A COMPARISON BETWEEN UAV AND HIGH-RESOLUTION MULTISPECTRAL SATELLITE IMAGES FOR BATHYMETRY ESTIMATION

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ABSTRACT:

Shallow water bathymetric surveys support Integrated Coastal Zone Management and Maritime Spatial Planning, e.g. in coastal erosion monitoring, shore protection design and landfall projects oil and gas pipelines. High-resolution multispectral satellite imagery, such as Quick Bird and Worldview, are increasingly used for this purpose. The present study shows the results of a comparison between high resolution satellite and Unmanned Aerial Vehicle (UAV) derived bathymetry. Accuracy was validated through an hydrographic survey performed with a Multibeam Echosounder (MbEs) at the same time of UAV acquisition. The drone was equipped with a small and light multispectral camera, acquiring in the same WorldView-2 sensors spectral bands. The study area, located in the central Tuscany coast (Italy), is approximately 0.5 km^2. Because of the high percentage of water present in UAV images, a new method was implemented to produce a georeferenced orthophoto mosaic. Multispectral images were processed to retrieve bathymetric data with Stumpf's algorithm. Different pairs of bands were tested to determine the best fit for real water depth data. The influence of sea bottom control points density on data accuracy was also analyzed. Results show the possibility to produce accurate remote sensing bathymetric maps with low operational costs and easy data processing, giving the chance to set up shallow water monitoring programs based on UAV surveys. A further advantage of this method is the capability to produce a full sea-floor coverage bathymetry in very shallow water areas, were MbEs is usually unable to work properly and to represent the aerial option to survey very shallow waters alternatively to Unmanned Surface Vehicles (USV) a.k.a. ASV (autonomous surface vehicles).

1. INTRODUCTION

Coastal environments are dynamic areas affected by long-term and short-term evolution. Nearshore hydrodynamic processes such as waves, tides, currents and fluvial discharges play significant roles in forcing short-term coastal morphological change.

The growing demand of bathymetric information is ascribed to marine navigation, environmental protection, exploration and exploitation of marine resources, fisheries, coastal defence, tourism and recreation.

Bathymetric data are usually acquired with Singlebeam Echo sounders system (SbEs) and lately also with Multibeam Echosounder system (MbEs). Such approaches require hard fieldwork and are extremely time-consuming, especially if wide areas have to be surveyed. In very shallow water, shipborne soundings regularly use a SbEs which is only capable to produce low spatial resolution data (Said et al., 2017).

Although the traditional hydrographic survey is still the first option to provide accurate bathymetric data, high resolution satellite images have been increasingly used for coastal monitoring and bathymetric mapping, particularly in shallow water areas. In the last years, satellite remote sensing have provided a cost and time-effective solution to gather bathymetric data in shallow water.

Bathymetric mapping is carried out through high-resolution multispectral satellite image processing, such as WorldView-2 and 3, Quick Bird etc. (Said et al., 2017). 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 (1978), Jupp (1989), and Stumpf et al. (2003). The latter, using a simple ratio of reflectance at different wavelengths, may be suitable for implementation in a procedure for regular monitoring programs of sensitive coastal areas.

For bathymetric mapping purposes the most accurate result reported so far using satellite multispectral approaches has a relative depth error of approximately 10% in water depths lower than 15 m (Panchang and Kaihatu, 2018).

Currently, UAVs (Unmanned Aerial Vehicles) are the fastest monitoring systems for coastal area and the processing of ortho-images provides a powerful tool for coastal and marine areas monitoring.

UAV technology has inherent advantages, such as full coverage of areas of interest with very high accuracy and the ability to quickly produce images with high spatiotemporal resolution.

This paper presents a methodology for remote sensing derivation of bathymetric data using a small and light multispectral camera mounted on a UAV. A comparison between bathymetric maps derived from multispectral UAV and Worldview2 images, using the Stumpf's algorithm, is

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also provided and their accuracy verified with a MbEs bathymetric survey.

2. LOCATION

The test area (Fig.1) is located on the central Tuscany coast at San Vincenzo (LI) in Italy. The area is approximately 300x400 m^2 and is characterized by a sandy beach with very shallow water and sandbars. Investigated depth was from the shoreline down to the inner edge of *Posidonia oceanica* prairie, at about 10 m depth. The coordinate reference system used for all the applied surveys was EPSG 32632 (WGS84/UTM 32 North) and national vertical datum referred to mean sea level recorded at Genova Tide Gauge in 1942.

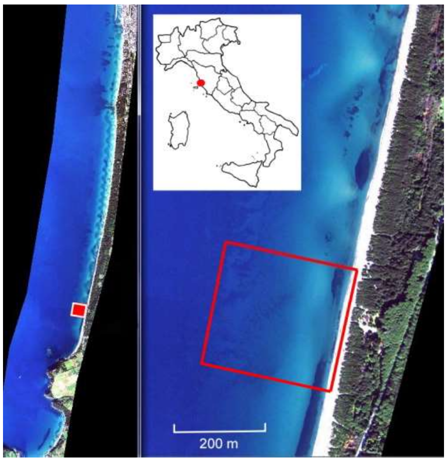

Figure 1. Location map on WV2 satellite image in true colours. In the red square the study area.

3. METHODOLOGY

Bathymetry was obtained by applying Stumpf et al. (2003) ratio transform algorithm on different band combination of WV2 and UAV multispectral imagery. Stumpf's 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 (Pushparaj and Hegde, 2017).

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 RWD.

Input data for the production of satellite-derived bathymetry map has been a WV2 image acquired on 13-12-2016 (panchromatic 50 cm res. + 8 multispectral bands 2 m res.). This was the most recent and good quality image available for the study area in terms of cloud coverage and sea waves conditions.

The Rational Polynomial Functions model has been used for the Ortho-rectification process using Ground Control Points (GCPs), taken from reference cartography. Nearest neighbour re-sampling technique has been used in order to preserve the original radiometric data. Radiance and reflectance conversion have been also applied. Finally, thresholding on band 7 (Near-infrared 1) was performed to mask out the emerged portion of the beach.

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 have 1280x960 pixels and the dimension of each pixel is 3.75 x 3.75 µm. 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-glint patterns produce, especially for UAV surveys, an irregular noise in the water reflectance difficult to be completely removed. Hedley et al. (2005) method 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 due to an almost complete presence of water in the images, a new technique has been tested.

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

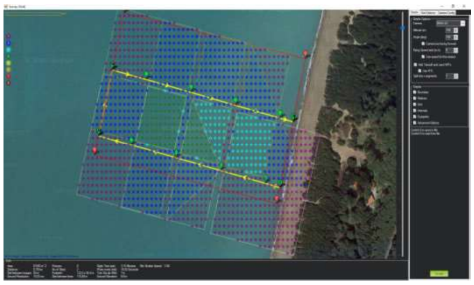

Figure 3. UAV flight plan

A SbEs, up to 2 m depth, and MbEs bathymetric survey down to 12 m were carried out on the same day on the study area (Fig. 4). These measurements have been converted into elevations relative to national vertical datum, and averaged at 5x5 m grid for noise reduction. A certain number of SBCPs (Sea Bottom Control Points) have been used for RWD output calibration (50, 200, 500 Pts). The remaining points were used for method validation and a verification of the goodness of the result.

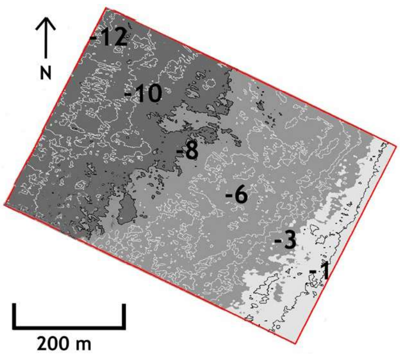

Figure 4. 2018 bathymetric survey

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 (SAT and UAV):

- Ortho-rectification – mosaic;
- Radiance and reflectance conversion;
- Land mask;
- Sun glint correction;
- Stumpf Relative Water Depth (RWD) testing different pairs of 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 (left) and the Relative Water Depth image (right) derived by applying the equation (1). Warm colours indicate shallow water (S) and cold ones for deeper waters (D).

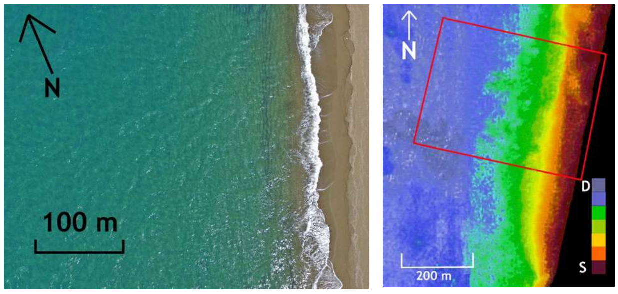

Figure 5. UAV RGB image (left) and Relative Water Depth image (right)

4. RESULTS

Depth values retrieved from UAV and from SAT images have been compared with measured depth in 28.000 points.

Scatter plot of Surveyed bathymetry *vs.* SAT RWD (Fig. 6) shows a points dispersion growing with the depth and in the bars area.

Poor correlation near the depth of closure, better with AUV RWD, where morphological changes are minor, are very likely due to accuracy reduction where light penetration is low, whereas point dispersion in the nearshore is mostly the result of morphological variation of the system in the time passed between the bathymetric survey and satellite image acquisition. Satellite data fairly average water depth between the bars and approximately 7 m depth; under-estimate depth in the bar area and in the very offshore part of the profile, whereas over-estimation is between -7 and -9 m.

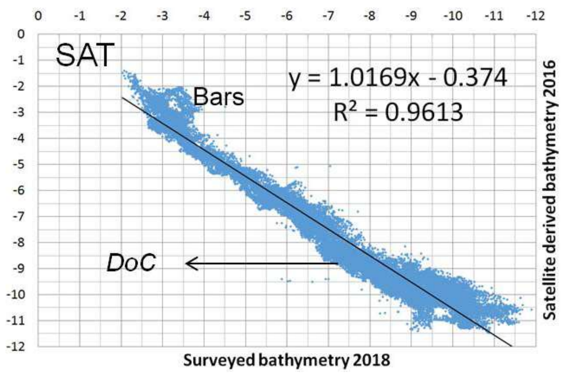

Figure 6. SAT RWD and measured bathymetry plot

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

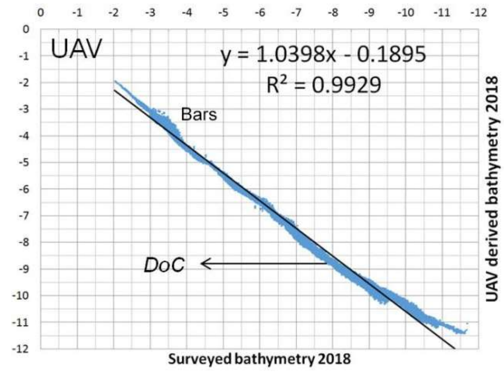

Figure 7. UAV RWD and measured bathymetry plot

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 for satellite than UAV estimated bathymetry from measured data is evident.

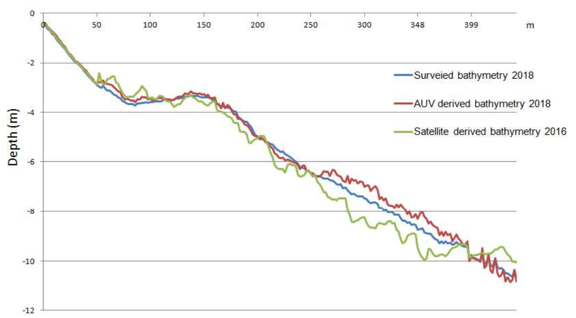

Figure 8. SAT-UAV RWD and surveyed profile

A verification of the goodness of the results was made also with the Mean Absolute Deviation (MAD) between measured and estimated values (m) at different depth ranges for the considered 28.000 points (Table 1).

Blue - Green		
Depth	**SAT**	**UAV**
0-5	0.43	0.21
0-11	0.59	0.47

Coastal Blue - Green		
Depth	**SAT**	**UAV**
0-5	0.49	0.29
0-11	0.71	0.60

Table 1. MAD for different depth and bands combination.

For both the methodologies best band combination in our test area and condition is Blue (440–510 nm) - Green (520–590 nm). On the contrary MAD using Coastal Blue – Green bands at 5 m depth was 0.29 cm.

Moreover, 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.

5. CONCLUSION

In the study area Stumpf et al. (2003) log-ratio model demonstrated to accurately estimate water depth in shallow water and homogeneous sea bottom. UAV derived bathymetry accuracy showed to be higher compared to what present in literature for satellite derived depth (Panchang and Kaihatu, 2018) and also confirmed in this research. This is more evident close to the depth of closure where morphological changes are minor reducing the possible error due to the two years before satellite data.

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, UAV surveys 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 sapling) 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 *circa* 20 cm (down to 5 m depth) it allows to connect the dry beach topography to the single- or 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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