Wetland monitoring through the deployment of an autonomous aerial platform

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Abstract. Wetlands in the Andean region have been altered and have been lost as a result of the agricultural frontier expansion and human activities. The disturbance of the paramo ecosystem by the destruction or alteration of the wetlands modifies the load and endowment of water to the hydrological systems, which provide water to main cities in the highlands. Therefore, the present work focuses on setting up the framework for wetland monitoring in the Andean paramo region using Unmanned Aerial Vehicles (UAVs). For this aim, the study was based on a mission profile using a fixed wing UAV incorporated with a RGB camera in one of the most documented wetlands in the Ecuadorian paramo region, Pugllohuma wetland. Furthermore, to assess the saturation of the wetland, field testing data has been collected to set the range values of saturation for the monitoring system. In the same way, a review regarding multispectral imagery for the assessment of water and vegetation indices is explored and highlighted for future work. This work is a first stage in the monitoring process and hence it aims to set a baseline study for the implementation of a more detailed methodology.

1. Introduction
Wetlands are zones considered between terrestrial and aquatic environments; wetlands might be periodical or permanent flooded which is the key factor that controls their ecosystems [1]. The importance of wetlands lies on the services provided for the ecosystems and human society. As wetlands are efficient at nutrients removal improving water quality [2] while recharge the aquifer, as well they store sediments that could affect lakes and rivers downstream [3], help to moderate flows, reduce flood likelihood [4], provide habitat for animal and plant species contributing in the
biodiversity conservation of the zone [5], lastly, wetlands are consider carbon sinks storing hundreds of gigatons of carbon in the entire world [6]. Moreover, wetlands provide fish supply to inland rural communities, where often is the primary source of animal protein; the alteration or modification to this primary services provided by wetlands, compromises the equilibrium and sustainability of ecosystems, in consequence, it would have potential adverse effects to freshwater supply, food production, carbon cycling, flooding, and so more [7].

In this way, diverse monitoring methodologies to assess wetlands condition have been implemented. Employing different platforms such as satellite imagery, manned airplanes or unmanned aircraft systems (UAS). Though satellite imagery could provide high resolution products by a high cost, it is limited by the long periods of revisiting time [8]. Another option is the manned airplane platform, its organization and performance are quite complex as well as its operational costs are considerable high [9]. In contrast, UAS have shown to provide high spatial resolution, high temporal resolution and lower operational costs [10]. Hence, UAS represent a suitable and affordable option in comparison to other platforms for monitoring applications.

Furthermore, over the past decades UAS have been used for diverse monitoring applications ranging from forest inventories, wildlife inventories, biodiversity conservation, precision agriculture, natural-resources management, fire mapping and many more [11]. The applications directly depend on the sensor selected, as the UAVs have the capacity to use different payloads such as optical sensors like RGB or multispectral cameras or non-optical sensors like LiDAR systems.

The payload selection is crucial for the aircraft sizing as it influences directly to the UAV’s autonomy and performance. Endurance and range needed for a specific mission are in function the payload selection, design and environmental requirements.

As mentioned, environmental conditions interfere with the UAV performance. Therefore, for our case of study is considered the environmental conditions of the Andean paramo region. Wetlands located in the Andean paramo region are founded between the 11° N and the 8° S latitude, territories comprehended from the Cordillera de Merida in northern west of Venezuela to the Huancabamba depression in northern west of Peru [12]. Additionally, there are two separated paramo complexes, the first one in the Sierra Nevada de Santa Marta in Colombia, and the second one in the Cordillera de Talamanca between Costa Rica and Panama [13].

In this regard, this work sets the baseline framework to determine the operating conditions and wetland characteristics using empirical methods, in order to set a mission profile able to be monitored with a fixed wing UAV.

2. Methodology

The proposed methodology is structured in sequential phases from the data gathering in fieldworks, description of environmental and technical considerations, UAV layout and performance assessment, flight planning, mission deployment and data processing. Figure 1 illustrates the sequential phases of the proposed methodology, its inputs and outputs for the wetland assessment.

2.1. Define monitoring considerations

The water amount of wetlands changes periodically from the rainy to the dry season, and thus its boundaries. Hence, it is important to mark off limits to the monitoring zone. Through insitu fieldworks an outline of the wetland area is established, considering the ground slopes, drains and topographic accidents. Due to the complexity of the wetland ecosystem, in a first sight fieldwork is not possible to exactly delimitate the wetland boundaries. However, an approximation of the wetland area is convenient for the proceeding phases.

After sketching up the boundaries of the monitoring zone, it is necessary to perform a vegetation baseline field study. Since the vegetation condition, kind and composition determine the wetland capacity to retain and storage water. Identifying the predominant, endemic, or introduced species, gives a brief idea of the type of wetland and its condition.

Subsequently, it is important to set up an analysis of the zone weather conditions. By the historic reports is performed a climatological study of the temperature, relative moisture, precipitation, wind...
direction and speed, maximums, average and minimums. The evaluation of these parameters would provide a weather forecast for the monitoring zone, defining rainy and dry season, periods of wind turbulence and calm, and many other environmental factors that could interfere with the correct performance of the UAV.

Parallel, during insitu fieldworks, it has to be identified potential suitable places for the departure and landing of the aircraft, considering the flat zones as the most appropriate for these tasks. In the same way, it has to be established where the ground control points (GCPs) would be installed and how many of them; the GCPs are used for the global positioning system (GPS) on the georeferencing correction of the images.

**Figure 1.** General methodology for wetland monitoring through the use of UAS.
The identification of environmental conditions of the zone through in situ fieldworks and post analysis works, is basic to define the requirements that will be subjected the UAV and its mission.

2.2. UAV platform definition
Once the environmental conditions, design requirements and payloads to use have been defined, it is possible to start with the UAV layout and sizing considering the aerodynamic necessities of the zone. Regarding the payloads selection for the proposed methodology, a RGB and a multispectral sensor were selected.

The propulsion system is designed according to the weight and airframe geometry. Afterwards, the weight of the whole drone system is calculated (airframe, telemetry system, payloads, and propulsion system) based on the thrust, payload and the performance achieved.

Lastly, it is assessed if the needs and considerations accomplish the aircraft sizing and propulsion system design. The complete methodology for the aircraft sizing and propulsion system is detailed in [14]. It is important to highlight that this methodology considers the aircraft layout for flights above 3000 m.a.s.l where harsh operating conditions and sensitive ecosystem such as paramo, demand efficient propulsion configurations with low environmental impact. As final products of this phase, the range and endurance of the UAV are obtained. Additionally, GPS and telemetry system are selected as well, according to mission requirements established in the previous phase.

2.3. Mission deployment
For the mission deployment is necessary to know in advance specific parameters such as flight autonomous of the UAV, cruise capacities and the flight time with each sensor.

Firstly, an analysis of the UAV flight autonomy under the environmental conditions is carried out. Factors like the wind speed or height above the sea level influence directly to the UAV autonomy, which generally is specified for optimal operational conditions at the sea level. Thus, is fundamental to obtain the achievable flight time under any environmental condition, through empiric tests or theoretical estimations. Both, range and endurance, have to be estimated for the defined mission.

Second, using the cruise velocity the time needed in order to complete the flight mission is calculated. In spite of the dynamic environment, in which the UAV performs this speed could change slightly during the flight. For this reason, this speed has to be previously programmed to a set point that the automatic system will try to maintain.

Afterwards, it is evaluated the flight time corresponding to each sensor (as the payloads weight and lenses maximum aperture influence to the aircraft weight). In general, RGB sensors have a higher resolution and wider lens aperture than multispectral sensors, it means images captured with RGB cameras would cover more area in the same flight mission than a multispectral camera. Depending on the sensor, is determined the flight height, which has to be programmed according to the resolution required. Once these parameters are known, the mission plan is deployed. The mission plan refers to the autonomous flights pre-programmed with a specific route in the autopilot mode.

The route is given through GCPs or waypoints, each waypoint has a height and a flight speed associated. In this way, the autopilot takes these parameters as set points to accomplish the mission. When the monitoring area is delimited, an approximated polygon that encompass the whole wetland and its boundaries is designed. This shape is taken as reference for the outlining of the flight route. It is essential for the flight route to be uniform distributed inside the polygon.

2.4. Image processing
After the fieldwork, the images captured with the sensors are saved on its corresponding memory altogether with the telemetry data which will be used to amend the images. In this phase, the free access OpenDroneMap software is implemented.

The main aim of the image processing is to acquire georeferenced and corrected orthophotos from the two different payloads selected, such that obtain a high resolution 3D model from the RGB camera photogrammetry. This is also useful to obtain several wetland coverage maps from the indices analysis through the implementation of the multispectral cameras.
The image processing requires the GCPs data obtained previously; which is imported to adjust and amend the georeferenced accuracy. The products obtained with photogrammetry image processing are: orthomosaic, full colour point cloud, digital surface model (DSM), digital elevation model (DEM) and the 3D textured mesh. The integrated analysis of this products in complement with insitu fieldwork providing a suitable framework for the delineation, condition and water saturation study of the wetland. Boon [15] has demonstrated that UAV photogrammetry for wetland monitoring applications, shows accurate products to determine the terrain and geomorphology of the zone, as well to acquire detailed slope profiles. Moreover, is possible to identify water saturation and accumulation areas, surface water input drains and obtain an integrated surface hydrodynamic analysis. The processing of the obtained data with the multispectral camera proceeds with the same methodology as the RGB camera with the OpenDroneMap software. Subsequent the orthomosaic is georeferenced and corrected, it is necessary to distinguish the different kind of bands captured with the multispectral camera. Through the use of ArcGIS or QuantumGIS software, it is visualized the diverse bands that compose the multispectral imagery. The band calculator command incorporated in both software calculate the diverse indices for vegetation or water assessment. The assessment of water on the soil coverture could be perform by several indices such as moisture stress index, water index (IW), normalized difference water index (NDWI), modified normalized difference water index (MNDWI) or water index CEDEX. Meanwhile, vegetation assessment is reached through the analysis of indices like Green NDVI or most common and used, the normalized difference vegetation index (NDVI). The mentioned indices use specifically the red, blue and green bands from the visual spectrum and the shortwave infrared (SWIR) or near infrared (NIR) from the infrared spectrum. NDVI has shown to enhance determination and delimitation of disturbed areas within a wetland, as well to map the invasive vegetation extents. In consequence, it provides an integral vegetation assessment [16]. In conclusion, multispectral imagery extracts valuable information of the wetland contributing on its assessment and understanding. It is important to highlight that in the present case of study; the image processing phase has not been carried out, since this will be part of the future work during the implementation of the afore mentioned methodology.

3. Case of study

3.1. Monitoring conditions
The pilot zone is located in the Conservation Hydric Area Antisana (ACHA) to the south east of Quito, Ecuador. The wetland is known as Pugllohuma and it is found in the high Andean paramo region above the 4000 m.a.s.l., covers approximately 15 hectares and has an annual average temperature of 5°C. Pugllohuma conforms part of a wetland complex which endows water to the capital city. Formerly the natural drainage network was modified due to the construction of artificial drains in order to take out the water and let the cattle to feed from the wetland vegetation. In response, Fondo para la Protección del Agua (FONAG) installed 18 hydrological wells since 2016, to study the aquifer recharge and its water quality. These wells are vertical excavations of 1-meter-deep and 10 cm diameter that allow to get temporal data of how the phreatic level varies. Furthermore, FONAG is trying to recover and restore the wetland, through the implementation of wood weirs on artificial drains in order to stop the continuous loss of water. This approach and others that are implemented for wetlands restoration, require periodical and accurate monitoring tasks. In consequence, the creation of a methodology for the assessment and monitoring of the wetland is urgently needed. The ACHA zone is characterized for its low calm wind frequency and high relative humidity above the 90%. The seasonality of the zone is divided in two: rainy season from May to October, and dry season from November to April. Moreover, it is considered the periods of high wind turbulence from
April to October. Thus, it is important to establish the weather conditions through all the year, and identify the periods where the monitoring operations have to be performed carefully. Table 1 shows the temperature and wind considerations, that could interfere with the UAV platform through all the year, based on the climatological study of the year 2018.

### Table 1. Temperature and wind characterization of the pilot zone for 2018.

| Month   | Temperature (°C) | Avg. Wind Speed (ms⁻¹) | Calm Wind Frequency (%) |
|---------|------------------|-------------------------|--------------------------|
|         | Avg   | Max | Min |                      |                          |
| January | 3.9   | 13  | -4.5| 2.9                   | 6.78                     |
| February| 4.5   | 15  | -6  | 2.37                  | 6.41                     |
| March   | 4.8   | 13  | -2.9| 2.83                  | 7.57                     |
| April   | 4.6   | 13  | -2.8| 3.77                  | 4.04                     |
| May     | 4.4   | 13  | -2.2| 3.2                   | 6.88                     |
| June    | 3.6   | 10  | -1.6| 5.26                  | 5.43                     |
| July    | 3.9   | 12  | -2.5| 4.64                  | 2.6                      |
| August  | 3.7   | 12  | -2.7| 5.45                  | 3.68                     |
| September | 3.5 | 13  | -5.1| 4.05                  | 3.49                     |
| October | 4.4   | 14  | -5.2| 2.27                  | 7.66                     |
| November| 4.9   | 14  | -2  | 2.04                  | 8.89                     |
| December| 5     | 13  | -3.2| 3.84                  | 5.38                     |

3.2. UAV definition

According to environmental considerations, a UAV able to resist constant periods of turbulence and low temperatures is needed. In the same way, telemetry system has to consider the high relative humidity on the zone that could interfere with the telecommunication range. In this context, table 2 presents the basic geometrical and technical features for the UAV platform definition.

### Table 2. Basic features for the UAV platform definition with an electric pusher propeller.

| Parameter          | Value     | Parameter                  | Value     |
|--------------------|-----------|----------------------------|-----------|
| Weight             | 2.5 kg    | Telemetry range            | 5 km      |
| Span               | 1.9 m     | Mean aerodynamic chord     | 0.25 m    |
| Endurance          | 85 min    | Length                     | 1.9 m     |
| Range              | 60 km     | Tail arm                   | 0.75 m    |
| Cruise speed       | 12 m/s    | Max diameter fuselage      | 0.25 m    |
| Max payload        | 0.5 kg    | Motor dimension            | 700 RPM/V |

3.3. Mission deployment

‘Figure 2’ shows the most common mission for the geographic information survey in any case. It is worth to note that in the mission plan has to be included the landing and take-off routes. When it comes to a fixed wing UAV, it is required a way free of obstacles in order to rise or descend in a safe way. In order to define the landing and the take-off tracks ways with no natural obstacles such as trees, mountains, animal communities need to be identified. Besides, for fixed wing UAVs is crucial to considerate the wind direction, since is better for the aircraft to land and take off against the wind direction. ‘Figure 3’ shows the planned mission, the departure and take-off tracks commonly used in the monitoring area.
3.4. Water saturation measurement
For the present case, it has been evaluated how the phreatic level varies through all the year. Subsequently, once the digital elevation model (DEM) was obtained and it was overlapped with the water table. ‘Figure 4’ and ‘Figure 5’ show the data obtained from the hydrological wells and the DEM. As observed in the comparison of these two diagrams the high saturation places are located in the high regions of the wetland, as result of the vegetation in the high regions. This latter is identified in situ where the vegetation shows a larger capacity of capturing water. These images show the effectivity of gathering data for monitoring of wetlands, however the difficulty of deploying drones for the climate of the zone, limits the periodicity of measurements and hence constrains the collection of data to generate policies of protection and management. In this regard, it is needed to either increase the performance characteristics of the UAV to make it suitable for operating with high wind gusts, or improve the resolution imagery from satellites.

4. Conclusions
This work shows a baseline framework for the use of fixed wing UAVs for monitoring of Andean wetlands in the paramo region. Furthermore, the operating conditions have been identified in order to accomplish properly the monitoring of wetlands and it has been identified that currently commercial UAVs are not able to operate adequately for the periodicity needed. Finally, the operating conditions, a roadmap of the monitoring process and a complementary study with the phreatic level, which highlights the suitability of monitoring saturation of wetlands using UAVs is shown. From this latter there is a good match between in situ observations and information compiled. Future work will be focused on strengthen the automatic flight control of the UAV and better segmentation of the imagery gathered.
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