A Remote Sensing Image Technology-Based Method of Detecting Building Defects in Aging Urban Residential Areas

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Abstract. This paper focuses on the identification of building diseases in old urban residential communities and reviews the advances of remote sensing technology in building land extraction, three-dimensional modeling, and disease detection. The article points out that existing methods have achieved significant results in macro-level building recognition and three-dimensional modeling, but there are still deficiencies in the refined identification of specific issues for old residential communities, such as high density, complex spectral characteristics, and facade diseases, including cracking, peeling, and water infiltration. To this end, this paper proposes the use of satellite remote sensing for large-scale identification of building land and subsidence screening, leveraging high-resolution drone imagery for fine modeling of individual buildings and surface defect detection, and relying on ground-based sensing technology for high-precision deformation monitoring and long-term tracking of key locations. The aim is to complement the shortcomings of single technologies—such as spectral mixing, building occlusion, and temporal continuity—through the coordinated use of satellite-based broad screening, drone-based detailed inspection, and ground sensor long-term monitoring, thereby improving the efficiency and accuracy of defect identification in old residential areas with high density and complex environments, and providing technical support for urban renewal and dangerous building management.

Keywords: Aging residential communities, identification of building defects, remote sensing imagery, collaborative monitoring.

1. Introduction

The early constructed urban residential communities in China are also confronted with serious problems including aging facilities, deteriorating functions, excessive use of energy, and the destruction of facades. Statistics reveal that as of 2026, there were going to be a large number of old residential communities in China waiting to be renovated, which would amount to 115,000 [1]. What is the most effective and precise way of determining and evaluating the spatial distribution of old cities' residential areas, the state of building structures, and the features of facade flaws has become one of the central scientific problems that should be resolved in the process of urban renewal, safety assessment, and fine governance.

Due to the benefits of extensive coverage, fast information gathering, and high spatiotemporal resolution, remote sensing technology has been extensively utilized in the process of extracting and surveillance of urban building land information. Since the emergence of deep learning technologies, semantic segmentation architectures of neural networks have taken over the mainstream paradigm in building land extraction. Li et al. incorporated MAML meta-learning into the model to describe sample spatial distribution patterns like dispersion, randomness, or aggregation using Moran's spatial statistic. Experimental results prove that the UNet trained by meta-learning scored 0.80 on mIoU in building segmentation, which is much higher than the scores of CNN and Transformer baselines, showing that explicit spatial distribution modeling can be used effectively to improve the accuracy of building extraction. Besides, in terms of building damage evaluation during disasters, Robbins and Kachouie came up with an end-to-end evaluation framework relying on multimodal public remote sensing data. Using the integration of NOAA aerial photos, Microsoft building footprints, and the FEMA damage tags, they systematically compared the performance of architectures including ResNet, VGG, and Vision Transformer (ViT) [2]. Studies have noted that ViT, with its global self-attention mechanism, is more effective at capturing spatial contexts and generalization performance in a

complex urban environment than CNN models [2]. As indicated by the discussed studies, the techniques that combine spatial information with deep learning are taking over the traditional methods of spectral indices in building information recognition using remote sensing, making them the dominant technology of choice in building information recognition.

The extraction of building footprints on a two-dimensional level will only reveal possible areas of risk. To determine façade defects, however, it is important to use 3D individualized building modeling and multi-source feature fusion. Researchers have also advanced greatly in this field. Cheng Hao developed a joint approach of applying UAV oblique images to Building Information Modeling (BIM). He used the extracted frontal patterns of buildings along with BIM geometry data to obtain detailed three-dimensional reconstruction of single buildings, which had a very high increase in geometric precision and texture realism of the models [3]. Xin Bowen et al. proposed and developed an evaluation system of remote sensing image fusion using the MATLAB platform. The system was a comparison of different methods of fusion such as wavelet transform, principal component analysis (PCA), and IHS transform, and served as a quantitative assessment tool for the preprocessing of multi-source remote sensing data in building environment analysis.

Even though these studies have achieved a lot in the field of building land extraction and three-dimensional modelling, available procedures are mostly centered on traditional building conditions or after disaster damage evaluation, and those that consider old urban residential areas pay little mind to the building; they cannot be used to identify with precision facade problems like cracking, spalling, and water leakage. In other words, this paper discusses the combination of remote sensing data with deep-learning algorithms to obtain high accuracy of building land extraction in older residential areas and automated detection of facade defects as a form of technical support to urban renewal and safety inspections.

2. Background of the Study

Aged buildings can be described as the already existing structures built in earlier years (generally before the year 2000). Regarding the structural form, most old buildings in China have masonry structure forms, i.e., bearing walls constructed of fired common bricks, stone masonry, or blocks, and supported by reinforced concrete slabs or prefabricated slabs [4]. The compressive strength of masonry structures is high, but tensile and shear strength are relatively poor. Their sensitivity to unequal settlement of foundations, temperature fluctuations, and lateral forces (e.g., wind forces and earthquake forces) renders them susceptible to wall cracking, tilting, and in some cases, collapsing. This is why they are the main target in the safety control of old buildings.

Serious dangerous buildings are houses with badly damaged structures, or where the load-bearing parts have become dangerous factors, and may even collapse or lose their ability to carry loads at any moment, and thus would be unfit to live in or be used. In accordance with the "Standards on Evaluation of Dangerous Buildings" (JGJ 125-2016), dangerous buildings are divided into four categories: A, B, C, and D (low- to high-risk). Of these, D-level dangerous buildings (where the bearing structures cannot support the usual requirements of normal usage and the entire building has hazards) represent the most imminent safety hazard. Viewed in relation to sociology, the appearance of the dilapidated housing is not just a natural phenomenon of the physical structural decay, but rather it is strongly connected with particular institutional transformations.

To evaluate different possible causes of disasters in old and unsafe houses which can threaten the life and property of the inhabitants, or residential safety risks, Yang Lijian et al., in their study of repairing the masonry-structure hazardous buildings, indicated that exterior wall cracking, wall pulverization, uneven foundation settlement, and materials aging were standard risk indicators [4]. Overall, the residential safety risks can be mostly summarized into the macro-scale foundation settlement, the meso-scale facade spalling, and the micro-scale wall cracking. Such risks tend to be highly concealed, develop slowly, and occur abruptly, causing serious difficulties to monitoring technologies.

3. Application of Existing Research Findings for Effective Identification

3.1. Space-Based Satellite Remote Sensing

Remote sensing of space-based satellites is still the main technological approach to acquiring information about urban building lands and tracking surface deformations, with major benefits including large-scale area coverage, short revisit times, and abundant archives of historical data.

When it comes to the information extraction of building land, building land displays high complexity in electromagnetic wave reflection spectra, which makes its direct extraction hard with the help of indices based on simple raw bands. To overcome this, a method of reducing the dimension of data is suggested, where instead of the original multispectral bands, index bands based on the original bands are used. They are the Soil-Adjusted Vegetation Index (SAVI), the Normalized Difference Built-up Index (NDBI), the Modified Normalized Difference Water Index (MNDWI), and the development of a new Impervious Surface Building Index (IBI). This feature can be used by IBI to make information on building land positive values, and information on vegetation and water masses negative values, thus improving target information and minimizing non-target information. The empirical analysis has indicated that this approach can reach an extraction accuracy level higher than 93.9 percent [5].

This fact served as the base for further expansions aiming at the features of various sensors. The spatiotemporal analysis of how the construction land in Zhengzhou expanded during 2001-2017 was performed by Xiao Xinyi et al. using the compressed data dimension approaches based on the images of the Landsat series, which confirmed that this approach is practical in the context of the monitoring of the city expansion, and the overall extraction accuracy was kept higher than 85% [6].

The use of Synthetic Aperture Radar Interferometry (InSAR) technology and time-series analysis algorithms, including SBAS-InSAR, in the sphere of monitoring of urban surface deformation has been extensively used to monitor ground subsidence. Conventional time-series InSAR methods are likely to detect strong-scattering, highly coherent permanent scatterers (PS), which are mostly found on buildings and hardened surfaces. Sparse monitoring points can be found in non-hardened regions like those regions vegetated or covered with bare soil. Ren Lulu designed an approach to extract surface deformation that combines high-resolution optical semantic data and multi-orbit SAR data. Through the application of deep learning models to create more accurate land cover classification masks based on optical images, this method limits the choice of homogeneous pixels to distributed scatterers (DS) and maximizes the accuracy of sample covariance matrix estimation [7]. Likewise, this technique may be extended to the investigation of urban building complexes. The findings show that the method made the density of monitoring points in vegetation-covered areas about 4.5 times higher and near the edges of complex building clusters by about 2.2 times, and thus compensated for the monitoring gaps of conventional InSAR in complex urban settings. The root mean square error of the deformation rate is constrained by ground GNSS reference stations and leveling measurements to no more than 3 mm/year [7]. Also, Wang Sanqian et al. developed a full three-dimensional reconstruction of urban scenes using high-resolution satellite imagery. Experimentally, this method was tested with WorldView-3 satellite images in Jacksonville, United States. The root mean square error of the reconstructed models in the plane and elevation was 1.12m and 1.15 m, respectively, with 81.3% completeness. To solve the common problems in satellite image modeling, including poor positioning accuracy, excessive matching noise, and lack of geometric information of features, the method uses methods such as rational function model adjustment, epipolar image generation, and dense matching. It completely reconstructs urban building edge point clouds and provides well-organized three-dimensional mesh models. The findings of the study indicate that high-resolution commercial satellite imagery (like the WorldView series) can perform detailed three-dimensional modeling in large-scale urban areas and could offer a valid source of data and technical assistance to extract urban complex block buildings and defects [8].

To sum up, space-based remote sensing has reached a high level of technological maturity and offers dependable accuracy in the identification of construction land at the macro level and subsidence

at the regional level. Nevertheless, because of spatial resolution constraints and spectral band arrangement, it is hard to satisfy the fine requirements of identification when it comes to facade damage of single structures in historical residential areas.

3.2. Airborne Unmanned Aerial Vehicle Remote Sensing

In comparison to space satellites, UAV remote sensing systems have the benefits of being able to move and be flexible, having a high spatial resolution and the capacity to get data at several angles. When buildings are filtered by satellites, UAVs can be used to target specific buildings, which can be shown to have special value when it comes to the detailed three-dimensional modelling and the detection of flaws on facades.

With respect to the three-dimensional architectural modeling and individualization, Cheng Hao investigated an individualization approach that combines UAV remote sensing oblique imagery with Building Information Modeling (BIM). The four façades and roofs of buildings were recorded by using lightweight UAVs in high-resolution oblique images. Corner detection, perspective transformation correction, as well as BIM geometric constraints were used to achieve accurate extraction and calibration of building textures. Meanwhile, the BIM model was simplified and rebuilt to get a lightweight geometric white model, which could be used in the context of 3D GIS applications, and a human-computer interaction texture mapping algorithm was created, using OpenSceneGraph and OpenGL [9]. It offers an effective balance between modeling efficiency and geometric accuracy and serves as a technical guide to the informatization and archiving of buildings within the old residential areas.

In the context of surface defect detection, drones with high-resolution cameras and infrared thermal imaging devices can successfully detect common defects on building facades, including cracks, spalling, and hollowing. Wang Dongmei et al. discussed in detail the use of UAV remote sensing technology in all stages of civil engineering project management, including the statement that in the operational and maintenance stage of the project, drones are capable of carrying out 360-degree aerial flights over buildings and stationary aerial observations of a building surface. With the help of graphic processing software, cracks are automatically detected and located in a three-dimensional manner, and it is intuitively represented on realistic models, thus being significantly less prone to error than manual inspection. On such a basis, Yuan Yinjun et al. further studied the application of LiDAR integrated with UAV remote sensing technology in building surveying and proposed a technical path that integrates macro coverage by UAV oblique photography, with precise measurement by ground-based airborne LiDAR. To illustrate, with a frame-structured office building in Shenzhen, images were taken using a DJI M300 RTK UAV with a five-lens oblique camera, and high-precision point cloud data of building facades, bottom, and detailed parts were measured with the RIEGL VZ-400i terrestrial laser scanner. The ability to accurately measure horizontal displacement at a millimeter level at the building top (maximum displacement 4. 2mm) was thus made possible and a cyclical variation trend in the widths of the cracks, which coincided with the seasons, i.e. increase in the winter and decrease in the summer (average widths of the cracks in winter and summer of 1. 27mm and 0. 91mm respectively), was observed [10]. This experimental study proved the utility and responsiveness of airborne platforms in monitoring building pathologies dynamically.

The use of drones in small streets in old residential neighborhoods is very vulnerable to distortion by uneven light and shadows of buildings. Thus, the detail enhancement based on GAN networks (where SSIM tends to be 1) is an essential initial stage towards the precise recognition of micro-cracks and spalling. From the viewpoint of image enhancement, Sun Yanhua et al. suggested a GAN-based approach to detail enhancement technology to solve the issue of decreased structural similarity due to external noise when acquiring images of urban buildings. Using this method, it is possible to achieve a significant improvement in structural similarity index (SSIM) between enhanced images and real images by the joint optimization of a multi-scale channel attention mechanism and several loss functions (luminance smoothness loss, spatial consistency loss, exposure control loss, multi-scale

structural similarity loss). The SSIM values of different urban building scene images are near 1 [11]. This method offers a better quality of information base for the further automated discovery of fine defects like cracks and spalling in the images of drones.

3.3. Ground Sensing Monitoring

The primary responsibility of ground-based sensing monitoring is to measure with precision and monitor over a long period of time the critical elements of high-risk buildings.

Historically, point sensors (leveling instruments, total stations, crack meters, and inclinometers) have been commonly used in ground monitoring techniques to measure building settlement, tilt, and crack development. Nonetheless, these techniques have some drawbacks, such as their high deployment costs, they cover a small area, and it is also difficult to achieve distributed measurements. One of the new technical solutions to overcome this problem is the introduction of distributed optical fiber sensing technologies like BOTDR. Xi Jun et al. systematically investigated a distributed optical fiber monitoring system based on Brillouin Optical Time Domain Reflectometry (BOTDR) of ground settlement and ground crack deformation to design four monitoring systems, namely horizontal fixed-point, horizontal direct burial, displacement measuring tube, and vertical direct burial monitoring [12]. The findings show that the horizontal fixed-point monitoring system can effectively track the relative displacement of soil on either side of ground cracks by fixing sensing optical cables at certain intervals in the soil. Indoor test accuracy may be as low as 0.05 mm, whereas field monitoring accuracy is about 0.1 mm, which makes it appropriate to use in distributed monitoring of ground crack deformations. In contrast, the vertical direct-buried monitoring method inserts sensing optical cables into holes and passes them through the main settlement compression layers, allowing measurement of distributed deformations of vertical soil layers. Compressive deformation layers were detected successfully at depths between 30 and 40 meters at the monitoring boreholes in Lüsì, Qidong [12]. It offers an automated and highly accurate monitoring system to follow the foundation settlement of old buildings over time and the movement of cracks in the surrounding ground.

Nonetheless, in terms of the safety inspection of the building structure, Ye Wanxue examined the technical system of safety inspection of existing building structures observing that conventional inspection processes like hammering and visual observation are primarily applied to detect evident surface anomalies of structures, and contemporary non-destructive inspection technologies like ultrasonic inspection, infrared thermography, and fiber optic sensing can be used to conduct precise inspections of the inner structure [13]. The fact shows that ground-based sensor monitoring has become more than just an independent monitoring tool; it is part of a closed loop together with reinforcement construction and safety evaluation, offering all-round technical assistance to the renovation of the old building.

4. Conclusion

To sum up, the discovery and surveillance methods of old structures have created a combined system that involves space-based macro screening, air-based fine modeling, and ground-based accurate verification. Satellite remote sensing based on space has advanced greatly towards extracting building land and monitoring ground subsidence, with the benefits of being able to acquire large quantities of data rapidly and localize clusters of old buildings quickly, although it does not offer enough spatial resolution to distinguish the particular defects of each building. At the same time, aerial drone remote sensing, with its high mobility and high resolution, fills this gap in scales, yet this technology cannot be used regularly and continuously because of airspace constraints and costs. And lastly, the use of ground sensors to monitor important locations highly accurately allows monitoring them over extended periods, and this information is fed back to the satellite to cover large areas. This organic mix of the three techniques can be used as a potent solution to the old problem of building surveillance.

The collective surveillance framework is used to cover the entire chain, starting with the macro-screening to the micro-verification. Satellite remote sensing defines the range, drones pinpoint the particular problems, and the ground sensors measure the area, all of which offer a systematic approach to accurate building identification and the real-time monitoring of the old residential buildings. The final goal is to guarantee the safety of life in elderly communities by technical means.

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