SEMI-AUTOMATIC UAV-BASED SFM SURVEY OF VERTICAL SURFACES

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ABSTRACT

UAV flight control applications designed for mapping, inspection and 3D model generation do not provide tools for autonomous flight and image acquisition of vertical surfaces, such as quarry walls or large cliffs, leaving the user to a manual flight operation. In this work we describe a workflow to program autonomous UAV missions designed to acquire images of vertical surfaces, with the desired parameters of distance to target and overlap, using the Litchi App. The study area is a inactive basalt quarry, where 540 images of a ∼25x200 m wall were taken in about an hour, following a layout of six flight lines, ensuring an 80% overlap between photographs.

Key words – *Structure from Motion, Photogrammetry, Litchi, Structural Geology, Quarry.*

1. INTRODUCTION

UAVs can be programed to fly autonomous missions for orthophoto and DEM generation with Structure from Motion–Multi View Stereo (SfM-MVS) [1], where the aircraft usually follows a square grid path while acquiring images at predefined distance or time intervals. The user can chose from a wide number of applications for flight control, including free or commercial, installed on a computer (desktop/laptop) or mobile device (phone/tablet), and with different sets of features, such as allowing the UAV to fly at a constant height over the terrain instead of the same height from the take off point regardless of variations in topography.

Despite the options offered by flight control applications, which include grid flight, double (crossed) grid, flight parallel to linear features (roads, power lines) or orbiting flight around vertical structures (towers), there is no option for autonomous flight and image acquisition of vertical surfaces, such as quarry walls, outcrops or large cliffs. If the subject of analysis is a vertical surface, the user is left with option of terrestrial photogrammetry [2, 3] or manual UAV flight [4], which will depend on a skilled pilot, will increase operation time and might not assure that the images will be taken from a constant distance from the target or that image overlap and orientation [5] will meet the requirements for a successful 3D reconstruction.

In this work we describe a workflow to program autonomous UAV missions designed to acquire images of vertical surfaces with the desired parameters of distance to target and overlap, using the Litchi App.

The intention is to simulate the grid pattern used for terrain mapping, but placing the grid in a vertical plane. This can be achieved by creating an individual mission running parallel to the vertical surface, with waypoints spaced according to the desired lateral image overlap. This mission is then repeated at different heights, proportional to the vertical overlap.

2. MATERIAL AND METHODS

2.1. Study Area

Situated at the outskirts of Campinas City (São Paulo State, southeastern Brazil), the Jardim Garcia quarry is composed of mafic intrusive rocks from Serra Geral Formation (Cretaceous, Paraná Basin). It is deactivated and used as a recreational area for activities such as rock climbing and aeromodeling.

This work focused on the west side of the quarry, a ∼25 m high and ∼200 m long SSE-NNW rock wall (Fig. 1). For georeferencing the final 3D model, climbing anchors were surveyed by irradiation from a total station located in an open traverse. The traverse coordinates were obtained by geodetic GNSS post-processing.

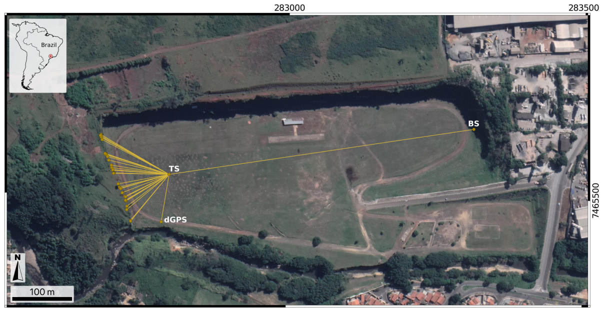

Figure 1: Situation map of Jardim Garcia Quarry with surveyed traverse and control points. TS: Total Station; BS: Backsight; dGPS: GPS base station. Satellite imagery ©2018 Digital Globe, powered by Google. UTM coordinates, zone 23 (South), WGS84.

2.2. Autonomous flight programming

The Litchi App (<https://flylitchi.com>) was used to program the autonomous flight of the UAV. Litchi is an Android/iOS application for UAV control aimed towards photography and video capture. Among its many features, it allows the user to fly on a path defined by waypoints, and to execute up to 15 different ‘actions’ at each waypoint, such as take a photograph, rotate the aircraft, tilt the camera gimbal and others. Although other applications have similar features, Litchi has a ‘Mission Hub’ (<https://flylitchi.com/

Figure 2: Litchi Mission Hub with imported flight path. The menu is used to define flight parameters and waypoint actions.

hub>) where missions can be created using a desktop or laptop computer, enabling the possibility of using multiple tools (e.g., GIS, GoogleEarth) to plan missions in a quick and easy way.

A DJI Phantom 4 Pro UAV was used for image acquisition. The aircraft digital camera has an 1" CMOS 20MP sensor, with FOV of 84° and 8.8 mm focal distance (24 mm at 35 mm equivalent). Images can be saved as JPEG or RAW, with 5472×3648 px (3:2 ratio). In this project we set the distance to the wall as 20 m and image overlap at 80% vertical and lateral. This resulted in an image footprint of 30×20 m, a pixel size of $\sim$0.5 cm, and distance between photos of 6 m horizontally and 4 m vertically. To avoid doming effects observed in datasets acquired with cameras positioned only at a perpendicular orientation about the target [5], we planned to acquire images at three orientations: N265° (perpendicular), N250° and N280°. Additionally, after these images were obtained, the camera gimbal was tilted -15° (downwards from the horizontal position) and the images reacquired, in a total of 6 images per waypoint.

The workflow described here requires the use Litchi Mission Hub (via browser), Google Earth (or GIS), an ASCII text editor and Litchi for mobile devices (for actual flight). In brief, the steps are:

1. Create first flight line in Google Earth and save as KML;
2. Import KML into Mission HUb and edit actions for first waypoint;
3. Export mission as CSV and open in text editor;
4. In text editor, adjust flight height and duplicate actions for all waypoints;
5. Save one mission for each required flight height as CSV;
6. Import CSV into Mission Hub and save into user account;
7. Fly each mission via Litchi mobile App.

The first step is to create the flight path in Google Earth or in a GIS software. Create a polyline parallel to the surface of interest, with nodes spaced according to the necessary lateral overlap (each node will be a waypoint in Mission Hub) and export it as a KML file.

Next, import the KML file into Mission Hub and edit manually the parameters only for the first waypoint (Fig. 2). Define flight height above the take-off point, set 'curve size' to zero and 'heading' to the azimuth of the first photo. Edit the actions of the UAV for this waypoint. In this project, we defined the following actions:

1. Hover for 1s (to stabilize the UAV);
2. Take photo (aircraft is oriented at initial 'heading' setting of N280°);
3. Rotate aircraft to N265°;
4. Take photo;
5. Rotate aircraft to N250°;
6. Take photo;
7. Tilt camera gimbal -15°;
8. Take photo;
9. Rotate aircraft to N265°;
10. Take photo;
11. Rotate aircraft to N280°;
12. Take photo;
13. Hover for 1s;
14. Tilt camera gimbal back to 0°.

Once the parameters and actions for the first waypoint are set, export the mission as a CSV file and open it in an ASCII text editor. The file has a long header with self-explanatory labels, followed by the waypoints and their actions.

```
latitude,longitude,altitude(m),heading(deg),curvesize(m),rotationdir,gimbalmode,gimbalpitchangle,
actiontype1,actionparam1,actiontype2,actionparam2,actiontype3,actionparam3,actiontype4,actionparam4,actiontype5,actionparam5,
actiontype6,actionparam6,actiontype7,actionparam7,actiontype8,actionparam8,actiontype9,actionparam9,actiontype10,actionparam10,
actiontype11,actionparam11,actiontype12,actionparam12,actiontype13,actionparam13,actiontype14,actionparam14,actiontype15,actionparam15,
altitudemode,speed(m/s),poi_latitude,poi_longitude,poi_altitude(m),poi_altitudemode
-22.9035544946994,-47.1184402458146,4,280,0,0,0,0,0,1000,1,0,4,265,1,0,4,250,1,0,5,-15,1,0,4,265,1,0,4,280,1,0,0,1000,5,0,-1,0,0,0,0,0,0,0
-22.9036275426808,-47.1184118144023,4,280,0,0,0,0,0,1000,1,0,4,265,1,0,4,250,1,0,5,-15,1,0,4,265,1,0,4,280,1,0,0,1000,5,0,-1,0,0,0,0,0,0,0
-22.9037005906621,-47.1183833829901,4,280,0,0,0,0,0,1000,1,0,4,265,1,0,4,250,1,0,5,-15,1,0,4,265,1,0,4,280,1,0,0,1000,5,0,-1,0,0,0,0,0,0,0
-22.9037736386434,-47.1183549515778,4,280,0,0,0,0,0,1000,1,0,4,265,1,0,4,250,1,0,5,-15,1,0,4,265,1,0,4,280,1,0,0,1000,5,0,-1,0,0,0,0,0,0,0
-22.9038466866247,-47.1183265201655,4,280,0,0,0,0,0,1000,1,0,4,265,1,0,4,250,1,0,5,-15,1,0,4,265,1,0,4,280,1,0,0,1000,5,0,-1,0,0,0,0,0,0,0
-22.9039197346061,-47.1182980887533,4,280,0,0,0,0,0,1000,1,0,4,265,1,0,4,250,1,0,5,-15,1,0,4,265,1,0,4,280,1,0,0,1000,5,0,-1,0,0,0,0,0,0,0
-22.9039927825874,-47.1182696573410,4,280,0,0,0,0,0,1000,1,0,4,265,1,0,4,250,1,0,5,-15,1,0,4,265,1,0,4,280,1,0,0,1000,5,0,-1,0,0,0,0,0,0,0
-22.9040658305687,-47.1182412259287,4,280,0,0,0,0,0,1000,1,0,4,265,1,0,4,250,1,0,5,-15,1,0,4,265,1,0,4,280,1,0,0,1000,5,0,-1,0,0,0,0,0,0,0
-22.9041388785500,-47.1182127945164,4,280,0,0,0,0,0,1000,1,0,4,265,1,0,4,250,1,0,5,-15,1,0,4,265,1,0,4,280,1,0,0,1000,5,0,-1,0,0,0,0,0,0,0
-22.9042119265314,-47.1181843631042,4,280,0,0,0,0,0,1000,1,0,4,265,1,0,4,250,1,0,5,-15,1,0,4,265,1,0,4,280,1,0,0,1000,5,0,-1,0,0,0,0,0,0,0
-22.9042849745127,-47.1181559316919,4,280,0,0,0,0,0,1000,1,0,4,265,1,0,4,250,1,0,5,-15,1,0,4,265,1,0,4,280,1,0,0,1000,5,0,-1,0,0,0,0,0,0,0
-22.9043580224940,-47.1181275002796,5,280,0,0,0,0,0,1000,1,0,4,265,1,0,4,250,1,0,5,-15,1,0,4,265,1,0,4,280,1,0,0,1000,5,0,-1,0,0,0,0,0,0,0
-22.9044310704753,-47.1180990688674,5,280,0,0,0,0,0,1000,1,0,4,265,1,0,4,250,1,0,5,-15,1,0,4,265,1,0,4,280,1,0,0,1000,5,0,-1,0,0,0,0,0,0,0
-22.9045041184566,-47.1180706374551,5,280,0,0,0,0,0,1000,1,0,4,265,1,0,4,250,1,0,5,-15,1,0,4,265,1,0,4,280,1,0,0,1000,5,0,-1,0,0,0,0,0,0,0
-22.9045771664380,-47.1180422060428,5,280,0,0,0,0,0,1000,1,0,4,265,1,0,4,250,1,0,5,-15,1,0,4,265,1,0,4,280,1,0,0,1000,5,0,-1,0,0,0,0,0,0,0
-22.9046502144193,-47.1180137746306,5,280,0,0,0,0,0,1000,1,0,4,265,1,0,4,250,1,0,5,-15,1,0,4,265,1,0,4,280,1,0,0,1000,5,0,-1,0,0,0,0,0,0,0
```

Figure 3: Contents of CSV file defining a Litchi 'waypoint' mission.

In the example CSV file shown in Fig. 3, the values of the `curvesize(m)` field were edited and rounded to zero, or else Litchi will not perform the defined actions at each waypoint but instead will fly through them as if in a video mission. Each action has a numerical code and an associated parameter, such as:

- `actiontype1`: `0` (stay hovering)
- `actionparam1`: `1000` (miliseconds)
- `actiontype2`: `1` (take photo)
- `actionparam2`: `0` (no associated parameter)
- `actiontype3`: `4` (rotate aircraft)
- `actionparam3`: `265` (azimuth)
- `actiontype7`: `5` (rotate gimbal)
- `actionparam7`: `-15` (angle)

From here it is easy to copy/paste the actions of the first waypoint to all the others. Adjust the flight height as needed. In this case, the ground was gently sloping so the last point was about one meter below the first one; the height of the waypoints were adjusted so the last points are one meter above the take-off point (Fig. 3).

Save one CSV file for each flight height, according to the vertical overlap defined beforehand. Import all files into Mission Hub and check for any errors. Once the missions are imported into the user's account, they can be opened in the mobile App for flight control. It is always safer to check all missions at the office, while connected to the Internet, which will also allow Litchi to download and cache the base map images, for better visualization during field work.

3. RESULTS AND DISCUSSION

In our fieldwork each flight line (with 16 waypoints) was flown in about 8 minutes. Total operation time, including returning the UAV to the initial position, uploading the new mission and replacing the battery (each battery was used in two missions) was around 1:15".

The 3D model of the quarry wall (Fig. 5) was generated with Agisoft Photoscan [6] using 534 images. Photos containing features such as sky and vegetation were masked to reduce processing time. The SfM step of the reconstruction identified 129,806 tie points between the images; using the 'high quality' setting of Photoscan, the MVS step produced a dense cloud with 39,599,660 points which was interpolated to a 3D mesh with 7,919,932 faces.

The layout of the flight lines and waypoints resulted in an image overlap greater than nine photos for almost all the wall area (Fig. 4). Small deviations from a perfect grid are expected due the precision of the onboard GPS used for navigation.

4. CONCLUSIONS

This work presented a workflow, based on the Litchi App, to program autonomous flight missions designed for acquiring images of a vertical surface in a layout similar to the grid pattern commonly used for terrain mapping.

The intent is to avoid manual UAV flight, decreasing operation time, and assuring not only the safety of users and assets, but also that images will be taken from a constant distance from the target and that overlap and camera orientation will meet the requirements for the 3D reconstruction.

The workflow is flexible and can be adapted to a variety of target configurations and user-defined parameters. Flight missions can be saved and shared, ensuring not only repeatability, but also reproducibility of data collection.

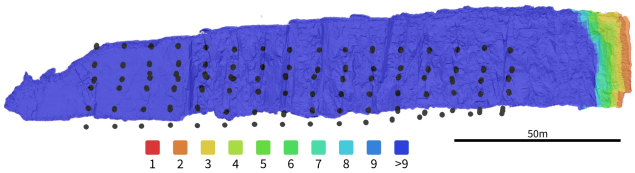

Figure 4: Image overlap map of the quarry wall, with camera positions (black dots). Note the regular layout of flight lines.

Figure 5: 3D model of the quarry wall. Perspective view.

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