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UAV experimentation for pavement distresses detection

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ABSTRACT – In recent years, due to the high costs of traditional road failure detection techniques, the research has focused its attention on the use of the drone for the recognition of deterioration by experimenting with low-cost 3D detection techniques. The use of these techniques allows to carry out monitoring operations according to a structured and effective planning to guarantee the safety of users. The purpose of this paper is to verify the gradient that determines the loss of accuracy of the 3D acquisition as the flight altitude changes. in this way, the practitioner will have a handbook through which he can decide the altitude of the flight to obtain that degree of metric accuracy. The application is conducted within a road inside the University campus using the DJ Mavic pro2 drone.

1. INTRODUCTION

Road networks are key drivers for economic success in any city, region, or country. However, globally today there are enormous challenges in trying to ensure the road networks are kept in good and acceptable states throughout their service life. These challenges arise from continually decreasing budgets, further impacted now by the current pandemic driven economic crises. The deficiencies often result in ineffective data collection and management practices.

Within the identified low-cost but accurate strategies and techniques to collect road condition data mainly using simple and readily available devices such as smartphones and drones, this paper focused the attention on the decrease of metric accuracy according to the increase of the height of the drone flight. The images in a 3D modelling workflow are used to reconstruct and segment pavements to pinpoint and analyse the distresses producing metric assessments of damage levels at specific points within road networks[1].

2. METHODOLOGY AND FIRST RESULTS

In order to verify the gradient that determines the loss of accuracy of the 3D acquisition as the flight altitude changes, it is necessary to plan the flight paths so that they are comparable with the 3D acquisitions of the ground truth model. In this procedure, there is a basic problem that concerns the value of the GSD, which determines the distance at which to carry out the flight. However, the assumptions of this research foresee flights at different altitudes, which, therefore, could not have the same GSD value compared to that of the ground truth. This determines a delta of error in the comparison between the clouds.

Regarding this aspect, the Ground Sampling Distance (Eq. 1) parameter was considered to correlate C2C computations to the spatial resolution of the images[1].

$$GSD = \frac{D \cdot px_{size}}{f} \qquad (1)$$

where D is the object distance, f is the focal length and px_{size} is the pixel size.

The field of view (FOV) was 46.7°, calculated using Equation (2):

$$FOV = 2 \times tan{-1}\ (d/2f) \qquad (2)$$

where d is the diagonal length of the sensor size and f is the focus length. Camera calibration was performed as part of the SfM process, which calculated the initial and optimized values of interior orientation parameters. The terrestrial images have been taken considering the 4 different distances that the environmental allowed. To avoid the problems due to the integration of different sources of images (visible misalignments, color and texture mismatches, noisy, etc.) there have been procedures developed. The pipeline proposed eliminating points that negatively affect the image orientation step and, consequently, the dense point cloud generation was utilized. In this work, since we used the same camera with the same sensor for the terrestrial images but with different light exposition and different distances, we experimented two different Python scripts to bring the chunks' coordinate system in accordance to the sides of the bounding box and to make a color correction between the different image chunks.

3. CASE STUDY

A parking area within the University campus was chosen as test road infrastructure to avoid the restricted rules imposed for the drone flights (Fig. 1). Four different height flights were conducted to assess the metric accuracy trough the comparison between the clouds of the different 3D models by drone, and the ground truth 3D model cloud [2]. The drone camera settings are summarized in Table 1.

All the pictures were captured in sequence moving horizontally, into a circular path, for each altitude considered. An overlap of approximately 80% was ensured by appropriately setting 2 m/s of horizontal speed, one picture by a second as acquisition rate, and considering from 30 to 60 degrees as camera gimble vertical inclination. These values were considered also as a suitable balancing to achieve high-resolution pictures in RAW format and sufficient battery life of the drone to complete an entire lap.

Table 1 Camera and UAV setting used for the surveys.

Device	DJI Mavic 2 Pro	Nikon Zfc
Camera resolution (megapixel)	20	20,9
Image size (pixel)	5568 x 3648	5568 x 3712
Sensor size (mm)	13.2 x 8.8	23.5 x 17.5
Focal length (35 mm eq.)	28	24
ISO	200	100
Shutter speed	1/60 to 1/125	1/250
Aperture	f/5.6	f/8

Concerning the acquisitions for the ground truth 3D model, a small portion of the selected area has been identified focusing on rutting and potholes as road pavement distress to investigate [3], as shown in Fig. 1. The ground truth 3D model was built using a Nikon Digital Mirrorless Camera (Table 1) [1][2].

Both UAV and camera photographic dataset were then imported into the Agisoft Metashape software through which the Structure-From-Motion (SfM) framework was used[4][5]. The processing output, after the alignment and the orientation of the pictures, provided the 3D dense clouds, the mesh and textured 3D models creation for each collected dataset respectively. The Bundle Adjustment process (BA) led to minimize the uncertainties in the camera pose and provided the required redundancy in processing, during the image registration and triangulation elaborations, to guarantee further refinement (Eq. 1)[6].

$$E = \sum_j \rho_j(||\pi(P_c, X_k) - x_j||_2^2) \qquad (1)$$

BA consists in the non-linear refinement of camera parameters P_c and point parameters X_k which minimizes the reprojection error by means of a function π that projects scene points to image space and through a loss function ρ_j to decrease the outliers.

In order to investigate the loss of accuracy of the 3D acquisition at different flight altitudes, the 3D models from the four different UAV flights were compared with the ground truth 3D model. The comparison between the different point clouds was carried out through the cloud-to-cloud (C2C) distance computation method using the opensource software CloudCompare (Fig.2). In particular, the C2C distance computation algorithm implements the Hausdorff distance between two subsets of the same metric space, which is defined:

$$H(A,B) = max[h(A,B), h(B,A)] \qquad (2)$$

$$h(A,B) = \mathrm{maxmin}||\mathrm{a} - \mathrm{b}|| \qquad (3)$$

where h(A,B) is the directed Hausdorff distance from the subset A to the subset B.

The graphical output of the Hausdorff distances, which were calculated through the match of the point clouds from UAV surveys and the one related to the ground truth model, and more specifically their Root Mean Square values, better underlined the loss of definition as the acquisition altitude is higher (Fig. 2). The considered road pavement distresses were well reproduced by using the SfM workflow with close up photo dataset as input. Focusing on the UAV detections, the metric accuracy related to the distress recognizing depends strongly on the altitude as well as the sensor resolution [4].

Figure 1 View from the top of the road within the University of Palermo Campus on the left; Selected pavement distresses for ground truth 3D models: potholes a), rutting b).

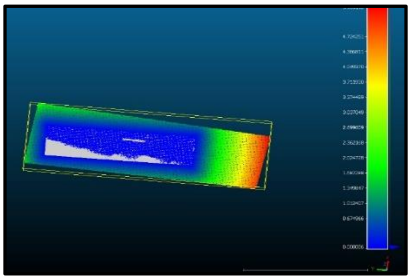

Figure 2 Graphical representation of Hausdorff distance between point clouds from drone and ground truth model: UAV 90m.

4. CONCLUSION

The Values carried out allow practitioner to establish at the beginning the height flight according to the accuracy to be achieved. Having a precise value of metric accuracy according to the flight height, allows us to avoid unnecessary and redundant initial setup tests.

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