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Method Article

Remotely piloted aircraft-based automated vertical surface survey

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ABSTRACT

Remotely Piloted Aircrafts (RPAs) are commonly used as a platform for collecting images which can be processed with Structure from Motion-Multi View Stereo (SfM-MVS) to generate 3D models. However, mobile applications for mapping planning are not designed for image acquisition of vertical surfaces, such as quarry walls or large cliffs, leaving the user to a manual flight operation, which does not ensure optimal overlap between images. Here we describe a workflow, based on the Litchi App, for automated RPA missions designed to acquire images of vertical surfaces or structures.

- An easy-to-follow 8 steps method to survey vertical surfaces using a Remotely Piloted Aircraft.
- It can be applied to outcrops, quarry walls, high cliffs and virtually any other type of vertical surface.
- The workflow is flexible and can be adapted to a variety of target configurations and user-defined parameters.

Specifications table

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More specific subject area:	Geology; Structural Geology
Name of your method:	*DJI Remotely Piloted Aircraft-based automated vertical surface survey*
Name and reference of original method:	*The method was described initially at a conference:* *Grohmann, C.H.; Viana, C.D.; Garcia, G.P.B; Albuquerque, R.W.; Barale, F.; Ferretti, F.A., 2019. Semi-Automatic UAV-based SfM survey of vertical surfaces. XIX Brazilian Symposium on Remote Sensing. Santos, SP.* https://proceedings.science/sbsr-2019/papers/semiautomatic-uav-based-sfm-survey-of-vertical-surfaces
Resource availability:	*Litchi app for DJI drones:* https://flylitchi.com/

Introduction

Remotely Piloted Aircrafts (RPAs) can be programmed to fly automated 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 a predefined distance or time intervals. The user can choose 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

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allowing the RPA 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 automated 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 the option of terrestrial photogrammetry [2,3], which is not well suited for high surfaces, where high camera tilt angles cause image border distortions; or manual RPA 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 will meet the requirements for a successful 3D reconstruction.

In this work we describe a workflow to program automated RPA 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 while 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.

Method

The Litchi App (https://flylitchi.com) is used to program the automated flight of the RPA. Litchi is a commercial (paid) Android/iOS application for DJI RPA 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 taking a photograph, rotating the aircraft, tilting the camera gimbal and others. The path and actions joint is called a mission. Although other applications have similar features, Litchi has a 'Mission Hub' (https://flylitchi.com/hub) where missions can be created using a desktop or laptop computer, enabling the possibility of using multiple auxiliary tools (e.g., QGIS, Google Earth) to plan missions in a quick and easy way.

The workflow described here requires a valid Litchi licence, and uses Litchi Mission Hub (via web browser), Google Earth or a GIS software, an ASCII text editor (such as Notepad) and Litchi for mobile devices (for the actual flight). In brief, the steps are:

1. Define lateral and vertical overlap of images, based on the RPA camera specifications.
2. Create the first flight line in Google Earth and save it as a KML file.
3. Import the KML into Mission Hub and edit the actions for first waypoint.
4. Export the mission as a CSV (comma separated file) and open it in a text editor.
5. In the text editor, adjust flight height and duplicate the actions for all waypoints.
6. Save one mission for each required flight height as a CSV.
7. Import the CSV into Mission Hub and save it into the user account.
8. Fly each mission via Litchi Mobile App.

The first step is to define the distances for lateral and vertical overlap of images, based on the image footprint size at the vertical surface. This will vary depending on the RPA used and the desired pixel size (Ground Sampling Distance - GSD). For instance, a DJI Phantom 4 Pro RPA digital camera has an 1″ CMOS 20 MP sensor (13.2 × 8.8 mm), with FOV (Field of View) of 84° and 8.8 mm focal distance (f - 24 mm at 35 mm equivalent). Images can be saved as JPEG or RAW, with 5472 × 3648 px (3:2 ratio). If the distance from the camera to the vertical surface (H) is set as 20 m, this results in an image footprint (dw x dh) of 30 × 20 m and a GSD of ~0.5 cm. With this configuration, to achieve a vertical and lateral image overlap of 80% we need to shift the image position by 20% of its width and height, and so the distance between photos needs to be of 6 m horizontally and 4 m vertically for this example (Fig. 1). A simple and free tool that can be used to calculate these dimensions is the 'GSD calculator' provided by Pix4D (https://support.pix4d.com/hc/en-us/articles/202560249-TOOLS-GSD-calculator).

The second 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, 6 m for our example, (each node will be a waypoint in Litchi Mission Hub) and export it as a KML file. In Google Earth, the 'Measurements' tab of the path creation dialog window can be used to guide the polyline creation. In QGIS the 'Advanced Digitizing' panel can be used to lock the length and/or angle when moving the mouse. Alternatively, the QGIS menu *Processing* > *Toolbox* > *Split lines by maximum length* tool can be used to split a line in multiple parts with a specified maximum length. For a near planar surface it is reccomended to use a slightly convergent patch to reduce dome error [6].

Next, import the KML file into Litchi Mission Hub (Missions > Import). Checking the "Add Take Photo Action" will automatically add a take photo action to each point of the flight path. Edit manually the parameters only for the first waypoint (Fig. 2). Define flight height above the take-off point (Altitude), set 'curve size' to zero and 'heading' to the azimuth of the first photo.

Then edit the actions (take photo, rotate etc.) for this waypoint. The actions will vary from one application to another, depending on the surface characteristics. It is recommended to evaluate the position and persistence of structures to define the actions so the image set can fully reconstruct the 3D surface. For instance, if there are vertical or near-vertical persistent structures (fractures, faults, etc.) it is recommended to include images with aircraft rotation, while if there are horizontal or near-horizontal persistent structures it is recommended to include images with camera gimbal tilt, limiting the variations to 15° so that there are no image edge distortions.

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

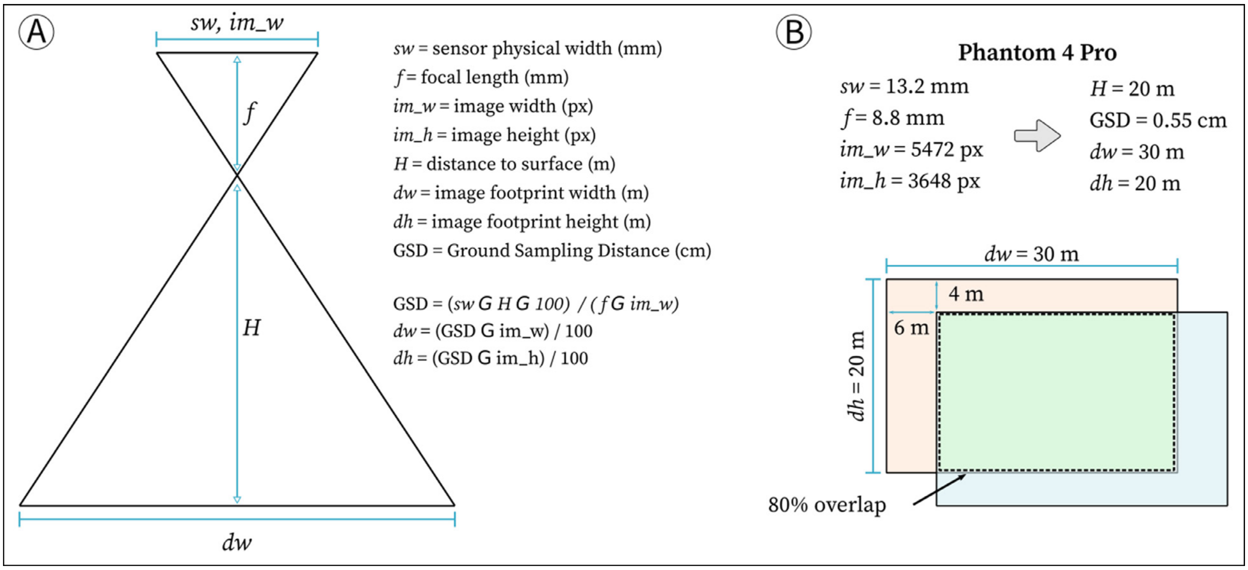

Fig. 1. (A) Determination of image footprint dimensions. (B) Example of calculations with Phantom 4 Pro RPA, distance from surface of 20 m and image overlap of 80% (area in green).

Fig. 2. Litchi Mission Hub with imported polyline (one flight path). The menu is used to define flight parameters and waypoint actions for the first waypoint. In this image, only one flight line is shown, as each flight line correspond to one flight mission.

and their actions (Fig. 3). In the example CSV file shown, the values of the curvesize(m) field were edited and set 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.

In the CSV file, each action has a numerical code and an associated parameter, such as: latitude/longitude/altitude(m): coordinates of waypoints heading(deg): azimuth to which the aircraft (and camera) is pointing curvesize(m): radius of curve between waypoints. Must be set to zero actiontype: 0 (stay hovering) actionparam: time in miliseconds actiontype: 1 (take photo) actionparam: 0 (no associated parameter) actiontype: 2 (start recording video) actionparam: 0 (no associated parameter) actiontype: 3 (stop recording video) actionparam: 0 (no associated parameter) actiontype: 4 (rotate aircraft) actionparam: azimuth in degrees actiontype: 5 (rotate gimbal) actionparam: angle in degrees, positive upwards, negative downwards

```
 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
```

Fig. 3. Example contents of a CSV file defining a Litchi 'waypoint' mission.

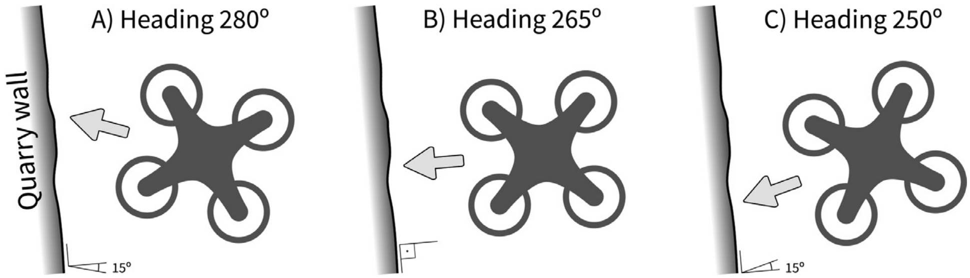

Fig. 4. Scheme of RPA orientation used in the method validation.

From here it is easy to copy/paste the actions of the first waypoint to all the others. Adjust the flight height as needed. Edit and save one CSV file for each flight height (that is, each flight height correspond to one flight mission), 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 fieldwork.

Method validation

The method was validated in a deactivated quarry used as a recreational area for activities such as rock climbing and aeromodelling. We used a DJI Phantom 4 Pro-RPA, set the distance to the wall as 20 m and distance between photos of 6 m horizontally and 4 m vertically (80% overlap lateral and vertical). 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° (approximately perpendicular to the quarry wall), N250° and N280° (Fig. 4). 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 following actions were defined for each waypoint:

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

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 was adjusted so the last points were one meter above the take-off point. In our fieldwork, each flight line (with 16 waypoints) was

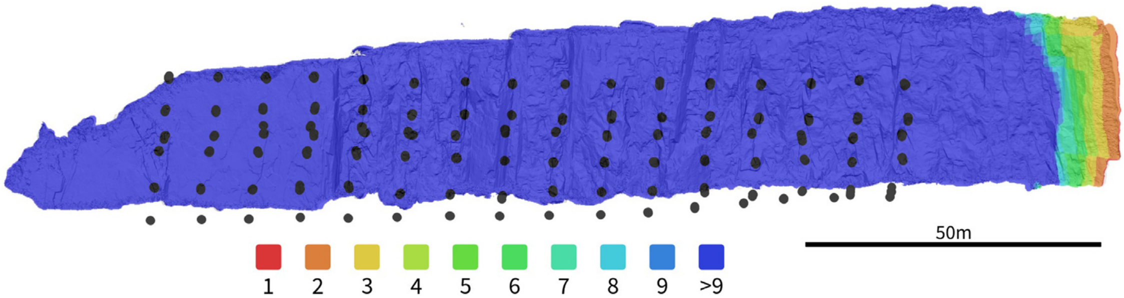

Fig. 5. Image overlap map of the quarry wall, with camera positions (black dots). Note the regular layout of flight lines. Colors represent number of overlapping photos in each sector of the quarry wall.

Fig. 6. Resulting 3D model of the quarry wall.

Fig. 7. Detail of the reconstructed dense cloud. Note that persistent horizontal and vertical planes were correctly reconstructed.

flown in about 8 min (i.e., one mission per flight line). Total operation time, including returning the RPA to the initial position, uploading the new mission and replacing the battery (each battery was used in two missions) was around 1:15″. The layout of the flight lines and waypoints resulted in an image overlap greater than nine photos for almost all the wall area (Fig. 5). Small deviations of the flights pattern from a perfect grid are expected due the precision of the onboard GPS used for navigation.

The 3D model of the quarry wall (Fig. 6) was generated with Agisoft Metashape Professional 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, 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 images taken at different azimuths and inclinations allowed the correct reconstruction of horizontal and vertical persistent structures on the rock wall (Fig. 7).

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.

Ethics statements

Not applicable.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Carlos H. Grohmann: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Camila D. Viana:** Methodology, Software, Formal analysis, Resources, Writing – review & editing, Visualization. **Guilherme P.B. Garcia:** Validation, Formal analysis, Investigation, Writing – review & editing. **Rafael W. Albuquerque:** Validation, Formal analysis, Investigation, Writing – review & editing.

Data Availability

Related data can be accessed at https://github.com/SPAMLab/data_sharing.

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