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Design a Web Platform to manage environmental monitoring information to be used in multicriteria evaluations of Green Infrastructures

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Abstract. The aim of the WEQUAL project "WEb service centre for QUALity multidimensional design and tele-operated monitoring of Green Infrastructures") is the development of a system able to support a quick environmental monitoring of watercourses where new hydraulic structures are intended to be built, encouraging the identification of design solutions supporting the diffusion of Green Infrastructures (GI). The WEQUAL's idea is to organize a service centre where users (designer, technician, researcher) can access the service through a personal account and carry out an assessment of alternative GI projects.

Through some automatic procedures, accessible via a suitable web platform, a set of algorithms may be applied to process raw data collected by an UAV (Unmanned Aircraft Vehicle) equipped with a 3D Lidar, multispectral camera and RGB camera, for the purpose of calculating the WEQUI Index. The WEQUI index is used to assess the eco-morphological status of the monitored watercourse, taking advantage from data related to NDVI index, Digital Terrain Model (DTM), Digital Surface Model (DSM) and a 3D point cloud classification.

The computed value of the WEQUI index may be used to assess the eco-morphological quality at ex-ante and ex-post river stabilization or protection intervention. The platform will provide a shared environment integrating indices calculations and environmental-parameters assessment for multidimensional evaluations.

Keywords: Information Management, Field Surveys, Data Logging, Multidimensional Evaluations, River Ecosystems, Environmental Monitoring

1. Introduction

In the last period, European Union (EU) increased its interest in Green Infrastructures (GI), especially in river environments, in order to safeguard biodiversity of ecosystems, with the principal aim to ensure proper safety levels to people, villages and infrastructures. For this scope, the European Environmental Agency (EEA) has stated different policies and directives on this topic, such as the Water Framework Directive (WFD-2000/60/EC) and Flood Directive (2007/60/EC) [1, 2]. The Water Framework



Directive aims at classifying water bodies and to identify anthropogenic impacts on them, in order to carry out qualitative and quantitative evaluation of the improvement of river systems, while the Floods Directive focuses on the design and planning phases of hydraulic works, with the aim of reducing the risk of natural disasters due to floods, landslides or erosion and safeguarding aquatic ecosystems [3]. In this way, EEA works towards ensuring high standards of ecological quality, biodiversity and riparian functionality in all riparian lands. The respect of those principles has become a key issue for technicians and specialists involved in river management.

The aim of the WEQUAL project (“WEB service centre for a QUALity multidimensional design and tele-operated monitoring of GI”), developed within the European EFRE-FESR Südtirol-Alto Adige framework, is the development of a new decision-support system, able to support a quick environmental monitoring of watercourses where new hydraulic structures are intended to be built. The system includes a data analysis service able to provide promptly the ecological indices usually required by the EU directives, which can be easily used then within multidimensional evaluation approaches, aiding decision-makers featured by different standpoints. In short, the project’s idea is to organize a service center managing both the web platform and the whole data collection and analysis process, in order to quickly and automatically assess the environmental impact of lateral and transverse hydraulic structures. Thus, the final user of the product, such as technicians, administrators or researchers, can use an innovative tool as a decision-support system. Through a personal account, the user can access the service and require the evaluation of alternatives GI projects, minimising in-field activity. Then, all the required assessments will be sent to the user via web by the service center.

2. Material and Methods

The paper describes the approach followed to collect and process data acquired by automatic survey carried out through remote sensing applications. For this task, a UAV equipped with different sensors has been specifically developed and used for raw data collection. All those data are then post-processed by interpretative algorithms, to obtain information for the evaluation of the required eco-morphological indices. All the implemented algorithms run in MATLAB or Python environment.

2.1. The methodology

Within the WEQUAL project, a new assessment method was developed, aimed at evaluating the eco-morphological quality of watercourses. The method is called WEQUI (WEQUAL Eco-morphological QUality Index) and is based on the analysis of the 15 quality indicators listed in Table 1. The method is multidisciplinary and applicable to both highly-natural watercourses and artificialised watercourses (i.e. characterised by the presence of artificial elements, as for example hydraulic structures or infrastructures, within the river corridor).

The WEQUI method was inspired by some existing methods described in the literature, which were used as a reference to recognise those elements that are the most relevant for eco-morphological characterisation of watercourses [3, 4, 5, 6, 7, 8]. In this way, 13 quality indicators were identified, concerning multiple aspects related to bio-physical aspects. Then, further two indicators were added to complete the method. These two indicators include a kind of assessment of the carbon emission and absorption observed during the whole life cycle of artificial structures, i.e. from the production/construction phase to the full-operating condition, when a new equilibrium is reached by the local ecosystem after construction.

WEQUI is intended to be used for two main purposes: (a) evaluating and monitoring the condition of homogeneous portions of a watercourse, leading to the identification of positive and critical elements affecting eco-morphological quality, and (b) estimating long-term eco-morphological alterations introduced by artificial elements, either present or designed.

In both cases, indicators are intended to be assigned according to both qualitative and quantitative information. Profitable quantitative information can be obtained through remote-sensing surveys, using proper sensors, as described in the next Sections. High-resolution data collected in this way can be

processed profitably, applying some custom algorithms specifically implemented within the WEQUAL project (see Section 3) and able to provide values of some significant variables and indices (e.g.: cross-section elevation and slope, vegetation metrics, NDVI). Such variables and indices can be used to guide effectively the attribution of several indicators of the WEQUI method. The assessment procedure leading to the calculation of the WEQUI index is integrated in a tailored web platform, conceived according to the Software-as-a-Service approach and currently under development. The web platform will be accessible through a simple login (registration will be free of charge). Such a tool is intended as a support for users applying the WEQUI method for both the (a) and (b) purposes.

Table 1. Indicators to be evaluated for the eco-morphological assessment of fluvial areas. They are divided into two categories: indicators which assessment can be based on remote-sensing data processing and indicators that require necessarily a different type of assessment.

Indicators assessable through remote-sensing data processing	Indicators differently assessable
1) Land use	3) Vertical continuity
2) Lateral continuity	7) Hydrologic regime
4) Longitudinal continuity	8) Chemical quality
5) Morphological heterogeneity	9) Macrobenthos community
6) Retention capability	15) Carbon footprint
10) Fish suitability	
11) Riparian strip vegetation	
12) Riparian strip width	
13) Riparian strip continuity	
14) Carbon sequestration	

2.2. Raw data acquisition

Within the project, different Unmanned Aerial Vehicles (UAVs) have been developed to collect data within riparian areas. UAVs are increasingly used in environmental monitoring due to their highly flexibility [9]. The flying platforms developed for WEQUAL show different configurations (fixed-wing and rotary-wing) and, therefore, different flight performances.

The AGRI-1900 (Figure 1a) is a fixed-wing UAV. This kind of configuration has a very high aerodynamic efficiency, resulting in higher flight endurance (typically 30 ÷ 45 min). Since the survey speed is quite high (12 ÷ 15 m/s – 43 ÷ 54 km/h), this platform is able to cover large area (25 ÷ 50 ha) with a single flight. The autopilot onboard increases the aircraft stability and aids the pilot in controlling the vehicle. The main drawback of the fixed wing configuration is that a wide area free from obstacles is necessary for take-off and landing manoeuvres. The flight altitude is high (100 ÷ 150 m AGL), thus the resolution of the survey is low. A fixed-wing platform returns outputs with the maximum representativeness, but with low details.

Rotary-wing UAVs have the capability to take-off and land in narrow spots as well as they are able to fly in hovering. Rotary-Wing UAVs carry out heavier payload in comparison with a fixed-wing UAV with the same Maximum Take-Off Mass (MTOM). The flight altitude is low (30 ÷ 70 m), thus the resolution of the collected data is high. Therefore, rotary-wing UAVs return the maximum detail level, but with low representativeness of the overall scenario. The main drawback of this kind of platform is the low endurance (typically 15 ÷ 20 min) and low survey speed, thus they can monitor limited area (2 ÷ 5 ha) with a single flight. The Q4E (Figure 1b) is a quadcopter and it has been specifically designed and developed within WEQUAL project, to carry an RGB camera or a multispectral camera. The DJI S900 (Figure 1c) is a multicopter with 6 rotors and it has been modified to embark a LiDAR sensor. Finally, the DJI Spark (Figure 1d) has been modified to reduce its weight below 300 g. Thanks to its

low weight, it can be operated in urban areas or close to critical infrastructures (railways or highways) without a specific permit to fly (ENAC, 2018).

Table 2 shows the main features of these four UAVs and the sensors they are able to carry onboard.



Figure 1. The UAVs developed during the WEQUAL project. Each one is used for different tasks and it is equipped with specific sensors: a) MAVTech AGRI-1900 for multicamera or RGB survey for large surfaces; b) MAVTech Q4E for multicamera or RGB survey for small surfaces; c) DJI S900 for LiDAR surveys; d) DJI SPARK for video recording.

Table 2. UAVs main features and sensors

	Mavtech AGRI-1900	Mavtech Q4E	DJI S900	DJI Spark
Configuration	Fixed-Wing	Rotary-Wing	Rotary-Wing	Rotary-Wing
Nr. Of rotors	1	4	6	4
MTOM [kg]	2.8	3.5	8.2	0.3
Diagonal wheelbase [m]	-	0.590	0.900	0.17
Wingspan [m]	1.90	-	-	-
Endurance [min]	45	20÷25	15	15
Survey speed [m/s]	12	6	3	2÷5
Surface per mission [ha]	40	4	5	-
Sensors	RGB camera Multispectral sensor	RGB camera Multispectral sensor	LiDAR	Integrated videocamera

The Sony RX-100 is the RGB camera used in the project. It has a resolution of 20.1 MP and a 3x optical zoom. During photogrammetric surveys, the focal length is fixed to the lower value (8.8 mm), thus the angle of view and the footprint are the maximum for this camera. The multispectral sensor is the Micasense RedEdge-M. It is able to acquire, at the same time, five different images in the bands of BLUE, GREEN, RED, REDEGE, NIR. The resolution of each image is 1 MP and, thanks to the GPS connected to the camera, the position of each image is stored in the Exif metadata. This information is very useful during the mosaicking procedure. RedEdge-M employs narrow filter that increase the sensitivity in comparison with modified camera, to capture the most relevant segments of the spectral curve and to obtain higher quality multispectral images.

Depending on the flight altitude, the RGB camera and the multispectral sensor record images with different Ground Sampling Distance (GSD). Table 3 shows the difference between the two sensors.

Table 3. Ground Sampling Distance (GSD) at different flight altitude for the RGB camera and multispectral sensor

Flight Altitude	Sony RX-100 GSD [cm/pixel]	Micasense RedEdge-M GSD [cm/pixel]
50	1.4	3.4
70	1.9	4.8
120	3.3	8.2
150	4.1	10.2

The LiDAR sensor is used to obtain the three-dimensional model of the riparian area. It exploits the Light Detection and Ranging technique to measure the distance between an object or a surface with a laser pulse. A GPS-INS platform determines the position and the attitude of the sensor. A PPK (Post Processing Kinematic) correction is performed to improve the geo-referencing of the dataset.

The LiDAR sensor employed in WEQUAL project is the Yellowscan Surveyor. It is capable to records two echoes: the first one is related to the top of the canopy, while the second one represents the soil. Depending on the flight altitude and the survey speed, the point cloud density changes, according to Figure 2. For the project purposes, 3D models with point cloud density of at least 100 points per square meters have been obtained.

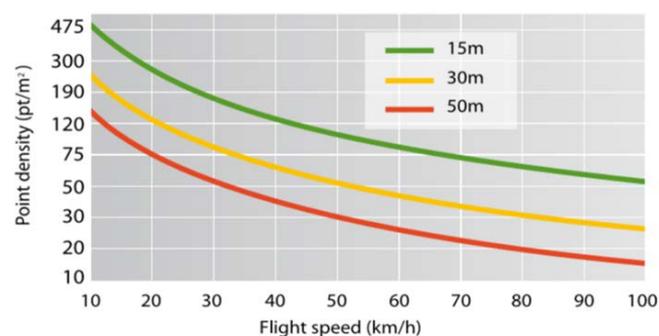


Figure 2. Point Cloud Density and survey speed for the Yellowscan LiDAR [10].

3. Results

Once remote-sensing data have been acquired and sent to the processing center, a set of ad-hoc algorithms are used to evaluate eco-morphological indices. Up to now, the implemented algorithms

allow to assess just a couple of indicators among those listed in Table 1, i.e.: the land use assessment and the riparian strip identification.

The process includes the use of NDVI, Digital Terrain Model (DTM), Digital Surface Model (DSM) and a 3D point cloud classification, achieved by a LiDAR survey.

The NDVI extraction permits to distinguish among areas covered by riparian vegetation rather than by water or soil (Figure 3). At this step, only multispectral data are considered to calculate the water, vegetation and soil coverage.

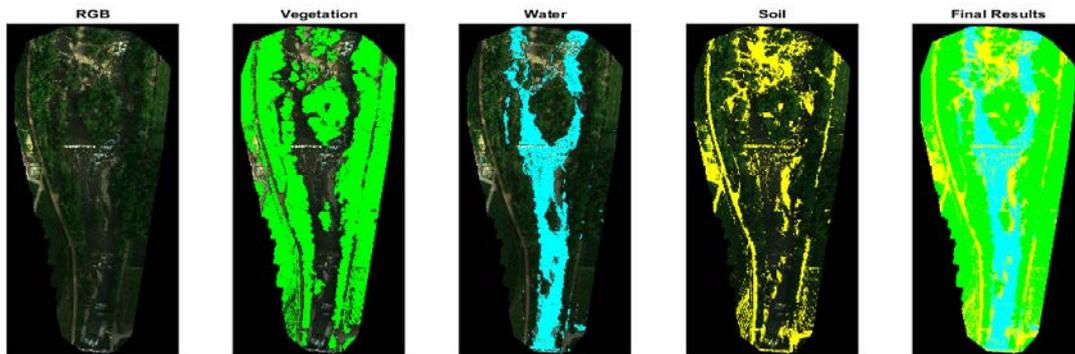


Figure 3. Graphical results obtained by the algorithm's elaboration for the distinction of the land cover. In Green, Cyan and Yellow are identified the vegetation, water bodies and soil, respectively.

Information provided by the vegetational index analysis is then processed together with data contained in the DTM/DSM maps. The digital models of the terrain are considered here to evaluate vegetation height, in order to provide a trees classification based on their height. In this work, four classes of plants are defined:

- “Grass”, height from 0 [m] to 0.5[m];
- “Bushes”, height from 0.5[m] to 1 [m];
- “Small Trees”, height from 1 [m] to 3[m];
- “High Trees”, height from 3[m] to 40[m].

At the end, the integration between multispectral data and LiDAR data generates the classification map of the investigated area differentiating water, soil and the 4 classes of vegetation (Figure 4).

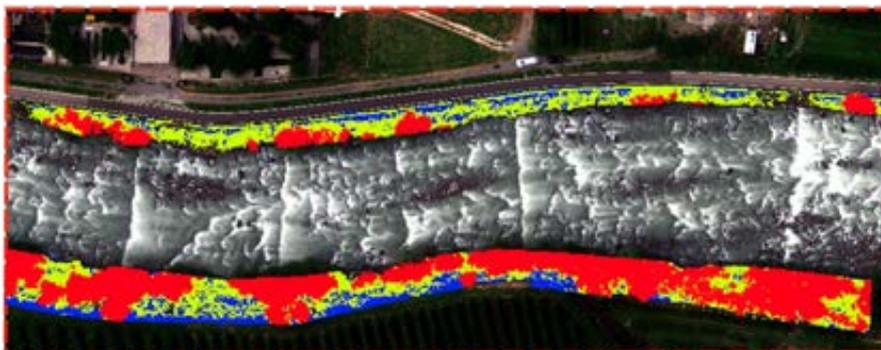


Figure 4. Graphical result of algorithm procedures for riverbanks, riparian and alluvial riparian vegetation (the green, blue and red colors refer to the herbaceous layer, riparian shrubs and riparian arboreal, respectively).

Acquired data could be considered also to support the assessment of other WEQUI indices, for example computing river sinuosity or the variability of banks and slopes or identifying the presence of artificial structures (for example transverse and lateral hydraulic structures). Processing data collected by the LiDAR survey, the algorithms can recognize river banks through the analysis of the frequency distribution of elevation and slope in the areas near the watercourse. Thus, the process identifies the riversides as well as their slope considering the cross-section of the river (Figure 5).

At the end, to provide the user a final evaluation of the eco-morphological state and impact of the riverside environment, the platform's multidimensional analysis tool combines results obtained from remote-sensing data processing and some other information in order to generate a concluding document where all the 15 eco-morphological indices of WEQUI are quantified and the quality level of the watercourse is classified.

Results produced by the automatic assessment procedures are currently under validation.

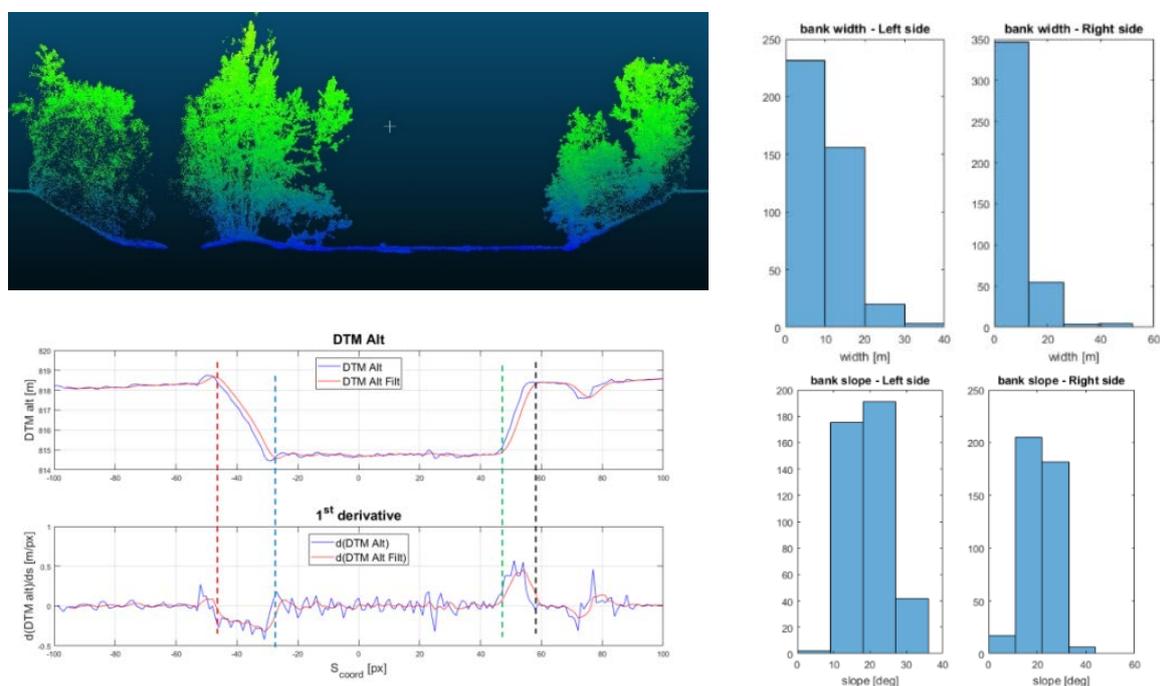


Figure 5. Exemplificative results obtained by the algorithms. Top left: a transversal river profile obtained by LiDAR (colors represent different classes of height). Bottom left: riverbank extraction from DTM. The algorithm identifies riverbank foot and head by means of first derivative analysis of the transverse profile. The slope values of the banks are used for the physical characterization of the banks. Right: side-features of the analysed sections

4. Conclusions

In conclusion, up to now, the developed algorithms led to the computation of some useful indices, supporting the calculation of the WEQUI index within a tailored web platform. These specific indexes could be used also to carry out multicriteria analyses, even enabling the possibility of integrating additional non-technical or non-ecological indicators such as investment required to build a new hydraulic structure, maintenance costs or social acceptance of citizens. Finally, the web platform is intended to get interests of GI designers and policy makers, providing a shared environment able to integrate detection and assessment of some complex indices and multidimensional evaluations supported by an expert guide.

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