Building Change Detection Based on Roof Feature Analysis Using Single Satellite Imagery and Building Database

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1. Introduction

Understanding the distribution and development of buildings is crucial for urban management and planning. High-resolution satellite imagery enables rapid building change detection. Additionally, satellite imagery is commonly used for change detection studies over large areas due to its extensive coverage. High-resolution satellite imagery, in particular, is advantageous for identifying individual buildings because of its high spatial resolution. Traditional building change detection methods have commonly used time-series satellite images. This method involves extracting target objects from images acquired before and after changes and comparing the results to detect the changes. However, this approach is more suitable for medium- or low-resolution satellite imagery, where positional errors caused by building heights are minimal. High-resolution satellite imagery presents challenges, such as building relief displacement in urban areas. The use of change detection techniques with multi-temporal imagery may result in relief displacements being misinterpreted as changes. Additionally, current change detection methods have limitations in producing reliable results due to object detection errors in each image. Therefore, we argue that a more suitable approach for high-resolution satellite imagery is required in order to overcome the limitations of the multi-temporal approach.

Building databases provide individual building information and 3D building data, which are publicly available from national and local governments. By projecting this building information onto an image, we can define clear targets for assessing changes and thereby avoid object detection errors. In this study, we propose a new building change detection methodology based on roof similarity using a single satellite image and a building database. The paper is organized as follows: Section 2 outlines the methodology, algorithms, and data used. Section 3 presents the experimental results and discussion. Finally, Section 4 offers conclusions and suggestions for future research.

2. MATERIALS AND METHODS

2.1 Materials:

This study utilized high-resolution optical satellite images from KOMPSAT-3A, KOMPSAT-3, and CAS-500 satellites. The images used in the experiment had a spatial resolution of 0.7m for KOMPSAT-3 and 0.5m for KOMPSAT-3A and CAS-500. They allowed for clear identification of roof shapes. An image acquired in 2023 was used for the experiment, while images of the same area taken in other years were used for validation. The study area was Seocho-gu district in Seoul metropolitan area, South Korea, which has been undergoing active redevelopment. The building database used was publicly available data provided by the Korean government, and 3D building vector models were utilized. The 3D building vector models were employed to consistently identify building shapes, enabling more precise extraction of roof areas.

2.2 Methods

Since small residential areas are difficult to identify even with high-resolution satellite images, this study focused on areas primarily consisting of apartments to highlight building changes. As noted by Chen et al. (2021), buildings in certain urban areas, such as apartment complexes, tend to exhibit more regular arrangement patterns compared to irregular patterns in villages. These regular patterns are key elements for clearly representing urban components. Therefore, areas with similar types of buildings clustered together, sharing morphological similarities and visually identifiable in satellite imagery were selected. First, we generate a true-ortho image by removing the relief displacement of buildings. Despite precise geometric correction, satellite images can still contain distortions caused by relief displacement. This issue is especially pronounced in buildings, where the building’s footprint and roof may appear in different locations on the satellite image. It also causes errors in accurately identifying the building’s position. In this study, we generate a true-ortho layer using the realistic urban orthoimage generation technology proposed by Kim and Kim (2023). This layer adjusts the building roof to its correct position at ground level to ensure precise alignment. Next, we reproject the building database onto the true-ortho image to accurately extract the roof areas. We then quantify the geometric features of each roof and stored them as vectors. The following features are used: 1) Delaunay triangulation is applied to the extracted roof boundaries, allowing us to calculate internal angles and shape ratios of the resulting triangles, which quantified the roof's morphological characteristics. 2) A graph is generated for each roof based on Delaunay triangulation, and we analyze the structural complexity of the buildings by modeling them with nodes and edges. 3) Additionally, we create graphs between buildings and applied a community detection algorithm to analyze the relationships and connectivity between them. These features allow similar buildings to be grouped together, and the features are considered meaningful. Therefore, the clustered data is used as training data for the deep learning model. A CNN model is trained using both geometric feature vectors and roof images. The trained model is then used to predict building clusters in validation satellite images and identify candidates for building changes. In this study, we design a multi-input CNN model that simultaneously learns image data and geometric feature data. Both data types are combined for final classification, and we apply appropriate optimizers and loss functions during training. Early stopping is used to prevent overfitting, and we train the model for up to 50 epochs to achieve optimal performance. The trained model classifies the validation satellite images and identifies building changes, with the classification results compared against actual building changes.

3. Results and Discussion

In this study, we generated a true-ortho layer to effectively address the issue of relief displacement that can occur in high-resolution satellite imagery. As shown in Figure 1, the roofs and foundations of buildings were accurately aligned, significantly reducing distortion. This accurate representation of building positions was also observed in areas with significant terrain elevation variations. They greatly reduced the positional errors that could arise in traditional time-series satellite image methods. The application of the true-ortho image was essential in improving the accuracy of building detection. Additionally, the prediction results from the CNN model successfully classified buildings based on their roof characteristics. As seen in Figure 2, buildings with similar roof shapes were grouped together in the predictions. The model demonstrated high classification accuracy on the validation data. Based on these results, we visually identified building change candidates. We focused on regions where geometric features and color information were inconsistent. Buildings in the same area that were classified as different or not assigned to any group were typically identified as potential change candidates. This was likely due to differences caused by reconstruction or demolition of existing structures. Furthermore, we analyzed changes in the presence or shape of buildings by comparing them with historical building data. Specifically, when a new building appeared or an existing building was removed in the same location, these were classified as potential building change candidates.

Figure 1: True ortho layer of study area

Figure 2: Prediction result

4. Conclusion and Recommendation

In this study, we proposed a novel building change detection methodology based on roof similarity by combining a single high-resolution satellite image with a building database. The results demonstrated that the proposed method was highly effective in accurately detecting building changes and reducing errors commonly associated with time-series approaches. By precisely projecting building information onto the true-ortho image and utilizing a deep learning model, this methodology significantly improved the accuracy and reliability of urban change detection. Therefore, the proposed methodology was confirmed as a practical tool for detecting changes in urban development and management. However, this study primarily focused on areas with regular building structures, such as apartment complexes; therefore, further discussion is needed regarding the applicability of the method to areas with irregular building patterns. Future research should apply this methodology to a wider range of urban environments and validate its effectiveness in regions with non-uniform building layouts. Additionally, to enhance the performance of the deep learning model, incorporating more training data and a broader range of geometric features into the model is necessary. Improving the model's structure, such as increasing its depth, or fine-tuning hyperparameters to achieve the optimal model, is also expected to be a key task in future studies.

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