DOI: 10.3217/978-3-99161-057-1-078

RTK-Enabled UAV for Structural Health Monitoring Without GCPs

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ABSTRACT: This study presents a structural shape monitoring system combining Real-Time Kinematic (RTK) technology with an Unmanned Aerial Vehicle (UAV) for georeferencing without Ground Control Points (GCPs). Traditional GCP-based methods, though accurate, require substantial field efforts, limiting efficiency. This approach employs RTK-enabled UAVs for direct georeferencing, achieving sub-2 cm positioning accuracy. Experiments involved detecting shape changes using a target structure with attached brick shapes of varying depths (8 mm, 20 mm, 44 mm, and 84 mm). Successful detection was achieved for depths of 20 mm or greater, with limitations for smaller depths due to sensor and resolution constraints. Depth and volume estimation errors, initially 11% and 3%, were reduced to 6% and 1% through point cloud registration, improving alignment and geometric accuracy. The study also identified challenges like occlusions and patternless surfaces, which impacted reconstruction quality. These findings highlight the system's potential to enhance structural health monitoring, offering an efficient, scalable solution for infrastructure inspections, with applications in civil engineering and beyond.

KEY WORDS: Structural health monitoring, Real-time kinematic positioning, Point cloud, Unmanned aerial vehicle, Photogrammetry, Change detection, Structure from motion, Civil engineering

1 INTRODUCTION

Recently, the integration of unmanned aerial vehicles (UAVs) with photogrammetry technology has been widely utilized across various fields. For example, it is used for large-scale 3D mapping of extensive areas such as terrain, forests, and coastal regions, as well as for the 3D mapping of individual objects such as buildings, bridges, and roads. Additionally, it is employed for monitoring construction progress and detecting deformations in roads, landslides, and ground subsidence. UAV-based photogrammetry has potential applications in structural health monitoring by detecting changes in structural geometry.

Traditional UAV-based photogrammetry lacks scale and orientation information, which has conventionally been compensated for by using ground control points (GCPs) to generate 3D models. Since the point cloud is aligned to a real-world coordinate system based on GCPs, the process requires installing GCPs around the target area and measuring their precise coordinates.

Figure. 1 RTK UAV

However, the use of GCPs is time-consuming and costly, which can hinder the efficiency of UAV-based photogrammetry. Additionally, in areas with difficult access, such as valleys and rivers, deploying GCPs can be challenging. To address this issue, recent advancements have enabled georeferencing without GCPs by utilizing UAVs equipped with Real-Time Kinematic (RTK) receivers (Figure 1: RTK UAV). UAVs equipped with RTK receivers have been reported to achieve terrain mapping accuracy of 2–10 cm without GCPs, making them suitable for various applications over extensive terrains [1-2]

In this study, structural health monitoring was conducted using a UAV equipped with RTK technology without the need for GCPs. The contribution of this research lies in the quantitative evaluation of monitoring accuracy in terms of the positional accuracy of the point cloud and the sensitivity to detecting structural deformations.

2 METHODOLOGY

2.1 Photogrammetry

Photogrammetry consists of Structure from Motion and Multi-View Stereo to reconstruct 3D structures from overlapping, unoriented, and uncalibrated images, producing sparse and dense 3D point clouds. Structure from Motion involves the simultaneous reconstruction of the unknown three-dimensional scene structure, as well as the estimation of camera positions and orientations, based on a given set of feature correspondences [3]. After successfully recovering the intrinsic and extrinsic parameters of the camera in the Structure from Motion process, Multi-View Stereo is employed to create a 3D densified reconstruction [4].

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2.2 *Georeferencing*

Georeferencing is the process of aligning and scaling a generated 3D model to a real-world coordinate system. There are two approaches to georeferencing: rigid registration and non-rigid registration [5]. Rigid registration is applied after Structure from Motion, modifying the reconstructed point cloud to align with the RTK-surveyed coordinates of GCPs on the ground or GNSS-geotagged data from UAV-captured photos. Non-rigid registration, also known as adaptive registration, introduces a more dynamic approach. It utilises pose priors—the RTK-geotagged data in the UAV-captured photos—as flexible constraints during the Structure from Motion Bundle Adjustment phase.

3 EXPERIMENTS

The target structure is shown in Figure 2. A flight path was generated as a double-grid trajectory for 3D photogrammetry using the built-in app on the UAV's remote controller and deployed in all the survey cases.

Figure. 2 Target structure

Structure from Motion (SfM) and multi-view stereo processing were performed using Pix4Dmapper v4.56, as shown in Figure 3. These processes were employed to generate a dense point cloud representation of the target structure based on UAV-acquired images.

Figure 3. Target structure (Point cloud)

Figure 4 presents the comparison of two point clouds of the target structure acquired at different time intervals using the Cloud-to-Cloud (C2C) absolute distance measurement in millimetres. This method quantifies the geometric differences between the two datasets by calculating the shortest distances between corresponding points in the point clouds. The resulting C2C distance values indicate structural deformations or displacements over time, allowing for an assessment of changes in the target structure's shape and stability.

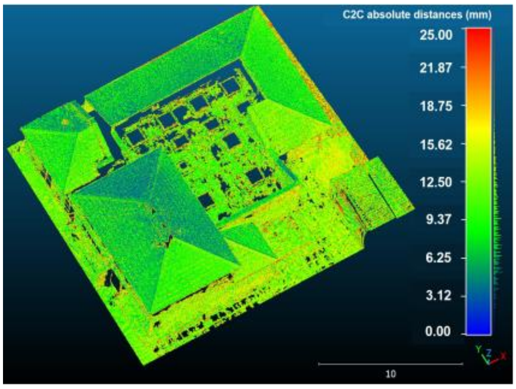

Figure 4. C2C absolute distance (mm)

4 CONCLUSION

This study evaluated the feasibility of using an RTK-equipped UAV with GCP-free georeferencing for structural shape monitoring. The results demonstrated that the generated point clouds achieved centimeter-level accuracy, with positioning differences of less than 2 cm compared to RTK rover measurements. The method successfully detected variations in brick depths down to 20 mm at a UAV altitude of 15 m, though it failed at 8 mm, suggesting that close-up images could improve detection but would introduce higher operational complexity. Point cloud registration was found to enhance alignment, reducing depth and volume estimation errors from 3% and 4% to 1% each. However, patternless surfaces and occlusions negatively impacted reconstruction accuracy, highlighting the need to consider such factors for effective structural shape monitoring.

ACKNOWLEDGMENTS

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT)(RS-2021-NR059168)

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