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Advances in micro-cartography: A two-dimensional photo mosaicing technique for seagrass monitoring

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ABSTRACT

Seagrass meadows are complex ecosystems representing an important source of biodiversity for coastal marine systems, but are subjected to numerous threats from natural and human-based influences. Due to their susceptibility to changing environmental conditions, seagrasses are habitually used in monitoring programmes as biological indicators to assess the ecological status of coastal environments. In this paper we used a non-destructive photo mosaicing technology to quantify seagrass distribution and abundance, and explore benefits of micro-cartographic analysis. Furthermore, the use of photogrammetric tools enhanced the method, which proved to be efficient due to its use of low-cost instruments and its simplicity of implementation. This paper describes the steps required to use this method in meadows of *Posidonia oceanica*, including: i) camera calibration procedures, ii) programming of video survey, iii) criteria to perform sampling activities, iv) data processing and micro-georeferenced maps restitution, and v) possible study applications.

1. Introduction

Seagrasses are submerged vascular plants that grow in shallow marine and estuarine environments and fulfill important ecological roles on the shallow seaward margins of most continents. Seagrasses are considered as ‘ecosystem engineers’ given their ability to change numerous aspects of their environment (Duarte, 1999). Their importance is summarized in a set of axioms, which have become familiar to coastal managers and conservationists, often referred as ‘ecosystem services’ (Costanza et al., 1997; Duarte, 2002; Orth et al., 2006; Irving et al., 2011): i) act as primary producers, converting sunlight and carbon dioxide efficiently into organic form; ii) recycle nutrients and supply organic food to a variety of dependent food webs; iii) stabilize the seabed in which they grow and prevent erosion of the shoreline; iv) structure and oxygenate the seabed into a complex environment, which provides places for many organisms to exist; v) act as nursery area for many commercially-caught species, and vi) create an important natural sink for carbon.

Posidonia oceanica (L.) Delile is the dominant seagrass species in the Mediterranean Sea, and is also confined to this biogeographic region (Den Hartog, 1970). *P. oceanica* is a slow-growing climax species (Duarte, 1991) and develops large stable meadows, some of which are known to be older than 6000 years (Picard, 1965), and is recognized as a priority natural habitat under the EC Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora (EEC, 1992). Human-induced losses of *P. oceanica* are primarily related to coastal development, pollution, trawling, fish farming, moorings, dredging, boat anchoring, dumping and introduced species, which are likely to increase in the coming decades (Boudouresque et al., 2009). Knowledge of the spatial distribution, quality and quantity of *P. oceanica* habitat is fundamental for their sustainable management, to protect them from anthropogenic impacts (Jackson et al., 2001; Micaleff et al., 2012) and to assess coastal environmental quality. This is even more important considering the ecosystem services provided by *P. oceanica*, which can be estimated in a monetary value of approximately 216.7 USD m^{-2} a^{-1}, based on calculation of resources employed by nature (Vassallo et al., 2013).

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A plethora of optical and acoustic methods to monitor shallow sublitoral benthic habitats and communities, including seagrass beds, are available to marine researchers: light detection and ranging (Lidar) and multibeam sonar are used for broad scale studies; side scan sonar, remotely operated vehicles (ROVs) and towed cameras are generally employed for mesoscale studies, while photo - quadrats and video transects usually performed by SCUBA divers are often used for fine scale studies (Grizzle et al., 2008; Lirman et al., 2008; Rooper, 2008; Van Rein et al., 2009; Micaleff et al., 2012; Mallet and Pelletier, 2014). Additionally, optical methods based on satellite or aerial imagery can be reliably applied in intertidal areas when images are taken during low tide. Differently, in the sublittoral zone such methods are limited by cloud coverage, sea surface roughness and water clarity (Vis et al., 2003) and may be used in shallow water in only a few cases. However the underwater optical imaging provides short-range, high-resolution visual information about the ocean flHow (Prados et al., 2014).

Video-photography plays a valuable role in marine environmental research, especially in fine and meso-scale studies. Video and photographic images have been used effectively to study the distribution and abundances of seagrasses for many years (Romero, 1985; Inverson and Bittaker, 1986; Kirkman, 1996; Norris et al., 1997; Sgorbini et al., 2002; Yamamuro et al., 2002; Lathrop et al., 2006; MCDonald et al., 2006; Rende et al., 2010; Schultz et al., 2011; Irving et al., 2013; Lyons et al., 2013; Schultz et al., 2014) and, as a non-destructive technique, it has the advantage of leaving the meadow intact and causing minimal environmental disturbance, if any (McDonald et al., 2006). Nevertheless, interpretation of the video-photographic images is often time-consuming, subjective and non quantitative (e.g. low resolution, out of focus, etc.) (Crawford et al., 2001; Short et al., 2007).

Photo mosaicing represents a suitable technique to overcome these limitations, especially if a photogrammetry approach is applied to images. In essence, video-mosaicing merges several images of the same scene into a single and larger composite image photo mosaic (Escartín et al., 2008; Hoseini and Jafari, 2011) by aligning and stitching photographs together. A similar technique is widely used in photography for the production of panoramas. However, an interest in using photo mosaicing to map deep-sea environments is growing among the scientific community, and several works have focused on developing algorithms to reliably build underwater mosaics (Gracias and Santos-Victor, 2000, 2001; Eustice et al., 2002; Martin and Martin, 2002; Pizarro and Singh, 2003; Vincent et al., 2003; Allais et al., 2004; Gracias and Negahdaripour, 2005; Ferrer et al., 2007; Escartín et al., 2008; Drap, 2012; Marcon et al., 2013; Prados et al., 2014).

The photo mosaicing technique has received growing interest in the last decade (Zoghlami et al., 1997; Torr and Zisserman, 1999; Shum and Szeliski, 2000; Elibol et al., 2010, 2011, 2012, 2013) and it has been used in different types of underwater studies, such as the assessment of coral reefs (Lirman et al., 2007), macroalgal communities (Guinda et al., 2013) and in underwater archaeology (Henderson et al., 2013). To date, no study has been performed on seagrass ecosystems using this technique.

This research aimed to assess the benefits of photo mosaicing technologies when implemented by use of low cost photogrammetric instruments for monitoring seagrass ecosystems. We also show environmental quality based on seagrass distribution and abundance. To achieve these goals, seabed video mosaics were performed using a consumer video camera in meadows of *P. oceanica* and micro-cartography maps were produced. The steps required to undertake this method are identified and discussed. Possible study applications are suggested.

2. Material and methods

2.1. Study site and data acquisition

Field activities were carried out in July 2013 at the Penisola del Sinis – Isola di Mal di Ventre Marine Protected Area (Central Mediterranean, W Sardinia, Italy). Sampling was performed in a *P. oceanica* meadow at 3–5 m depth near its upper limit (39°59′23.18″N, 8°18′21.44″E). Video transects were taken following paths parallel to the coastline and maintaining a fixed distance from the bottom and a constant diving speed. Many video transects were acquired in the sampling activities but only one (50 m long and 3.7 m wide) is shown in this paper as an example. Videos were recorded using an underwater Towed Video Camera System Platform (Rooper, 2008), equipped with a caudal fin in order to reduce pitch and roll movements and stabilize video acquisition, a SeaViewer's Sea-Drop™ 6000 high-definition underwater video camera, with a surface console and two GoPro Hero 2 cameras (Fig. 1), which is a consumer-brand high-definition sport camera with an 11 MP HD CMOS sensor, 1/2.3″ in size. It uses a fixed-focus lens, which is made with professional-grade glass and has a maximum aperture of f/2.8. The GoPro Hero 2 records at different video resolutions and field of view (FOV). In this work we have used a 11 MP widescreen 1080p resolution at 25 fps and a FOV of 127°. The GoPro Hero 2 camera was positioned face down; this allowed us to obtain vertical images at the same distance from the sea bottom (Fig. 1). All video recordings were made in optimal conditions (calm and clear waters, no currents), in order to avoid non focused and moved images. Moreover, high frame rate allows to solve problems related to these movements of the plant.

2.2. Camera calibration

A calibration procedure is required to evaluate intrinsic and extrinsic parameters of a camera in order to reduce the distortion produced by the wide-angle lenses present on the GoPro Hero 2 camera. These parameters can be exploited for different purposes. In our case we focused on intrinsic parameters that allow recovery of any camera distortion to obtain rectified images more suitable for mosaicing, even from a wide-angle camera like GoPro.

Several calibration algorithms and methods have been developed and discussed in the literature, both in air and water (Bruno et al., 2011; Piaia Silvatti et al., 2012). Amongst them, we employed the *Jean Yves Bouguet's* Camera MATLAB® Calibration Toolbox, which is based on a perspective camera model, to calibrate our GoPro Hero 2 (Bouguet, 2010). This method provides different parameters and it is valid both in air and water. As shown in Bianco et al. (2013), these parameters implicitly model the refraction effect at the water-acrylic and acrylic-air interfaces of the housing, avoiding the explicit evaluation of ray tracing paths, which is not totally reliable due to its dependence on water temperature, pressure, and salinity.

The toolbox provides the following parameters:

- position of the principal point in the image plane (principal point);
- effective focal length;
- degree of pixel asymmetry (skew coefficient);
- image distortion coefficients (radial and tangential distortions).

The toolbox requires the acquisition of a calibration sample (i.e. a checkerboard); the coordinates of known points are correlated with corresponding coordinates on the image plane, facilitating the searched parameters by re-projection error minimization.

In this work we have calibrated the camera both in air and in