

UAV multispectral images for bathymetry estimation

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Abstract- Bathymetric data are commonly used for coastal erosion monitoring and engineering projects. Multispectral satellite imagery is nowadays commonly applied to derive bathymetry with different literature algorithms. The present study shows the results of a Unmanned Aerial Vehicle (UAV), also known as drone, derived bathymetry (UDB) equipped with a multispectral camera acquiring in the same WorldView-2 sensors spectral bands. An hydrographic Multibeam Echosounder (MbEs) survey was performed in the same period in order to validate the method accuracy. The study area is approximately 0.5 km² and located in Tuscany (Italy). Because of the high percentage of water in the images, an alternative method was also implemented for producing a georeferenced orthophoto mosaic. Multispectral images were processed to retrieve bathymetric data with Stumpf and Lyzenga algorithms. Results show the possibility to produce accurate UDB in shallow waters with low operational costs and the capability to obtain a full sea-floor coverage where MbEs is usually unable to work properly.

I. INTRODUCTION

Coastal environments are dynamic areas affected by long-term and short-term evolution caused by natural and/or human impact. A large portion of the world's population has always inhabited this areas and they represent a critical part of the economies of all nations bordering the sea [1].

Bathymetric data demand has recently increased considerably due to the upgrade of marine charts navigation, exploration of marine resources, environmental protection and coastal erosion or defence projects.

Bathymetric surveys are generally performed with Singlebeam and also with Multibeam technology to get more detail. Such approach requires hard field work and are extremely time-consuming and expensive, especially for wide and shallow water areas. At less than c.a. 2 m depth, a MbEs survey is very limited because of it's dimensions and characteristics and usually the bathymetry is carried out with a small boat equipped with SbEs echosounder and with a topographic survey near the shoreline.

Although the traditional hydrographic survey is still the first option to provide accurate bathymetry data, high resolution satellite images have found an increasingly application for coastal monitoring and bathymetric mapping. In the last years, satellite remote sensing have provided a cost and time-effective solution to the determination of the bathymetry in shallow water areas. Bathymetric mapping is carried out through high-resolution multispectral satellite image processing, such as WorldView-2 and 3, Quick Bird etc. [2,3]. Multispectral imagery derived bathymetry is based on the principle that electromagnetic radiation at different wavelengths can penetrate the water column to different depths.

Various methods have been proposed by several authors e.g. Lyzenga [4, 5, 6], Jupp [7], and Stumpf et al. [8]. The use of passive sensor data in bathymetry is affected by water, and bottom signals. Satellite images are also complicated by the atmospheric correction.

For bathymetric mapping the most accurate results reported for satellite multispectral approaches present a relative depth error of approximately 10% in water depths less than 15 m [9].

Actually, UAV is the fastest monitoring system for terrestrial and coastal areas. The processing of ortho-images provides a powerful tool for many habitats

monitoring. UAV technology has inherent advantages, such as full coverage of areas of interest, a very high accuracy and the ability to quickly deliver high temporal and spatial resolution images.

This paper presents a methodology for remote sensing bathymetrical data derivation using a small multispectral camera mounted on UAV. UAV Derived Bathymetry (UDB) accuracy has been verified through the comparison with a traditional bathymetric surveys.

II. LOCATION

The test area (Fig.1) is located on the central Tuscany coast at San Vincenzo (LI) in Italy. It is approximately 300x400 m and characterized by a sand beach and very shallow water with sandbars. Investigated depth was from the shoreline down to the *Posidonia oceanica* prairie inner edge, at about -10 m. Coordinate reference system for all the applied surveys was EPSG 32632 (WGS84/UTM 32 North) and the Military Geographic Institute (IGM) vertical national datum.

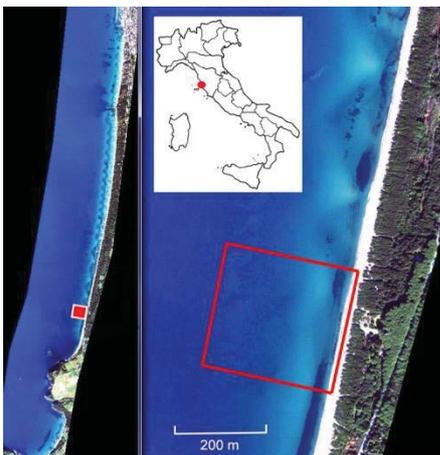


Figure 1. Location map and study area in the red square.

III. METHODOLOGY

Bathymetry was derived by the use of AUV multispectral images computed with widely used Lyzenga and Stumpf methods. The results were compared also with a bathymetric data survey.

Stumpf Relative Water Depth (RWD) algorithm uses a log-transformation to linearize the relationship between band spectral value and depth.

The algorithm uses a pair of bands in order to reduce the number of parameters and determine the depths. Because both bands are equally distributed, the error due to the varying radiation in the atmosphere, water column, and seafloor is reduced [10].

Equation 1 is used to estimate the depth in shallow water:

$$Z = m_1 \frac{\ln(nR_w(\lambda_i))}{\ln(nR_w(\lambda_j))} - m_0 \quad (1)$$

where Z = derived relative depth

m_1, m_0 = constants

R_w = observed radiance

$\lambda_{i,j}$ = bands

n is a constant chosen to keep the ratio positive for any reflectance value

Relative Water Depth was computed with ENVI™ 5 suite for different combination of band pairs (Coastal Blue-Green; Yellow-Green; Blue-Green) in order to estimate their influence in the accuracy of resulting Stumpf RWD.

The equations developed by Lyzenga are based on the fact that sea surface radiation is approximately a linear function of bottom reflectance and an exponential function of water depth. Lyzenga used an albedo-independent method to derive a bathymetric map from a multispectral scene. The method takes into account the exponential relationship of light attenuation through a column of water to develop a linear transformation function that relates observed radiance with water depth.

Equation 2 is the algorithm for loglinear inversion model:

$$Z = m_0 + \sum_{i=1}^N m_i \ln[L(\lambda_i) - L_\infty(\lambda_i)] \quad (2)$$

Where Z = derived relative depth;

m_0, m_i ($i = 0, 1, \dots, N$) constant coefficients for N spectral bands;

λ_i = bands

L = observed radiance

L_∞ = deep-water radiance

In the case of shallow water, the radiance observed by the satellite consists of four components: atmospheric scattering, surface reflection, in-water volume scattering, and bottom reflection.

In Lyzenga's 1981 correction method, sea-surface or atmospheric scattering are implicitly assumed homogeneous over the target area.

In Lyzenga's 2006 they are expected to vary from pixel to pixel and variations are related linearly to the radiance of the NIR band.

ArcGIS and ENVI™ 5 were used for data processing.

The UAV used for this study was a hexacopter equipped with MAIA WV (Fig. 2), a multispectral camera specifically designed to be employed on board of drones. MAIA WV has a 9 sensors array with 1.2 Mpixel (8 multispectral + 1 RGB) acquiring in the VIS-NIR

spectrum. It acquires on the same wavelength intervals of WV2 satellite, from 433 to 875 nm. CMOS sensors settled in MAIA has 1280x960 pixels and the dimension of each pixel is $3.75 \mu\text{m} \times 3.75 \mu\text{m}$. Each sensor is global shutter and they shoot simultaneously: it follows that it is not necessary to stabilize acquisition with gimbal, which is indispensable with rolling shutter sensors to avoid distortion, crawling and blurring pixels in the images. Images pre-processing software allows to correct raw image geometrical distortion and radial distortion; it also allows to stitch the images of each single band into one multispectral image with the pixel-pixel convergence.



Figure 2, UAV equipped with MAIA multispectral camera used for the survey

Nine multispectral images were acquired on April 2018 at 150 m flight height (Fig. 3) with fair weather conditions and in the morning with the sun low on the horizon (Fig. 2) for sun glint reduction. Sun-glitter patterns produce, especially for UAV survey, an irregular noise in the water reflectance difficult to be completely removed. Hedley method [11] was applied for this correction.

Given the impossibility of applying a SfM (Structure for Motion) 3d model and a bundle adjustment to generate the orthophoto, because of the almost total presence of water in the images, an alternative technique has been tested.

Images were georeferenced using the UAV control-unit flight parameters as GPS position, heading, pitch & roll and knowing the camera ground footprint for that elevation (96x72 m), also verified with an RTK GPS survey. Furthermore, two buoys equipped with a GPS, recording position in real time, have been used as sea control points. Finally, a GeoTIFF image mosaic has been produced.



Figure 3, UAV flight plan

A SBEs, down to 2 m depth, and MBEs bathymetric survey down to 12 m were carried four days after on the study area (Fig. 4). These measurements have been converted into elevations relative to national vertical datum, and averaged at 3x3 m grid for noise reduction. A certain number of SBCPs (Sea Bottom Control Points) have been used for UDB output calibration (50, 200, 500 Pts). The rest of the points were used for method validation and verification of the results.

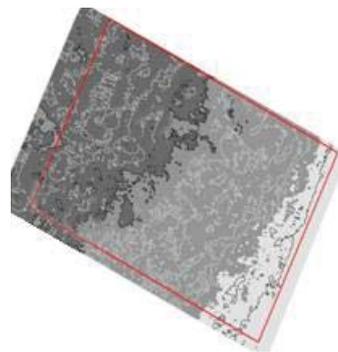


Figure 4, 2018 bathymetric survey

Significant morphological variations are present from the shoreline to the external side of the bar system (approx. 4 m depth), whereas offshore this limit minor changes occur.

Images processing sequence:

- Ortho-rectification and mosaic;
- Radiance and reflectance conversion;
- Land mask;
- Sun glint correction;
- Stumpf and Lyzenga methods testing different bands;
- Density slice at spectral reflectance intervals;
- Density slice calibration, with real survey depths, testing different number of SBCPs;
- Bathymetric map and DTM (Digital Terrain Model) at different scale resolution.

Figure 5 shows a UAV RGB image (a) and the UDB image (b) derived by applying the equation (1). Warm colours indicate shallow water, blue for deeper waters.



Figure 5a. UAV RGB Image

Figure 5b. UDB map using Stumpf method.

IV. RESULTS

The assessment of accuracy was made by comparing the UDB data generated by both models with the real bathymetry data (Full Dataset) acquired by MbEs and SBEs

In order to validate the results depth values retrieved from Lyzenga and Stumpf methods have been compared with 28.000 measured depth points derived from the bathymetric survey.

In general both models produced encouraging results. Stumpf processing is simpler compared to Lyzenga, that requires multiple regression methods, but delivers slightly rough results. Both models show a points dispersion growing with the depth and in the bars area around -4 m depth. The last could be explained with the fact that the bathymetric survey was performed some days after the UAV flight and the bars are a very dynamic area. The increase of dispersion after the depth of closure of the sediments, around -9 m for this area, must be attributed to the methodology.

Scatter plot of Surveyed bathymetry vs. Stumpf UDB is showed in Figure 6.

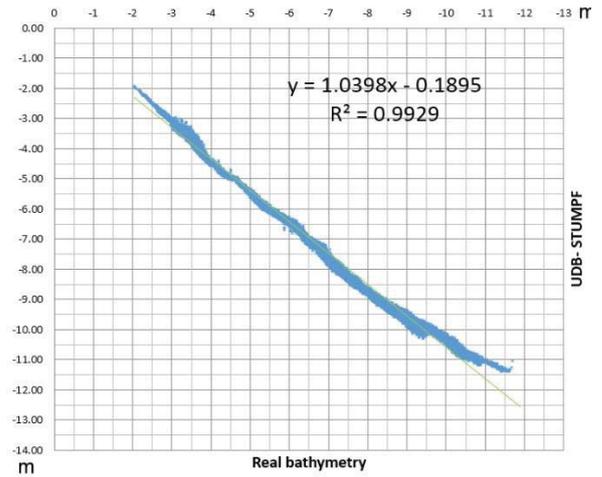


Figure 6. Stumpf UDB and measured bathymetry plot

In Surveyed bathymetry vs Lyzenga UDB graph (Fig. 7) points dispersion is lower and correlation higher. Under-estimation is in shallower and deeper water, whereas in intermediate water a light over-estimation is present. The same is significantly increasing approximately below 10 m depth.

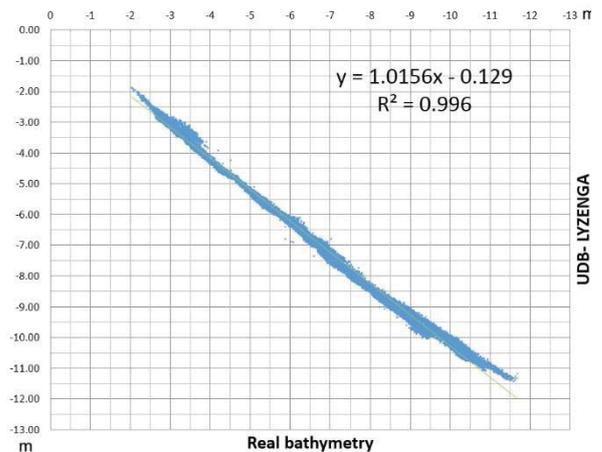


Figure 7. Lyzenga UDB and measured bathymetry plot

A comparison between surveyed and estimated bathymetric profiles, located at the centre of the study area, is reported in Figure 8, where a larger deviation from measured data for Stumpf than Lyzenga estimated bathymetry is evident especially for deeper data.

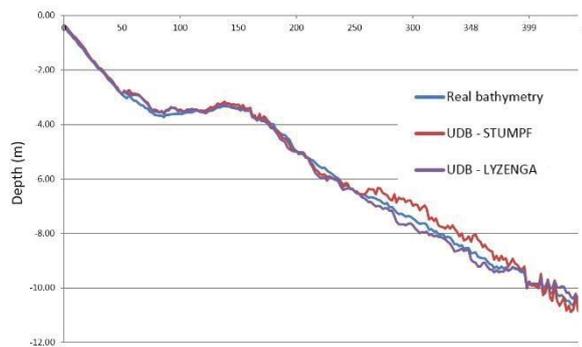


Figure 8. UDB and surveyed profile

A verification of the goodness of the results was made also with the Mean Absolute Deviation (MAD) between measured and estimated values (m) for both methods at different depth ranges for the considered full dataset points (Table 1, 2).

For Stumpf method best band combination in our test area and condition is Blue (440–510 nm) and Green (520–590 nm). On the contrary, using Coastal Blue and Green bands down to 5 m depth, MAD is 0.29 m (Table 1).

Table 1. MAD for different depth range and bands combination in Stumpf method.

Depth	Cost. blue, Green	Blue, Green
0-5	0.29	0.21
0-11	0.60	0.47

Table 2. Lyzenga and Stumpf UDB MAD at different depth range.

Depth	Lyzenga	Stumpf
0-5	0.19	0.21
0-11	0.41	0.47

Our test showed also as not many calibration points are necessary to obtain the most accurate bathymetry. Using 50, 200 or 500 calibration points the difference in terms of accuracy is less than 1 % of the depth down to -5 m.

V. CONCLUSION

In the study area Stumpf and Lyzenga UDB demonstrated to accurately estimate water depth in shallow water and homogeneous sea bottom. The methods may be suitable for implementation in a procedure for regular monitoring programs of sensitive coastal areas.

Lyzenga UDB accuracy showed to be slightly higher than Stumpf. In any case UDB seems to be more accurate than satellite derived bathymetry.

Furthermore, a disadvantage in using satellite images for any beach monitoring is the availability of data acquired in the requested period. Clouds presence and sea conditions can also limit images availability. On the contrary, UDB can guarantee low cost and easily acquired images for coastal monitoring on small to medium size areas.

Data availability with UAV survey is more immediate than with satellite and this is useful when other field activities must be carried out immediately after the survey and based on acquired data (e.g. sediment or water sampling) or in case of an urgent coastal monitoring. Moreover, it can be combined with the 3D survey of the emerged coast and is not necessary to perform any atmospheric correction.

With an accuracy of about 20 cm (down to 5 m depth) it allows to connect the dry beach topography to the MbEs survey, at depth where the latter cannot operate.

Further tests are necessary to better understand the real potential and limits of this methodology in order arrive to a standardization of the process and make it an useful tool for shallow water bathymetry.

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