Adaptation of TIN-based Ortho-Mosaicking for DEM Error Mitigation

Kim S.[1] and Kim T.[2*]

[1] *Inha University, 100 Inha-ro, Michuhol-gu, Incheon, Republic of Korea. 22241153@inha.edu*

[2*] *Inha University, 100 Inha-ro, Michuhol-gu, Incheon, Republic of Korea. tezid@inha.ac.kr*

Abstract: Ortho-mosaicking is an essential process for generating large-area image products from UAV imagery. Conventional LiDAR-based DSMs provide high accuracy but require expensive equipment and significant processing time. Stereo-based DSMs are relatively efficient yet they are still computationally costly. To address these limitations, this study proposes a TIN-based ortho-mosaicking method with adaptive grid generation using, a nationwide low resolution DEM. The method first constructs a rough DSM from sparse PCD obtained through tiepoints and bundle adjustment. It then analyzes terrain gradients and elevation to detect error-prone regions. PCD is first extracted from the DEM grid across the study area. Points located in the identified error-prone regions are adaptively expanded or merged to stabilize the corresponding grid cells. Finally, the grid corners are back-projected onto the image plane. The patches are then assembled using homography to form a mosaic while maintaining geometric consistency. Experimental results demonstrate that the proposed approach enables fast and seamless ortho-mosaicking, particularly in areas containing high-rise buildings.

Keywords: UAV Image Mosaic, Geometric correction, Grid adaptation, Urban Mapping

1. Introduction

Unmanned aerial vehicle (UAV) imagery is widely used for urban monitoring. It offers strong advantages in flexibility and cost. However, UAV imagery has a limited field of view. For large areas, mosaicking is therefore essential.

Traditionally, mosaicking has relied on digital surface models (DSMs) derived from LiDAR surveys (Lin et al., 2019). This approach provides high accuracy, but requires expensive equipment. Processing LIDAR point clouds also demands significant time. Stereo UAV imagery provides another way to generate DSMs. Compared with LiDAR, it is less costly. Yet, DSM generation is computationally heavy. As a result, it is not suitable for near real-time mosaicking of large areas.

To address this, a previous study proposed a TIN-based mosaicking method (Yoon and Kim, 2024). It uses sparse point clouds from tie points and bundle adjustment to construct a TIN, and performs mosaicking on this surface. This method greatly reduces both time and cost, enabling near real-time mosaicking. Still, TIN-based mosaicking has limits in urban areas. It works well in flat terrain where elevation values are uniform. In cities, where building heights vary, the results depend heavily on the density and accuracy of sparse point clouds (PCD). Without reliable points within building structures, the mosaic often shows misalignments and distortions.

This study proposes a new approach. We use a nationwide low resolution digital elevation model (DEM) to create uniform point clouds and build adaptive grids. This allows us to produce orthorectified-like mosaics even without detailed building-level DSMs, improving efficiency for large-scale urban monitoring.

2. Methodology

An existing nationwide 5 m-resolution DEM was employed in this study to enable fast generation of ortho-images. However, the DEM does not include building height information. As a result, when ground points are back-projected onto the image plane, accurate elevation values cannot be obtained, leading to misalignments in the mosaicking process. To address this issue, we adopt~~ed~~ an adaptive grid-based mosaicking approach that selectively avoids building areas.

2.1. Detection of Error-Prone Regions

The proposed method begins by constructing a rough DSM based on a TIN~~,~~ using a sparse point cloud obtained through tiepoints and bundle adjustment. For each TIN triangle, the surface gradient and elevation (z) values are computed to identify terrain features, particularly building structures. Once building areas are detected, a buffer is applied as a safety margin. This explicitly defines the surrounding regions that are prone to geometric errors during back-projection and resampling.

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2.2. Adaptive grid generation

A nationwide 5 m-resolution DEM is used to generate a PCD on a regular grid. The ground elevation at each DEM cell center is converted into a point and placed uniformly across the study area. This DEM-derived PCD is employed when back-projecting ground points onto the image plane. The elevation (z) values at these locations are highly important. Points that fall within predefined vulnerable regions are likely to cause observation inconsistencies and projection errors. Therefore, they are defined as vulnerable points. All PCD generated in this process are then used for the initial grid generation.

The initial grid size is determined according to the DEM resolution. Square grids are first generated at uniform intervals, including both reliable and vulnerable points. Each grid cell is then evaluated for the presence of vulnerable PCD. If a cell contains vulnerable points, it is merged with adjacent cells to form a larger grid cell. When adjacent cells also contain vulnerable points, the grid extent is iteratively expanded until a stable grid is formed that no longer selects problematic points. Through this iterative merge process, regions with concentrated vulnerable PCD are enclosed by merged grids. In contrast, areas composed mainly of reliable points remain in stable, unmerged grids. These stable grids are then used for subsequent adaptive grid-based mosaicking.

2.3. Mosaic Generation

Each stable grid is assigned to the image that best represents its region in near-orthographic projection, determined by projecting its center into image space with the given exterior orientation. Using this reference, seamlines are defined to set mosaic boundaries. The grid vertices are then inversely projected to estimate quadrilateral patches, which are placed in the mosaic domain using homography transformations to ensure geometric consistency and continuity.

3. Results and Findings

The experiment was conducted using a UAV dataset acquired over Incheon, which included high-rise buildings. Figure 1 shows a slope map generated from the TIN DSM with sparse PCD and the adaptive grids derived from it. The results indicated that areas with large slope variations, such as building regions, could be effectively detected and that adaptive grids could be reliably generated to encompass the buildings.

Figure 2 compares mosaics with and without the adaptive grid. The DEM-only mosaic (left) shows severe distortions in building areas, whereas the adaptive grid mosaic (right) demonstrates that these distortions are effectively reduced. This confirms that the proposed method enabled stable mosaicking even in complex urban environments. Furthermore, the study verified that a mosaic could be produced within 200 seconds using about 60 UAV images and showed that the method met both accuracy and near real-time requirements

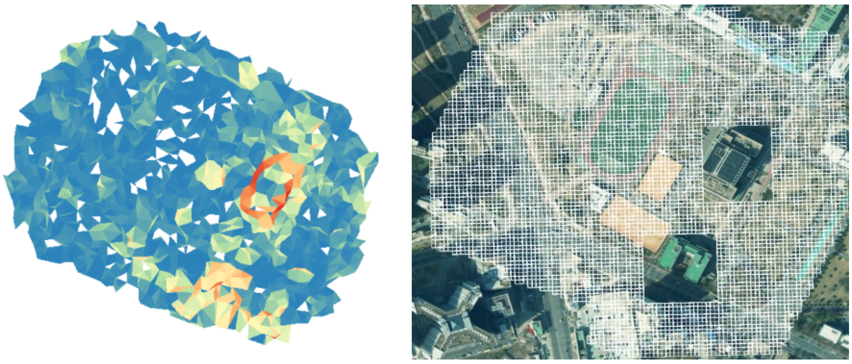

Figure 1. Slope Map & Adaptive Grid Result

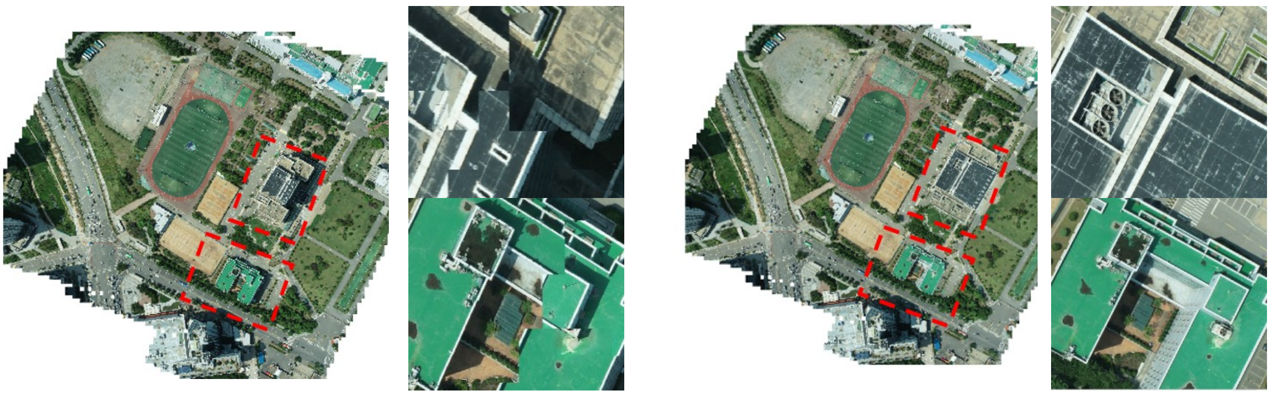

Figure 2. Mosaic Result (Left – Without adaptive grids, Right – With adaptive grids)

4. Conclusion

This study proposes an ortho-mosaicking method with near real-time capability by utilizing a nationwide low resolution DEM. The approach extends the conventional TIN-based framework by incorporating DEM and adaptive grid generation. This effectively reduces distortions and enables stable mosaicking even in complex urban areas with high-rise buildings. The main contribution of this study lies in demonstrating near real-time generation of ortho-images. This is achieved without the need to construct a separate DSM containing building height information. However, further studies are needed to validate its scalability and generalization in densely built-up urban environments.

References

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