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UAV data acquisition method for transportation tunnel inspection

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Abstract: In a large-scale underground transportation network, miles of tunnel linings require regular inspection and assessment. In civil / geotechnical industry, common routine tunnel maintenance still highly relies on labour-intensive visual inspection, manual data acquisition and subjective assessment, which leads to significant cost for a large-scale tunnel network over many miles. In this paper, the tunnel surface texture is acquired using a commercial DJI Mavic2 UAV customized by DJI MSDK automation.

Due to limited GPS signal in an underground tunnel, optical flow method is used for localization. In railroad tunnels without a priori maps, the adaptive flight procedure allows the UAV to determine the tunnel axial direction and adjust the UAV orientation and position relative to the tunnel in real time. Compared to manual acquisition and manual control, the UAV automatic data acquisition procedure allow a larger inspection scope, it has higher stability and greater efficiency at a lower cost, and can create a 3D visual model of the entire tunnel in the simple geometry of railway tunnels. Compared to more sophisticated programs, the light-weight platform can be easily compiled on any DJI Mavic 2 model with low computation power and adapt to similar underground environments without the need of pretrained datasets.

In future studies, the obtained tunnel images can be used to train convolution neural networks (CNN) for automatic cracks & leakage detection and tunnel condition assessment.

Keywords: Structural health monitoring, image acquisition, UAV, point clouds

1 INTRODUCTION

Drones have been widely used for many years for surface inspections of outdoor structures without a priori maps. However, the positioning and control of drones relies on GPS + GLONASS positioning. In weak GPS conditions, common UAV navigation is based on visual positioning or other methods of navigation devices. In addition to visual positioning there are also other methods based on Lidar, radio, wifi positioning and etc.

Visual positioning in UAV tunnel surface inspection mainly faces the challenge of insufficient light. Compared with open-air conditions, the dark and GPS-denied underground tunnel space environment poises many challenges for automatic UAV flight. Particularly, insufficient illumination reduces the manoeuvring accuracy of the UAV and causes drift. Several studies have specifically investigated stable navigation [1] and data acquisition methods [2].

Considering the unfavourable subsurface engineering environment, this paper proposes a lightweight UAV automatic data acquisition method incorporating with visual localization. The method is further developed with the existing mobile SDK of DJI UAV, which controls the UAV to follow a designated trajectory. The developed method enables the UAV to fly automatically along the tunnel axis at a constant distance close to the walls without an a priori map, while collecting image data from the tunnel surface. Given the complex tunnel geometry, the flight path of the UAV can be flexibly programmed and fine-tuned for different underground sections (e.g. shafts, cross passages). The data acquired can be used for 3D point cloud reconstruction of the 3D tunnel infrastructure. Compared to the point cloud model created by Lidar, the 3D point cloud reconstruction method in this paper can restore the colour within the tunnel space and contain more tunnel surface texture details. Based on advanced machine learning algorithms, defects in the 3D point cloud tunnel model can be classified.

2 METHODOLOGY

The tunnel surface texture is acquired using a DJI Mavic2 UAV customized by DJI MSDK automation. The DJI Mobile SDK enables automation of DJI products. The flight strategy is programmed in java, as well as some subsystems of the product, including the camera and gimbals. Using the Mobile SDK, a custom mobile application was created to automate the full potential of DJI's aerial platform.

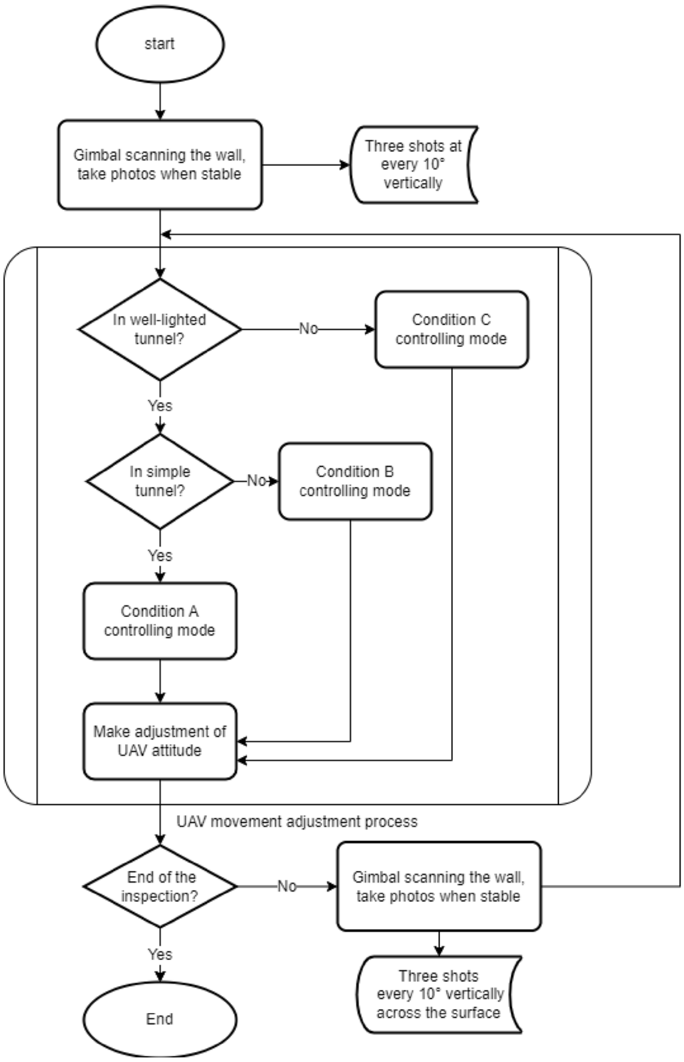

Figure 1 Flowchart of the complete drone automatic controlling logic

The aim of the UAV inspection mission was to obtain a spatially continuous 3D model of the tunnel containing details of defects such as surface cracks and water seepage. The study is based on the assumption that the geometry of the tunnel has a roughly constant diameter and small curvature. The navigation method is a feedback adjustment method for position and forward direction based on the relative position of the UAV within the tunnel structure. The movement behaviour of the UAV in a simple geometric environment is to first scan the environment in front of and behind the take-off point, and then to advance axially along the tunnel and acquire images. At the end of each movement, the gimbal camera pitch is automatically adjusted to scan the image detail at different heights along the entire wall in front of the UAV, and the front and rear distance indicators work simultaneously to determine the amount of displacement and yaw adjustment and continue the cycle. After scanning the two tunnel side walls, the images can be stitched together to obtain a complete model of the tunnel.

The position adjustment of the drone is controlled by the pitch speed and time (1s as default), and the yaw is an absolute angle in the east-north-earth coordinate system. The magnitude of their adjustment is shown in the equation (1) and (2):

$$pitch = \begin{cases} 1.5, s.t. target\ adjustment > 1.5\ m \\ 80\% * (disatanc\,e_{front} - distanc\,e_{back}), s.t. target\ adjusment \leq 1.5\ m \end{cases} \quad (1)$$

$$yaw' = yaw - Minabs(distance\_front - distanc\,e\_back, 5) \quad (2)$$

The automatic UAV data acquisition program was applied to an abandoned tunnel near Cork. The inspected segment was around 40 m long. The tunnel surface is lined with cut Stone below 2m's height and brick above. In this segment, the maximum tunnel diameter in horizontal direction varies from 5.7 m to 5.8 m, and the height of tunnel roof is from 5.0 m to 5.2 m.

3 RESULTS & DISCUSSIONS

The automatic data acquisition program permits the drone to fly smoothly in the tunnel and get video clips and images. The reconstructed 3D model produces orthogonal projection image without evident dislocation.

As can be seen from the results of several models, the factors that affect the quality of the reconstructed model are location, data format, and lighting. The images captured by the drone have a higher resolution at a height close to the lens. In addition, the reconstruction of the video-captured model takes longer than the reconstruction of the image-captured model, and the reconstruction quality of the latter is higher. Illumination conditions need to be above 15lux to complete the normal navigation process. For this purpose, the spotlight lumens should be at least 40% of the total energy to accommodate data acquisition in pure darkness. For environments with weak light intensity, supplemental light is used as appropriate.

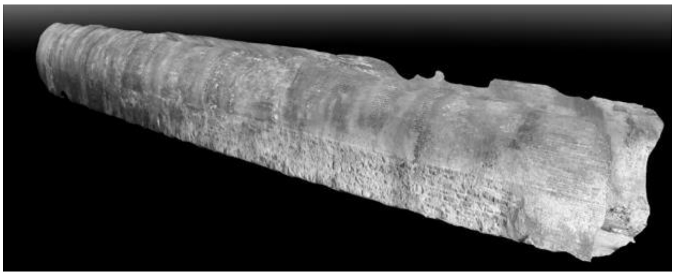

Figure 2 Railway tunnel geometry

4 CONCLUSIONS

The five-step control method for drones is based on real-time control of the distance between front and back obstacles. The data acquisition method is applied on the Mavic2 UAV and can be adapted to GPS-denied tunnel environments with various light intensities. The data allows for tunnel surface point cloud models to be reconstructed, which once unfolded can be used for defect detection including small size cracks and water leakage. The advantages of automated UAV inspection over traditional manual inspection are safety and stability, adaptability and low cost. The automatic inspection method in this paper is also one of the many automatic inspection processes that are easily transferable and have low requirements for computing power and electricity.

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