheric, terrestrial and subsurface environmental key parameters [2].

3. The Operandum H2020 Project

The H2020 OPERANDUM project was designed to address the main hydro-meteorological risks (droughts, floods, landslides, storm surge and coastal erosions) that heavily affect rural and urban areas through the implementation and assessment of NBS. One of the main aims of OPERANDUM is to test the performances of various NBSs (green, blue and hybrid types) in response to the different hydro-meteorological hazards that are being investigated [5]. The ambition of OPERANDUM was to provide science-based evidence for the usability of NBS ranging from local to landscape scales, fostering the market opportunities, upscaling and replication in Europe and other territories. In particular, one of the main objectives of OPERANDUM was to demonstrate the potential of a suite of different NBSs in response to a range of different hydro-meteorological hazards. The innovative use of the Living Lab concept (Open Air Laboratory, OAL) provides a strong basis for demonstrating the potential of NBSs and a contribution to the evidence about the effectiveness, as well as possible trade-offs that might need to be considered in their implementation. This potential must be demonstrated not only under today’s climate, but also tested across a range of possible future climates. The analysis of the present climate for each of the European OALs has been made on the basis of observational data and reanalysis datasets (e.g. ERA5 [6]), while the analysis of future climate scenarios is based on state of art high resolution regional climate model projections (e.g. EUROCORDEX [7]). The concept of OAL was introduced in a specific project devoted to the delivery of scientific products to the community to investigate

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environmental issues [9,12]. An OAL is not intended as a merely laboratory site, but as a location where real natural hazards are coped with efficient tools, being the OAL as a bridge between the decision-makers and the scientific community. The OPERANDUM OALS were positioned in several areas of Europe, specifically where NBSs are installed or are likely to be installed. The coping of natural hazards is performed by using a variety of strategies, including remote sensing tools [13], social vulnerability mapping and cost analysis.

The OAL Italy consists of three different sites of the Po Valley, an area characterized by a warm and temperate climate with hot summers. It is a very heterogeneous area in terms of land use and is subject to various risks: floods and consequent penetration of salt water, with threats to ecosystems and biodiversity; drought; saline intrusion into estuaries during periods of drought, with pollution of wells; storm surges and consequent coastal erosion. The specific sites of interest are the Panaro River, Po di Goro and a coastal area (Lido di Volano).
Four types of NBS have been considered: artificial dune, meadow of marine herbs, installation of herbaceous plants and installation of halophytic species. In the present work, the image acquisition was performed at the Lido di Volano area, subjected to coastal inundation and erosion due to storm surge and waves. Here two different NBSs were proposed to mitigate these hazards, i.e. the sand dune and the marine seagrass set up in the coast's proximity [9]. The combination of these two interventions represents a promising approach for the coastal protection solution. The artificial dune was constructed as natural barrier between sea and land. It is built with natural materials (sand) and reinforced with coconut fiber and a wood structure through naturalistic engineering techniques. Native herbaceous and shrubby vegetation are then inserted on the dune. The dune has been designed by using an accurate hydro-morphodynamic modeling of the site, considering also the erosive dynamics and the local present and future climate. The effectiveness of artificial dune has already been demonstrated for example in [8]: it was shown that along the Oregon coast a dune provides a good level of protection. In [9] Gallotti et al. presented a series of sites where specific hydro-meteorological hazards are coped with NBSs. In particular, they discussed a multi-model strategy aimed to assess the efficiency of the dune realized in OAL Italy, since single numerical models are not able to simulate all the processes involved. Storm surge were modeled by a sea level model and a wave model. The models were coupled offline for two scenarios: the first one is related to the present climate, while the second one to a future period under climate projections with the "business as usual" IPCC RCP8.5 scenario [14].

4. Experiments and results

4.1 Site description

The Volano Beach is located over the coast of the Adriatic Sea, in the Emilia Romagna region. It is natural area and belongs to the Po Delta Biosphere Reserve. This area is strongly affected by marine erosion and storm surges, which cause the sea water flooding the lagoon, threatening biodiversity and freshwater ecosystems. The main alongshore current is oriented northward and tends to move the local sediments in this direction. The main wind regimes are Bora (north-east) and Scirocco (south-east).
In this site an artificial dune was created as NBS, which is useful both for monitoring the NBS and for validating the repeatability of the experiments and measurements. Figure 1(a) shows the region of interest, identified by the yellow line, while Figure 1(b) shows an enlarged view of this area.

Figure 1 - (a) Region of interest for the experiments (yellow line); (b) An enlarged view of the site.

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4.2 Drone Camera

The sensor employed for the acquisition is the MicaSense Altum, which provides multispectral images for agricultural applications and is very interesting in terms of precision, flexibility and power, all in a small and light package, ideal for aircraft/from drone. Figure 2 summarizes the technical specifications of the sensor which acquires images in 6 bands: red, green, blue, red edge, near infrared and thermal. Acquisition of these images occurs at the same time, and this synchronization simplifies alignment and use of the data for advanced analysis.
Images are acquired with five high-resolution lenses, so you can get the level of detail you need on plant health and create detailed digital surface models, even from 120 meters, increasing time-of-flight efficiency. Moreover, a high capture rate lets you fly faster and at lower altitudes without compromising data quantity or quality. The high-resolution images can be used to acquire data on plant health, phenotype, water stress and soil health, all in one flight.
The Altum sensor integrates with a wide variety of drones from different manufacturers, and flight planning and camera configuration are also settable from other commercial software. From an output standpoint, the Altum produces standard 16-bit Tiff files that are easily compatible with a variety of editing programs.

Lens and Imager Information

	Multispectral	Thermal
Pixel Size	3.45 um	12 um
Resolution	2064 x 1544 pixels	160 x 120 pixels
Aspect Ratio	4 : 3	4 : 3
Sensor Size	7.12 x 5.33 mm (8.9 mm diagonal)	1.92 x 1.44 mm
Focal Length	8.0 mm	1.68 mm
Field of View (h x v)	48° x 36.8°	57° x 44.3°
Thermal sensitivity	--	< 50 mK
Output bit depth	12-bit	14-bit
GSD @ 120M (~400ft)	5.2 cm	81 cm
GSD @ 60m (~200ft)	2.1 cm	41 cm

Center Wavelengths and Bandwidth

Name	Center	Bandwidth
Blue	475 nm	20 nm
Green	560 nm	20 nm
Red	668 nm	10 nm
Red edge	717 nm	10 nm
Near infrared	840 nm	40 nm
Thermal	8-14 um	

Figure 2 - Micansense Altum techincal specs.

4.3 Data calibration

In order to use the image analysis tools correctly, it is necessary to calibrate the reflectance data. In fact, every object absorbs and reflects a certain amount of light. The amount of light reflected and absorbed by an object (also called "reflection") can be measured using specialized equipment. Without a calibration process, data captured on different days or at different times of day cannot be accurately compared for changes. To do this, an image of a calibrated reflectance panel must be captured immediately before and immediately after each flight. Panel images are used to compensate for lighting conditions at the time of image capture. Images of a calibrated panel taken before and after each flight provide an accurate representation of the amount of light reaching the ground at the time of capture. The Altum MicaSense sensor used for the acquisitions includes a calibrated “panel” that can be used to calibrate the reflectance values of the sensor (Figure 3).

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Figure 3 - Micasense Altum calibration panel.

Typically, this also applies if a single field is covered in multiple flights, *i.e.*, always take a panel image before and after each flight for that field. This is because between one flight and another, the lighting parameters of the scene could change. Before capturing the panel, you must ensure that the camera has a good GPS position so that the panel images contain appropriate location and time information. This is important for post processing. The panel must be positioned flat on the ground, away from any objects that could affect the light that illuminates it. And the drone with the sensor should be held in such a way that the panel is centered in the field of view and in such a way that there are no shadows on the panel. The camera should be directly above the panel if possible, or slightly offset to avoid shadows. Shadows on the panel will invalidate the reflectance compensation readings. Also, if the light reflects off another object and then the panel, the readings will be inaccurate. Finally, it is important to make sure that the light sensor has a full view of the sun and that you do not have to cover the light sensor when capturing a panel. This could cause incorrect reflectance calibration in image processing software.

4.4 Mission Planning

In order to guarantee repeatability and comparability with image acquisitions carried out at different times, it was necessary to pay attention also to the repeatability of the flight. In this sense, particular attention was paid to mission planning through the "mission planner" software. The generated flight trace guarantees an overlap between the acquisitions (both frontlap and sidelap) of at least 75% and that there is sufficient space at the end of each flight trace to allow the aircraft to realign itself for the next pass. Furthermore, the flight plan created (shown in Figure 4) has allowed and will allow for the future to fly over the region of interest always in the same way (same speed, same altitude and same path), making image acquisitions made at different times comparable.

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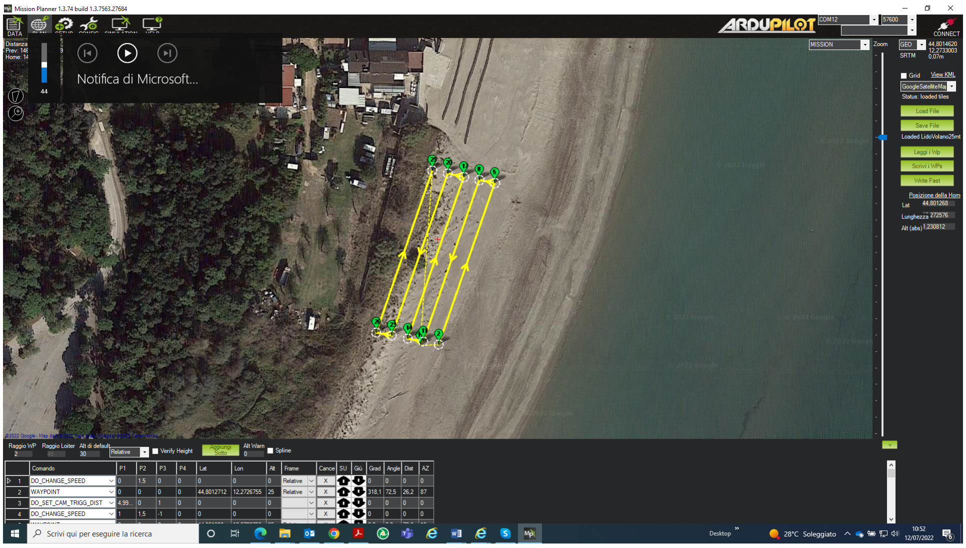

Figure 4 - Acquisition path.

4.5 Data Processing

For the processing of the acquired data, many commercial software allow you to create image processing workflows, starting from the calibration of the radiometric data, up to the generation of orthomosaics, three-dimensional reconstructions and volumetric measurements. On the orthomosaics it is possible to define evaluation indices of the state of health of the vegetation and, where possible, also indices of the humidity level of the soil. It will therefore be possible to carry out data processing with minimal intervention by human operators by relying on image processing platforms acquired in proximal sensing which guarantee very often optimal quality levels of the result. The typical operations to be carried out and any modifications to be made in case of measurement specializations are indicated below.

The first operation to be carried out to obtain consistent results between the various acquisition campaigns is radiometric calibration, i.e. the correction of the individual bands of the acquired images to standardize what was acquired at different times and with different lighting conditions. At this point, the operator is able to calculate the NBS effectiveness indicators on images that are coherent with each other. At the end of the project, the indicators and the relative ranges of effectiveness of the NBS will therefore be disclosed. In order to identify the ranges of effectiveness of the indicators, for each new type of NBS it will be necessary to interface with domain experts. During operation, sector operators will also be able to interface with domain experts to enrich or refine the ranges of effectiveness proposed by this project. In fact, this interaction is both important for specializing the measurements for specific NBS and, at the very least, also for introducing new and more refined measurement levels.

Figure 5 shows the NDVI calculated over the area of interest behind the NBS. Indeed, the role of NBS was to protect this area from the sand of the beach which cause a damage on the vegetated areas. As can be observed, the NBS was effective since the vegetation shows high values of NDVI which means it is healthy.

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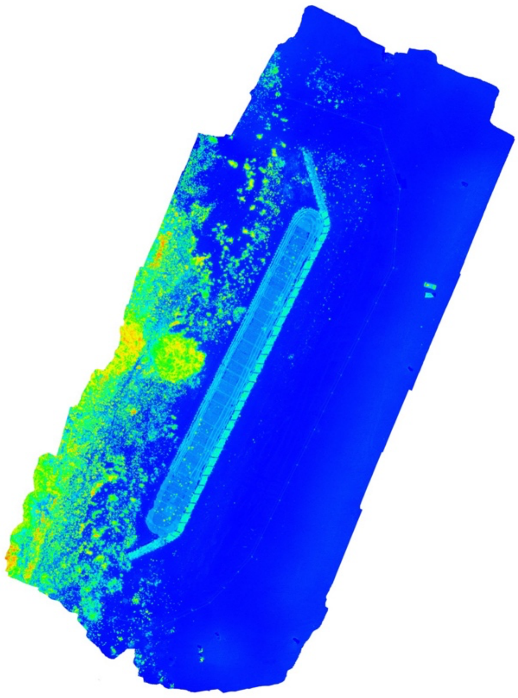

Figure 5 - NDVI of the vegetated area.

5. Conclusions

In this work, a repeatable and scalable image acquisition method over an artificial dune built in OAL Italy is presented. The dune is aimed to reduce storm surge and consequent coastal erosion. For this purpose, a drone is used suitably equipped with a multispectral camera and an advanced drone autopilot. High resolution spatial and temporal image sequences have been acquired in visible (RGB), red edge, near infrared and thermal infrared (LWIR) bands. Image processing allows to evaluate the surface of NBS, vegetation status and terrain temperature. Based on these acquisitions, selected indicators have been computed to evaluate the NBS.
Given the subjection to wear and the dynamic nature of some NBS, it is essential to monitor their evolution over time. Operators in the sector will be able to observe both geometric/structural and morphological/functional changes. Thanks to proximity remote sensing (acquisitions with a drone) and radiometric calibration procedures, it will be possible to track the changes of NBS characteristics. Thanks to this activity, economically inexpensive (cheap), it will be possible to evaluate the evolution of the effectiveness of the NBS and to plan ordinary and possibly evolutionary maintenance activities.

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