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Quality enhancement in digital twin production of complex architectures with integrated use of terrestrial and aerial images

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Abstract

The concept of digital twin is included in many working disciplines today and its popularity is constantly increasing. There are photogrammetry-based mathematical models belonging to the geomatics discipline in the production of digital twin and three-dimensional (3D) model production can be easily realized with current advanced remote sensing technologies like unmanned aerial vehicles (UAV). However, when architectural components such as porches and eaves are taken into account, the inadequacy of altitude-based perspective creates serious problems in digital model production. In the solution of these problems, the need for terrestrial imaging arises and quality enhancement can be provided by data fusion. In this study, it is aimed to produce a high-quality digital twin of the Gebze Technical University Geomatics Engineering Department building. This building stands out with its different architectural structures due to its densely patterned exterior and reflective surfaces. Terrestrial and aerial photogrammetry were used in an integrated way with the aim of producing the highest quality of all facades of this building, which has a very difficult structure for the production of digital twins. Visual and statistical analyzes of the final outputs were carried out and the problems encountered in integrated methods due to complex architectural structures and alternative solution methods were discussed.

Introduction

In recent years, there has been an evolution towards the digital era in the production and protection of objects [1]. With the changing technological equipment and user demands, the concept of digital twin has emerged in order to use the models of objects effectively [2]. Until today, this concept has had many definitions such as digital double, digital master and digital shadows [3-5]. Finally, the concept of digital twin has been accepted as the closest copying of physical objects to the real thing and displaying the relations of these objects with each other in the virtual environment [6].

Digital twin production is gaining importance day by day and finds its place in many fields of work [7]. To obtain maximum quality in digital twin production, all facades of the object must be displayed in detail at the appropriate illumination condition and overlap rate. With the integrated use of different methods, it becomes possible to cover all surfaces of the structure subject to the model [8].

In this study, it was aimed to increase the quality of digital twin production in complex structures and data fusion processes were carried out in this direction. Terrestrial photogrammetry was employed to capture a comprehensive view of the under-awning areas, which proved challenging for the UAV's limited viewing geometry. In addition, by being integrated oblique flight data, this technique enabled the acquisition of precise data pertaining to the roof surfaces of the building, where traditional terrestrial photogrammetry alone fell short. As a result, the targeted fusion study was carried out successfully, and the geometric accuracy and spectral analysis results were examined in detail.

Study Area and Materials

The study area is located on the campus of Gebze Technical University, within the borders of Kocaeli, Türkiye. Unlike many buildings on the campus, the Geomatics Engineering building, which stands out with its different architectural plan, was chosen for 3D model production. This building, which was built on an area of approximately 1500 m^2, consists of intense reflective surfaces as all its facades are covered with glass. DJI Phantom IV Pro V2.0 UAV was used for oblique imaging and NIKON D3500 digital single-lens reflex (DSLR) camera was used for terrestrial imaging to obtain images of the exterior surface of the building. Nikon camera has a 24-megapixel sensor while DJI Phantom Pro IV V2.0 UAV has a 20-megapixel CMOS (Complementary Metal Oxide Semiconductor) sensor. In addition to these devices, CHC i80 Global Navigation Satellite System (GNSS) receiver and Geomax Zoom25 total station were used to determine the coordinates of ground control points (GCPs) and checkerboards, respectively (Figure 1).

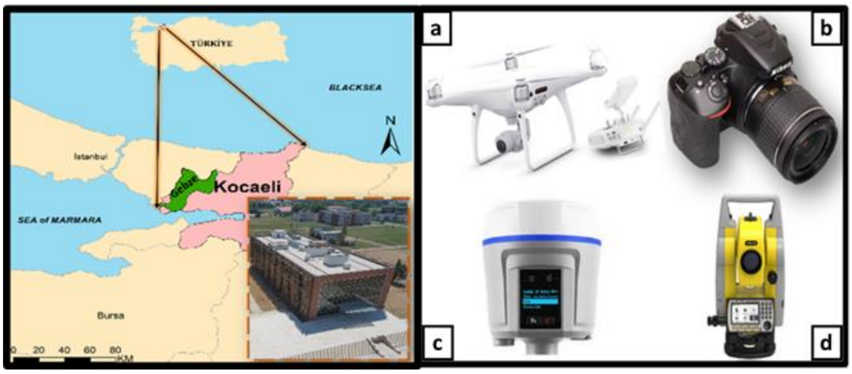

Figure 1. Study area, GTU geomatics engineering building, and used devices: (a) DJI Phantom Pro IV V2.0, (b) Nikon D3500, (c) CHC i80 GNSS and (d) Geomax Zoom25, respectively.

Methodology

The study consists of six steps: field reconnaissance, data acquisition, image enhancement, digital twin generation and statistical and visual analysis of the final products, respectively. Within the scope of the study, the field reconnaissance of the building was carried out. For the oblique flight performed with the UAV, it was taken into account that all images contain GCPs. In line with this goal, a total of 18 GCPs were installed, 12 on the land surface and 6 on the roof of the building. In addition to these, 20 checkerboards are positioned on the four facades of the building for terrestrial imagery. After the coordinate measurements of all control points were completed, image acquisition was performed. The NIKON D3500 DSLR camera was used with an 18 mm fixed focal length and fixed base interval for the capture of terrestrial images. The location of the image capture points is determined in computer-aided design (CAD) environment depending on the 22 m base distance and focal length where the entire front will be located in a single photo frame. The base distance between the two photographs was determined by taking into account the overlay rate (Figure 2). In the same way, image acquisition was performed by maintaining the overlap rate in oblique flight, but spectral mismatch occurred in terrestrial and aerial image acquisition due to different perspectives. This problem has been solved by applying the same filter to all images with the color editing facility provided by Adobe Photoshop Lightroom software.

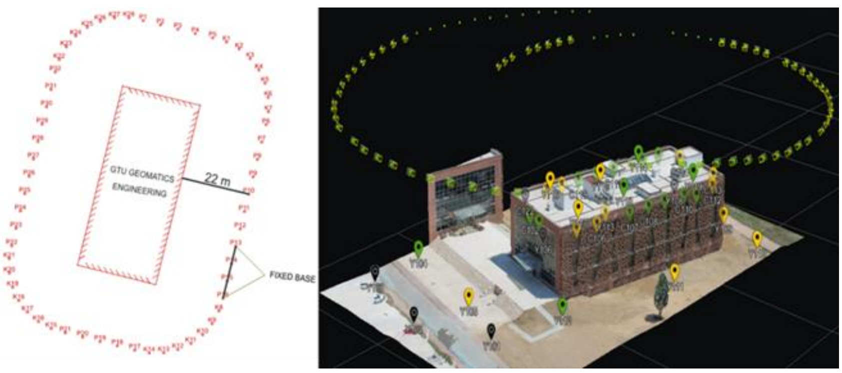

Figure 2. (a) Terrestrial and (b) Aerial photograph shooting points

ContexCapture software was used for the processing, fusion, and 3D building model production of all images with the help of photogrammetric methods. Ensuring that both aerial oblique imagery and terrestrial imagery for

3D modeling have accurate georeferencing or, at the least, a distinct spatial reference is a crucial step of integrating their processing (1). All data sources were evaluated simultaneously during the processing of the images, with the aim of producing dense point clouds obtained from both sources with common relative accuracy. As a result of the defined workflow, the root mean square error (RMS) for exterior orientation was calculated as 1.7 cm.

Results

3D modeling work was carried out with the terrestrial and airborne datasets acquisition for the building and the final outputs were given in Figure 3. After the fusion of data from different sources, the shadow effect due to the perspective has clearly emerged (Figure 3a). On the other hand, building roof surface modeling, which is often mentioned in the literature as a weakness of terrestrial photogrammetry, was also encountered in this study. It has been observed that the canopy located above the building entrance cause to distortions in the images taken with a perpendicular view to the façade (Figure 3c). The imaging problem experienced by the UAV in the areas under the canopy of the building caused insufficient point density in the point cloud and created interpolation errors (Figure 3d). Spectral mismatch caused by the shadow effect has been resolved by image enhancement methods (Figure 3b). Interpolation errors caused by a lack of data are eliminated by the fusion of images obtained from different sources with high geometric accuracy. The resulting products demonstrated the success of the proposed fusion method and ensured the realization of the goal of increasing quality in digital twin production.

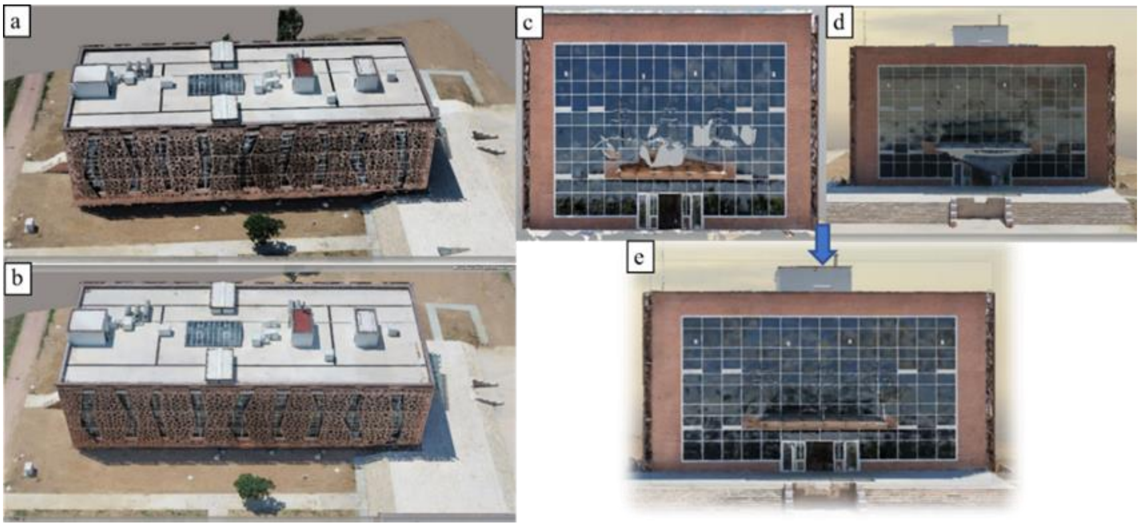

Figure 3. 3D building models (a) before image enhancement (b) after image enhancement, Modeling results (c) with terrestrial data and (d) with aerial data

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