

A METHOD FOR GENERATING HIGH-RESOLUTION VIRTUAL OUTCROP MODELS AT THE LUSITANIAN BASIN, WEST OF PORTUGAL

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Resumo:

Virtual Outcrop Models (VOM) are digital and 3D representations of rock exposures at the Earth's surface. Traditionally, these models have been built using the technology of Light Detection and Ranging (LiDAR). A new way to construct these models is the Structure from Motion (SfM) algorithm. SfM is used to generate 3D models from raster images (2D) based on parallax effect. SfM algorithms use photography's acquired from a terrestrial or aerial digital camera. The first one depends on a stable place to set the camera and the manual configuration of the angles and positions used to capture the scene. The second can be obtained by airplanes or Unmanned Aerial Vehicle (UAV). The resolution of a VOM depends in a few parameters, as the photo resolution (camera and object distance), the overlap rate between the photos and by the computer configuration used during the processing. Aiming the desired resolution along all the study area, it's important to maintain the calculated setting during all acquisition flights. On targets placed in a map view this task can be done easily. On geological targets, rarely the object of study is placed this way. Due to this problem, this work proposes a new semi-autonomous way to acquire data, with UAV, aiming to produce high-resolution VOM. The study area corresponds of exposed rocks from a Jurassic succession situated at Lusitanian Basin, west coast of Portugal. Two main steps were followed to acquire aerial photographs of the area. The first one was focused on the construction of a low-resolution digital elevation model (DEM), using elevation information based on Shuttle Radar Topography Mission (SRTM). All data obtained at the first stage was then processed to construct a DEM with higher resolution compared with the SRTM. Using the results of the previous process as a control for autonomous flights in lower altitude, it was planned flights with 20m height. The data obtained with this second flight campaign was then processed to generate high resolution VOMs. The low-resolution models obtained an average resolution of 2 cm/pix, produced a DEM with an average resolution of 8 cm/pix. Models produced with photos obtained at the second flight campaign resulted in an average resolution of 8 mm/pix, DEMs with resolutions next to 3 cm/pix. Using this method for data

acquisition made possible to solve the problem of low continuity of flight settings during campaigns and making possible the construction high resolution VOMs.

Palavras-chave: VIRTUAL OUTCROP MODELS, DIGITAL ELEVATION MODEL, RESERVOIR ANALOG

Modalidade de Participação: Iniciação Científica

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1 INTRODUCTION

Virtual Outcrop Models (VOM) are digital and three-dimensional (3D) representations of rock exposures at the Earth's surface (e.g., Pringle et al., 2001, Pringle et al., 2006, Tavani et al., 2014, Casini et al., 2016, Vollger & Cruden, 2016, Cawood et al.). VOMs are mainly used to quantify the geometrical relations between geological features for geoscience teaching and research purposes. They can be an important tool for the Petroleum Industry when used as analog model for subsurface oil and gas reservoirs, where only sparse well information is available (Pringle et al., 2006, Howell et al., 2014, Bisdorn et al., 2014, Bisdorn et al., 2016, Tavani et al., 2016, Eltom et al., 2017).

Traditionally, these models have been built using the technology of Light Detection and Ranging (LiDAR). In the last twenty years, the improvements in computer science have brought a new set of tools to the construction of VOM. One of them is Structure from Motion (SfM) algorithm (Tavani et al., 2014). SfM is used to generate 3D models from raster images (2D) based on a parallax effect (Tavani et al., 2014, Vollger & Cruden, 2016). The implementation of these algorithms on software's with a graphical user interface (GUIs) brought several new possibilities for geological modelling in a way much more accessible than LiDAR (Cawood et al., 2017).

SfM algorithms use photography's acquired from a digital camera to construct a stereo pair, working with the same principles of stereophotogrammetry (Tavani et al., 2014, Vollger & Cruden, 2016). In other words, it must contain at least two overlapped photos, taken from two different positions. With the position of the camera, the parallax effect can be obtained by the apparent position displacement of the object, with respect to the camera location (Vollger & Cruden, 2016).

Photographs can be acquired using any terrestrial or aerial digital camera. The first one depends on a stable place to set the camera and the manual configuration of the angles and positions used to capture the scene. The second can be obtained by airplanes or Unmanned Aerial Vehicle (UAV). They can cover a bigger area of the object, and they can be collected in an automatic way (Cawood et al., 2017). The advent of Unmanned Aerial Vehicle (UAV), and the popularization of them (affordable prices) made it an efficient tool for obtaining aerial photographs, both horizontal and vertically, in a fast and cheap way.

The resolution of a VOM depends in a few parameters, as the photo resolution (camera and object distance), the overlap rate between the photos and by the hardware and software configuration used during the processing steps (Vollger & Cruden, 2016). All of them should be defined previously in a UAV photo acquisition campaign. Aiming the desired resolution along all the study area, it's important to maintain the calculated setting during all acquisition flights. On targets placed in a map view, parallel to the horizon, this task can be done easily with series of software (open source and closed source) aiming to control flight lines, velocity and shutter interval of the UAV.

On geological targets, with focus on stratigraphy, structural geology or analogous study, rarely the object of study is placed on a map view. Usually, they occur like cliffs, escarpments, quarry walls and road cuts. For this reason, the vertical control of the flight campaign is extremely important to maintain the desired resolution at the VOM. While important, obtaining a homogenous overlap rate and consequently the desired VOM resolution with the common flight configuration is a hard task.

Due to this problem, this work proposes a new semi-autonomous way to acquire stereo pairs, with UAV, on vertical and horizontal geological targets, aiming to produce high-

resolution VOM. The study area corresponds of almost 5 kilometers of exposed rocks from a fluvio-marine Jurassic succession, of Lourinhã Formation situated at Lusitanian Basin, west coast of Portugal.

2 MATERIAL AND METHOD

Unmanned Aerial Vehicle corresponds to the object remotely controlled in a semi-autonomous or autonomous way. This vehicle can be equipped with a photogrammetric measurement system, with a digital camera, infrared, thermal or LiDAR. This tool has brought many advances in aerial photo acquisition, with the possibility of vertical and horizontal flights, capturing images in a close distance and producing high-resolution tridimensional stereo pairs.

The resolution obtained at VOM's generated by UAV acquisitions depends on a series of parameters. The first one is the photo resolution. This can be understood by the ability to distinguish between closely spaced objects. On digital cameras, this is determined principally by the number of pixels occurring in the image, with a relationship directly proportional to the resolution.

The distance of the object of interest from the camera also influences the final result. The relation between the camera setup with the distance from the object determines the Grounding Sampling Distance (GSD). This, describes the relation of the photo pixel size to the terrain units, usually in cm or mm. The lower the GSD value is, the higher the photo resolution (Vollger & Cruden, 2016).

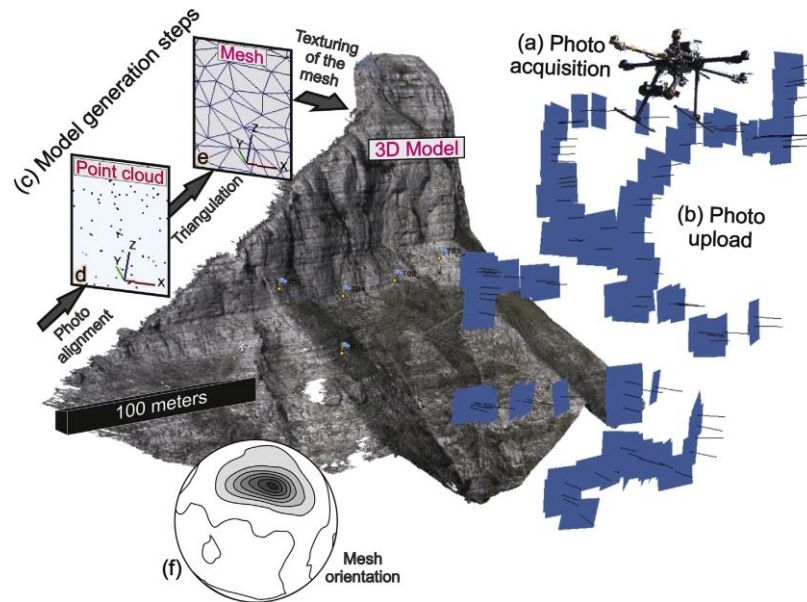
The overlap rate in each photo of a stereo pair (OL) should be at least 60% of side overlap (OL_{side}) and 80% of forward overlap ($OL_{forward}$) to ensure the reconstruction of all study object (Agisoft, 2018). In UAV photogrammetry, the desired $OL_{forward}$ and GSD can be used to calculate the shutter interval, based on the flight velocity (Vollger & Cruden, 2016). The desired OL_{side} and the photo width (in pixels) can be used to calculate the space between each flight line ($S_{flightline}$; Vollger & Cruden, 2016). Also, the motion blur, that happens due to the movement of the camera when taking the photos, need to be minimized during the acquisition process. It can be estimated by the relation of flight velocity, camera exposure and the desired GSD.

Aiming to keep these parameters constant throughout the data collection campaign, two main steps were followed to acquire aerial photographs of the study area. Both steps were done using a UAV from the branch DJI, model Phantom 4, with the software UgCS. With this software, it is possible to program flight routes, flight height, flight line spacing and photo acquisition interval. UgCS control the flight height based on Digital Elevation Models (DEM) of the study area.

The first step was focused on the construction of a low-resolution digital elevation model of the study area. For this, it was programmed flights, at the UgCS software interface, based on data from the Shuttle Radar Topography Mission (SRTM), with a resolution of 30m per pixel. The UAV flew at an average height of 70m, based on the radar image, with an average flight lines spacing of 50m (Figure 2).

All data obtained at the first stage was then processed at the software Agisoft Photoscan 1.4.2, to construct a DEM with higher resolution compared with the SRTM. Agisoft Photoscan is a user-friendly software based on the SfM algorithm. This program focuses on building three-dimensional models for different purposes, like architecture, engineer activities and geosciences. The main workflow necessary to build the models are quite simple, it is based in four main steps: Align Photo, Dense Cloud generation, Mesh Surface and Texture creation (Figure 1).

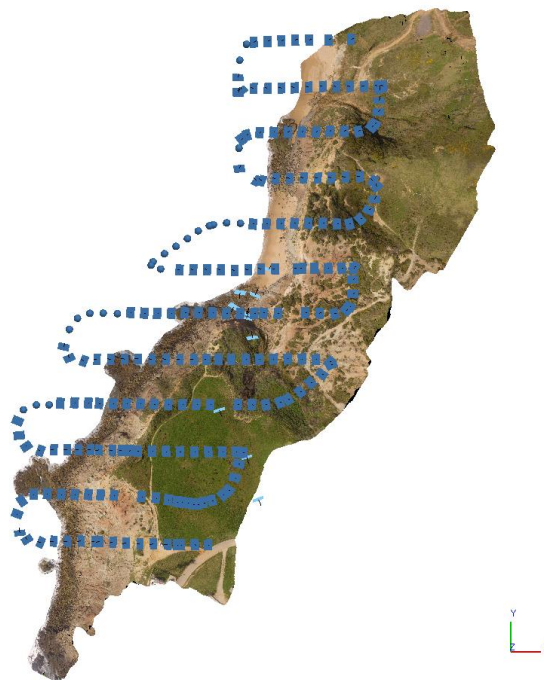
Figure 1 Virtual Outcrop Model data acquisition and processing



Fonte: Modificado de Corradetti et al. (2017)

After processing the low-resolution DEM, based on the high-altitude photos, it was then done a second data acquisition campaign (Figure 3). Using the DEM resulted of the previous process as a control for autonomous flights in lower altitude, it was planned flights with 20m height with flight lines spaced 10m. The data obtained with this second flight campaign was then processed to generate high resolution VOMs following the same method described for the DEM generation at the Agisoft Photoscan.

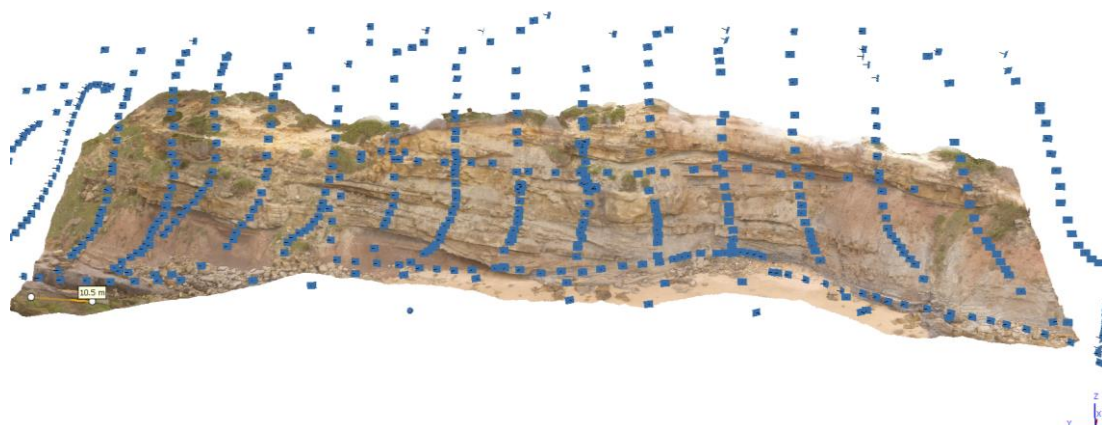
Figure 2 Low Resolution Digital Terrain Model resulted from the first data acquisition campaign.



3 RESULTS AND DISCUSSION

Using the method described for the acquisition of the data, we obtained low-resolution VOMs after the first data acquisition stage and high-resolution VOMs after the second stage. The low-resolution models obtained an average GSD of 2 cm/pix, produced a DEM with an average resolution of 8 cm/pix with an average point density of 140 points/m². Models produced with photos obtained at the second flight campaign resulted in an average GSD of 8 mm/pix, DEMs with resolutions next to 3 cm/pix and with an average point density of 915 points/m².

Figure 3 High-resolution Virtual Outcrop Model generated after the second processing stage.



4 FINAL CONSIDERATIONS

Using this method for data acquisition made possible to solve the problem of low continuity of flight settings during campaigns. The generated models resulted from the first stage was important for maintaining settings for low altitude flight lines during the second data acquisition step. Models generated after the second data campaign presented a high resolution compared with usual models, and can be very useful for many geological purposes as, reservoir analog modelling, geomechanically analysis, structural modelling, risk analysis and many others applications.

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